# EnviroInfo 2014

28th International Conference
on Informatics for Environmental Protection
10th - 12th September, 2014
Oldenburg, Germany

# INFORMATION AND COMMUNICATION TECHNOLOGY FOR ENERGY EFFICIENY

*CONFERENCE PROCEEDINGS*

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# EnviroInfo 2014 –
# ICT for Energy Efficiency

28th International Conference on Informatics for Environmental Protection

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## Conference Homepage

http://www.enviroInfo2014.org

# *Preface*
# EnviroInfo 2014 – ICT for Energy Efficiency
# 28th International Conference on Informatics for Environmental Protection

Jorge Marx Gómez[1], Michael Sonnenschein[1], Ute Vogel[1],
Andreas Winter[1], Barbara Rapp[1], Nils Giesen[1]

## 1. Introduction to the EnviroInfo 2014

The EnviroInfo 2014 is the 28th edition of the long standing and established international and interdisciplinary conference series on leading environmental information and communication technologies. Combining and shaping international activities in the field of applied informatics and environmental informatics in making the world a better place for living, the EnviroInfo conference series aims at presenting and discussing the latest state-of-the-art development on ICT and environmental related fields.

Under the supervision of the Carl von Ossietzky University Oldenburg, the 28th EnviroInfo conference discusses the special topics of ICT for energy efficiency as main conference theme as well as the whole range of cross-cutting topics in ICT and environmental sciences. As the EnviroInfo conference series strengthens the interdisciplinary activities in the fields of sustainable development, participants from industry, higher education and research institutes have been invited to exchange ideas and solutions for current and future problems.

The EnviroInfo 2014 is held at the University of Oldenburg and organized by the Department of Computing Science chaired by Jorge Marx Gómez, Michael Sonnenschein, Ute Vogel, Andreas Winter, Barbara Rapp, and Nils Giesen.

General conference topics are:

- Water Management
- Sustainability Reporting
- Environmental Management Information Systems (EMIS)
- GIS: Tools and Applications
- Carbon Footprinting
- Sustainability: Dimensions and Indicators
- Tools for Modelling and Simulation of Environmental Systems
- Climate Change and Scarce Resources
- Environmental Protection and Health
- Material Flow Management and LCAs
- Biodiversity
- Decision Support
- High Performance Computing and Big Data
- Mobility and Sensors
- Educational Programs in Environmental Informatics

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Special Topics of the EnviroInfo 2014 are:

- Renewable Energy
- Smart Grids
- Resource and Energy Efficiency
- Green IT and Energy Aware Software Development
- Green Business Process Management
- Cloud Computing

122 contributions have been submitted to the EnviroInfo conference tracks – after a thorough reviewing 90 of them have been evolved to a full paper for the conference proceedings at hand.

In the scope of the EnviroInfo 2014 four workshops are organized by independent workshop chairs. Topics are:

- Usability and user oriented process models for EMIS (Chair: Volker Wohlgemuth),
- Lower Saxony Research Group „Smart Nord" (Chair: Michael Sonnenschein),
- Energy Aware Software Development (Chairs: Andreas Winter, Christian Bunse, Stefan Naumann),
- Sustainable Mobility (Chair: Benjamin Wagner vom Berg)

Altogether 18 short papers of workshop contributions can be found in these proceedings.

## 2. The Conference Site

The University of Oldenburg traces its roots back to 1793, when Duke Peter Friedrich Ludwig of Oldenburg created the first training college for teachers. The University of Oldenburg was finally founded in 1973 and named after Peace Nobel Laureate Carl von Ossietzky in 1991.

Today 182 Professors and 1036 research assistants teach 12019 students in Educational and Social Sciences, in Computing Science, Business Administration, Economics and Law, in Linguistics and Cultural Studies, in Humanities and Social Sciences, and in Mathematics and Science.

30 years before, the University of Oldenburg recognized Energy Research for an environmentally friendly, safe and affordable energy provision as a great challenge for our society: The photovoltaic array at the University of Oldenburg‘s "Energielabor" has been installed in the 80th and is now among the oldest arrays still in operation in Germany. Today, diverse research groups from different scientific disciplines support the energy research at the University of Oldenburg. They have joined forces in the research consortium ENERiO – Energy Research in Oldenburg, which finds a very fruitful atmosphere at the university in teaching and research. In ENERiO, the energy-related research is additionally supported by the following institutions:

- ForWind, the joint Center for Wind Energy Research of the Universities of Oldenburg, Hannover and Bremen conducts fundamental research in wind energy and provides scientific support for industrial projects.
- The institute NEXT ENERGY, which has been founded in 2007 by EWE AG in conjunction with the University of Oldenburg and the State of Lower Saxony, focuses on material research for photovoltaics, fuel cells and energy storage, system development and system integration.
- A very important part in the IT-related energy research plays the Energy R&D division of OFFIS, an associated institute of the University of Oldenburg. Its research in this application domain focuses on system analysis and distributed optimization, architecture

engineering and interoperability, smart resource integration, and simulation and automation of complex energy systems.

Computing science in Oldenburg was established in 1985. Currently, the Department of Computing Science incorporates 18 professors doing research in two main subjects on safety critical and embedded systems and on energy efficiency in information and communication technology.

## 3. The Host City of Oldenburg

Oldenburg (in Oldenburg) is located in the north-western part of Germany, about 50 km west of Bremen and 130 km east of Groningen (NL) in the state of Lower Saxony. Oldenburg was first mentioned in 1108 and has developed to an urban municipality and modern University City with more than 161.000 inhabitants, today. Oldenburg was awarded “City of Science” in 2009.

Oldenburg is a city of contrasts where classicism meets modernism, a cosmopolitan flair complements historical architecture, urban variety is balanced by a natural landscape, imaginative catering goes hand in hand with assorted retail outlets, and a rich culture harmonizes with scientific innovation. For all these reasons Oldenburg is the city with the highest number of home comers, who return to their hometown even after being away for many years.

## 4. Conference Highlights

More than 100 talks on exciting subjects are the foundation of the conference. Plenary presentations (invited talks) are given by:

- Prof. (em.) Dr. M. Jischa, Honorary President of the German Chapter Club of Rome: “Technology drives civilisation dynamics – but do we have a target?”
- Dr. Jörg Hermsmeier, EWE Aktiengesellschaft – Head of Department Research & Development: “Energy for tomorrow”
- Dr. Chris Preist, University of Bristol, Reader in Sustainability and Computer Systems: “Understanding and Reducing the Energy Impact of Digital Services”
- Dr. Sascha Roth, Project Director Group Sustainability Reporting at Volkswagen AG: “Volkswagen Group Sustainability Reporting”
- Prof. Dr. Niko Paech, University of Oldenburg, Department of Business Administration, Economics, and Law: “Post growth economics: Challenges and future outlook”

At the EnviroInfo2014, business representatives and scientists have the opportunity to join our special event “Business-Science-Speed-Dating” (BSSD). Assisted by a moderator, the BSSD brings business representatives and scientists from different parts of the world and from various scientific fields together and helps to explore the possibilities of innovative joint projects in fruitful discussions.

For the twelfths time, the TC “Environmental Informatics” of the German Informatics Society (GI) awards a prize for an excellent student’s contribution in the field of Environmental Informatics and to present their work at the conference. Such work takes the form of projects undertaken either as part of a course or for a degree (excluding PhD) at an academic university or a university of applied sciences.

The conference chairs are greatly indebted to

- all participants for their contribution to our conference,

- all active members of the program committee for their assessment of about 140 submission to the conference and to the workshops,
- the members of the organizing committee, not to forget the secretaries and the many helping students from the University of Oldenburg,
- the University of Oldenburg for allowing us to use the lecture hall and its technical equipment free of charge during the conference,
- and most especially our sponsors for their generous financial support of the conference.

We wish all participants interesting presentations and discussions and fruitful exchanges of ideas!

Oldenburg, September, 1st 2014

Jorge Marx Gómez, Michael Sonnenschein, Ute Vogel,
Andreas Winter, Barbara Rapp, Nils Giesen

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# Voluntary and Mandatory Company Sustainability Reporting: A Comparison of Approaches

B.M. Scholtz[1], A.P. Calitz[2], J. Marx Gómez[3] and F. Fischer[4]


## Abstract

This paper investigates the adoption of an Enterprise Architecture (EA) for improving the effectiveness of sustainability reporting through facilitating business-IT alignment and the incorporation of sustainability management and reporting into the strategy of a company. The paper highlights significant differences between voluntary and mandatory reporting of companies in South Africa with regards to integrating sustainability practices into their organization. In particular, the approach these companies take with regards to the use of EA for the support of strategic sustainability thinking is investigated. A survey of 28 South African companies was conducted to determine the integration of sustainability and environmental information and reporting into a company's EA. The results reveal an imbalance in the reporting focus. Economic reporting is still the most dominant type of reporting compared with environmental and social reporting, whilst companies reporting voluntarily seem to be more progressed in terms of integrating environmental information into their EA.


## 1. Introduction

Companies play a key role in sustainable development since their daily operations have a direct impact on the environment and society. Sustainable development is defined as *developments that gratify the needs of the current generation without jeopardising future generations' ability to satisfy their own needs* [1]. In order to monitor and communicate the sustainability measures a widely used instrument, the sustainability report is used. The Global Reporting Initiative (GRI) states that a sustainability report *"helps organizations to set goals, measure performance and manage change in order to make their operations more sustainable"* [2]. The sustainability report should include positive and negative information on the company's impact regarding economic, environmental and social matters. An increasing number of companies worldwide are reporting on their sustainability performance. According to the KPMG [3] report, 95% of the top 250 companies of the Fortune Global 500 list are publishing sustainability reports.

Although several companies are voluntarily reporting on sustainability, there is an increasing trend of mandatory reporting. Governments worldwide are increasingly obligating their companies to publish sustainability reports and this is supported by the corporate world [4]. The 2013 CEO Study on Sustainability of the United Nations Global Compact indicates that companies would welcome the intervention of governments to align sustainability on national as well as international levels. In South Africa, this is the present situation since companies listed on the Johannesburg Stock Exchange (JSE) are legally obligated to report on their sustainability performance and *"..the main drivers of sustainability reporting are corporate governance requirement, the Johannesburg Stock Exchange ... and the Socially Responsible Investment Index (SRI Index)"* [5]. As a result, South Africa is referred to as having a leading role in sustainability reporting in Africa.

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In order for companies to achieve their environmental sustainability objectives effectively, sustainable thinking needs to be established and companies must align these objectives with their organizational objectives [7, 10]. Sustainability reporting should *"fit into a broader process for setting organizational strategy, implementing action plans, and assessing outcomes"* [11]. The IRAS report [12] shows that whilst the number of organizations doing sustainability reporting is increasing, and several specialised software tools for sustainability reporting are available, they are not widely used by companies or are not used to their full potential. Some companies still rely on simple office software, whilst other companies which are using more advanced software and systems often do not align these with the main tools and processes of the company [7]. In order to overcome these misalignment problems, it is important to connect sustainability to the different levels of an organization (strategic, operational and technological), in order to follow a serious sustainability approach [10]. This can be achieved by the adoption of Enterprise Architecture (EA) in an organization which supports decision making and facilitates IT-business alignment [13, 14].

Several studies have addressed problems and solutions for sustainability reporting [15, 16]. However, research related to the differences in approaches between mandatorily and voluntarily reporting organizations is limited. This paper addresses this gap and investigates organizations in South Africa who are either reporting voluntary or mandatory. In addition the use of EA to support sustainability reporting is explored. The paper is structured as follows. Section 2 explores the differences between voluntary and mandatory reporting. The third section discusses the relevance of EA in connection to a company's sustainability management. In Section 4, the research methodology followed in this study is explained. The analysis of the results is presented in Section 5 and conclusions and recommendations are finally presented (Section 6).

## 2. Voluntary and mandatory sustainability reporting

Voluntary reporting implies that organizations source and publish data on their sustainability performance of their own accord. Supporters of the voluntary reporting approach argue that mandatory reporting is too inflexible and complex due to the variety of standards and that one size does not fit all companies (Table 1). Voluntary reporting is found to be more flexible; however organisations often have insufficient resources available and do not adhere to the required reporting standards. Other disadvantages of mandatory reporting cited are the high administration costs and the lack of innovation and creativity [17].

| | **Advantages** | **Disadvantages** |
|---|---|---|
| **Voluntary Reporting** | Flexibility<br>Proximity<br>Compliance<br>Collective interest of industry | Insufficient resources<br>Under-enforcement<br>Conflicts of interest<br>Inadequate sanctions |
| **Mandatory Reporting** | Standardization and comparability<br>Transparency and credibility to stakeholders<br>Changing the corporate culture<br>Legal certainty<br>Cost savings | High admin costs<br>Lack of innovation and creativity<br>One size does not fit all<br>Inflexibility<br>Complexity |

*Table 1: Advantages and disadvantages of voluntary and mandatory sustainability reporting.*

The mandatory reporting concept provides regulations on the sustainability reporting process itself as well as on the transparency and comparability of the reports. Supporters of mandatory reporting are, amongst others, non-governmental organizations (NGOs), which doubt that all companies report correctly when applying a voluntary reporting concept. This argument is supported by incidents of green washing such as the controversy Nestlé was involved in with its candy bar "KitKat" and the problematic topic of palm oil use [18]. On the other hand mandatory reporting has several advantages such as increased credibility to stakeholders, standardization and comparability.

The arguments are mainly based on the results of the research study carried out with the collaboration of the United Nations Environment Programme (UNEP), GRI, KPMG and other organizations [5].

One popular and globally accepted voluntary reporting standard is the GRI guideline [2]. In Sweden, state-owned companies are required to report on sustainability according to the GRI [19]. In South Africa, companies listed at the JSE are required to report using the King III Act, which also suggests using the GRI guideline. The GRI guideline is based on a multi-stakeholder process, meaning that the standard is reviewed in collaboration with different stakeholders (such as the reporting companies, the employees, NGOs and investors). One of the advantages of the GRI is that it is applicable to different kinds and sizes of organizations [2]. Due to the guideline's nature as a voluntary framework, it can invalidate the disadvantages of mandatory reporting and the line between both reporting forms can become blurred.

An UNCTAD review found that 87 % of 75 companies surveyed made some sustainability disclosure and concluded that South Africa has a leading role in sustainability reporting [5]. This leading role in reporting could be attributed to the standards and laws which were adopted in South Africa, as the importance of responsibility and transparency increased (Table 2). As a result the *"measurement and reporting on specifically social transformation issues (for example, black economic empowerment and employment equity) has become entrenched in legislation"* [5].

| Mandatory Standards | Voluntary Standards |
|---|---|
| 1998: Employment Equity Act | 1994: King Report on Corporate Governance |
| 1999: The Public Finance Management Act (PFMA) | 2002: State-Owned Enterprise Shareholder Compacts |
| 2003: Municipal Finance Management Act | 2003: Industry Specific Black Economic Empowerment Charters |
| 2003: National Black Economic Empowerment Act | 2004: Johannesburg Stock Exchange (JSE) Socially Responsible Investment Index (SRI Index) |
| 2008: Companies Act | 2007: Carbon Disclosure Project: Participation SA |
| 2009: The Consumer Protection Bill | |

*Table 2: Mandatory and voluntary standards of South Africa*

One of these standards is the King Report on Corporate Governance (the King Report). The aim of the King Report is to promote *"…the highest standards of corporate governance in South Africa"* [20]. Through the King Report, reporting principles were determined and the accordance to the GRI guideline proposed [17]. In 2004 the JSE Socially Responsible Investment (SRI) index was established with the aim *"... to measure leading JSE-listed companies against a series of reasonable social, environmental and governance metrics"* [12]. Even though the King Report is non-legislative, it gets enforced through the JSE listing requirement and establishes the mandatory character for JSE-listed companies; the act alone therefore represents a voluntary standard. Thus, through the King Report, listed companies are required to report and through the SRI index, encouraged to make the reports public [5]. The third version of the King Code of Governance for South Africa (King III) addresses new issues such as IT Governance, Business rescue and Fundamental transactions [20]. JSE-listed companies need to follow the "apply or explain" approach, which means companies have to state whether the principles of King III are applied or they have to explain why not. The Institute of Directors Southern Africa [21] states that *"the 'apply or explain' regime shows an appreciation for the fact that it is often not a case of whether to comply or not, but rather to consider how the principles and recommendations can be applied".* Sustainability reporting aims at integrating all areas of performance on the three topic areas; this can be achieved by integrating sustainability into the EA of a company.

## 3. Integration of sustainability through Enterprise Architecture

Enterprise Architecture (EA) is used to manage the day-to-day business of companies and their future development. According to The Open Group EA can be defined as *"… a coherent whole of principles, methods, and models that are used in the design and realisation of an enterprise's structure, business processes, information systems, and infrastructure"* [22]. The definition anticipates the complexity of EA**.** Because of the fast development of IT within the world's rapid technological advancement and an increase of complexity due to larger applications, software architecture was introduced. However, along with this progress, the alignment of business and IT arose as a problem. As a solution, companies needed to align the "… human, organizational, informational, and technological aspects of systems" [23]. Business strategy and IT must be aligned to facilitate the most effective use of technology and tools available [10, 24]. This alignment can be achieved through the implementation of an EA [13, 24]. To support the application of EA, frameworks such as the Open Group Architecture Framework (TOGAF) were developed [22]. According to TOGAF, an EA contains the following four components:

- **Business Architecture:** business strategy, governance and key business processes;
- **Data Architecture:** structure of an organization's logical and physical data assets;
- **Applications Architecture:** blueprint for the individual application systems, their interactions, and their relationships to the core business processes of the organization; and
- **Technology Architecture:** logical software and hardware capabilities that are required to support the deployment of business, data, and application services.

Internal drivers for the establishment of an EA are the aforementioned support for the strategic alignment and the linkage of business and IT. Moreover, external drivers can be derived from the requirement *"… to have a thorough insight into their structure and operations"* due to legislation [25]. Sustainability reporting is one example of what gets demanded by stakeholders, such as governments (external driver), and gives companies the opportunity to gain a competitive advantage and to improve organisational performance (internal driver).

However, even though more companies are reporting on sustainability, the approach is not embedded into all organizational processes and information generation can be difficult. Often there is also a missing alignment on a strategic level and/or at a technological level [26]. Studies have also revealed a lack of alignment of IT and the company's strategy [14, 24]. As a result sustainability reporting is often a silo application, being a *"… self-contained and isolated application …, which only provide[s] functionality to a specific business process*" [23]. To follow a consistent sustainability approach, sustainability aspects need to be integrated at all levels of the company (strategic, operational and technological). This alignment can be achieved by the adoption of the framework proposed by Scholtz et al. [26] which aims at the integration of sustainability into the EA. At a strategic level sustainability needs to be included in the goals and strategy of the company [10]. These goals need to be transferred onto the operational level and integrated into the company's processes. The data architecture generates the information needed for the sustainability reporting. The strategic and operational levels are supported through technology, which provides the technological solutions, for example collecting the data in order to create a report [26]. The integration of sustainability into the EA ensures that sustainability matters are considered on all levels of the business and enables companies to follow a more serious sustainability approach.

## 4. Research questions and methodology

The research study investigates the sustainability reporting process and the use of EA for supporting this process. A survey of 28 companies in South Africa was undertaken in order to perform a comparison of approaches to EA and sustainability reporting between mandatory reporting organizations (JSE-listed) and organizations which report voluntarily (non-listed). The research instrument used was an on-line questionnaire. The primary research question of this paper is: "*What are the differences between voluntary and mandatory reporting companies in South Africa regarding sustainability reporting in general and the integration of environmental information into the enterprise architecture?*". The following secondary research questions are therefore addressed in this study and were included in the questionnaire:

1) Do voluntary and mandatory reporting companies have a different focus regarding the reporting of economic, environmental and social matters?
2) What are the differences regarding the software used by companies for sustainability reporting?
3) Are companies integrating environmental information into the EA?
4) Are companies including the improvement of environmental concerns to their EA?

# 5. Analysis of results

## 5.1. Participant profile

The JSE-listed companies which participated are referred to as mandatorily reporting organizations due to the binding listing requirements of the JSE. The 28 participating companies consist of 17 listed (out of the 444 currently JSE listed companies) and 11 non-listed (voluntary reporting) companies. The companies are classified according to three types of industry: service, banking and finance, and manufacturing (Table 3). The companies ranged in size from companies with between 101 to 500 employees and companies with over 500 employees at the time of the survey.

| Company | Industry | Listing Status | Number of Companies (n) |
|---|---|---|---|
| Q, V, Z | Banking and Finance | Listed | 3 |
| F, M, N, O, W, AA | Manufacturing | Listed | 6 |
| G, K, L, P, T, U, Y, AB | Service | Listed | 8 |
| | | **Total Listed** | **17** |
| I, S, X | Banking and Finance | Non-listed | 3 |
| A, H | Manufacturing | Non-listed | 2 |
| B, C, D, E, J, R | Service | Non-listed | 6 |
| | | **Total Non-listed** | **11** |

*Table 3: Profile of the participating companies (n = 28).*

## 5.2. Analysis of Survey Results

The results showed that in practice participating organizations are not as balanced as they should be regarding the three areas of sustainability (Figure 1). The results showed that economic reporting was the most dominant in both sets of companies, listed (94%) and not listed (82%). Social reporting is the second most popular reporting field with 82% of the listed and 73% of the non-listed companies agreeing that they reported on social issues. This supports the focus on social reporting aspects noted in South Africa [27]. Of the listed companies 65% agree that they perform environmental reporting. As expected, this reporting field is less popular amongst the non-listed companies, where less than half (36%) agreed that they practice environmental reporting. The mandatory reporting organizations surveyed thus have a higher focus on environmental reporting than voluntary reporting companies. This can be due to the demands of shareholders and investors who want all potential risks due to issues such as climate change to be taken into account [7]. Another reason could be due to the higher number of participants from the manufacturing industry, in which environmental aspects are of more importance due to the severe impact on the environment compared to other sectors.

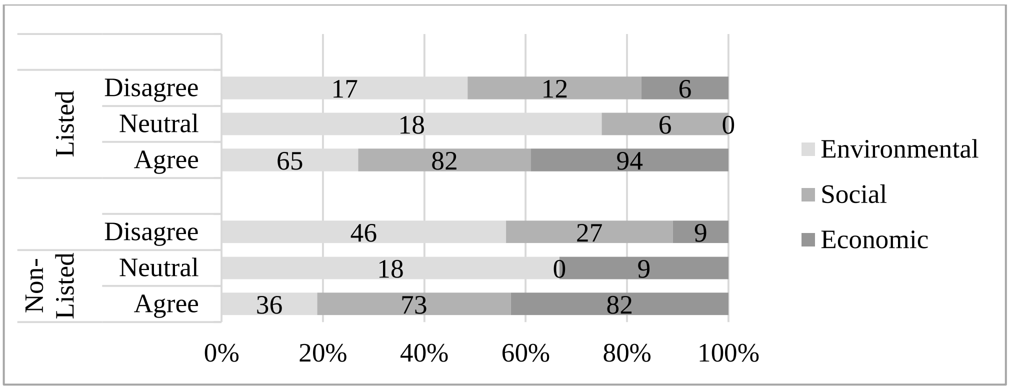


*Figure 1: Focus regarding the triple bottom line of sustainability reporting (n = 28).*

The results related to the guidelines used by participating organizations (Figure 2) highlight that the GRI is more commonly used by listed companies (47%) as compared with non-listed organizations (18%). In non-listed organizations the implementation of ISO 14001 and Environmental Management Systems (EMS) are the two most popular used guidelines with 45% and 36% respectively. However, listed companies are using the ISO 14001 standard (53%) and EMS (30%) as well. The results show that MS Excel is the most commonly used software tool for environmental reporting in non-listed companies (Figure 3) Even though the most popular tool amongst listed companies is internal information systems (65%), MS Excel is still commonly used (53%) as well as web-based reporting tools (53%). This result confirms previous studies [7; 31] reporting that companies are still not making sufficient use of available technology and are using spreadsheets to create sustainability reports.

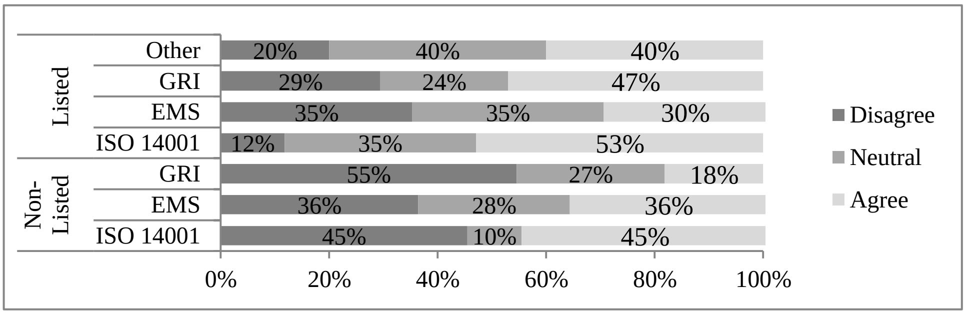


*Figure 2: Guidelines and methods used for sustainability reporting (n = 28).*

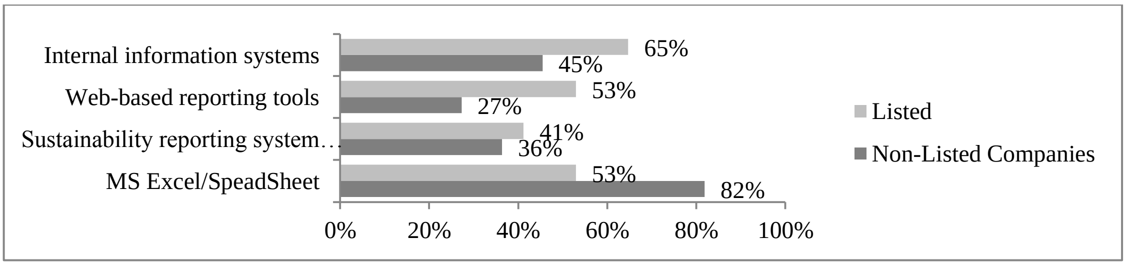


*Figure 3: Tools used to manage and monitor sustainability reporting (n = 28).*

According to findings of a market review by KPMG [15], the use of solutions such as MS Excel are mainly used in the early stages of sustainability reporting. However, with this application being limited *"in the field of maintainability and integrity of the data when organizations change and extend their sustainability reporting"* [15], companies move on to using sustainability reporting software. The survey results therefore suggest that the non-listed companies are at the early phase of sustainability reporting. Even though non-listed companies seem to be lacking behind in terms of environmental reporting, the results indicate that they are more advanced in integrating the environmental information into their EA, since almost two-thirds (63%) of the non-listed companies are integrating the environmental data into their EA (Table 2). However, only 24% of listed companies agreed that they integrate their environmental information into the EA. The majority of non-listed companies (72%) view the improvement of environmental concerns as a goal of EA, and only 24% of listed companies agree. This could indicate that environmental concerns play a minor role in the future development of the EA of listed companies or it could be because these companies see EA and environmental concerns as separate issues that are not related.

| | Non-Listed Companies | Listed Companies |
|---|---|---|
| Disagree | 10% | 47% |
| Neutral | 27% | 29% |
| Agree | 63% | 24% |
| **Total** | **100%** | **100%** |

*Table 2: Enterprise architecture with environmental information (n = 28).*

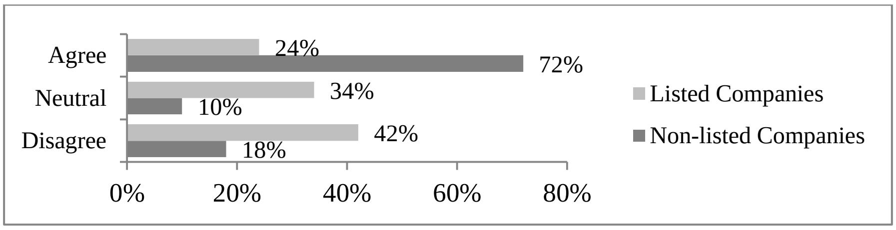


*Figure 3: Improvement of environmental concerns as a goal of EA (n = 28).*

## 6. Conclusions and Recommendations

The analysis of the survey results revealed that mandatory reporting companies seem to be more advanced in terms of sustainability reporting in general. However, the integration of environmental information into the EA appears to further developed than in companies that follow a voluntary reporting approach. A higher percentage of listed companies than unlisted companies stated that they report on all three sustainability aspects. With regards to the tools the companies are using to manage and monitor sustainability, most companies are still relying on MS Excel, web-based reporting tools and internal information systems. One limitation of the study was that the reasons for why non-listed companies had a low percentage of environmental reporting but an advanced integration of environmental information into the EA could not be determined. This could be a useful area for future research. Although the number of companies surveyed was relatively small, the paper still provides a valuable contribution in terms of a deeper understanding of the status of South African companies with regards to environmental reporting and EA and a deeper insight into the drivers of voluntary and mandatory reporting companies are provided.

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# Inter-organizational Sustainability Reporting – A harmonized XRBL approach based on GRI G4 XBRL and further Guidelines

Andreas Solsbach[1], Ralf Isenmannl[2], Jorge Marx Gómez[3], Frank Teuteberg[4]

## Abstract

The ongoing development and the alterations of sustainability reporting, like the change towards internet-based reporting which allows stakeholder orientation and integration of supply chain disclosure, will lead to an increased generation of sustainability reports (or corporate social responsibility reporting). By April 2012, 53% of the S&P 500 companies provide corporate sustainability reports and 63% are based on the Global Reporting Initiative (GRI) guidelines, 5% are referencing towards GRI so that only 32% are non-GRI reports. This is a huge increase of sustainability reporting compared to 19%-20% in 2011. [1] A proposed Directive of the Council of the European Communities [2] regarding the disclosure of nonfinancial and diversity information by certain large companies and groups, what will be realized by sustainability reports, will possible lead to mandatory reporting instead of voluntary reporting. Larger companies and groups will force their suppliers to report impacts of their processes and products in the supply chain due to supply chain disclosure. Therefore, companies are forced to reduce efforts in the process of generating a sustainability report, increase the value and accessibility of reports by machine readable reports. The paper will present the approach of inter-organizational sustainability reporting to enrich the current GRI G4 XBRL [3] version towards an inter-organisational reporting. Further guidelines for harmonizing such as United Nations Global Compact [4], Organization for Economic Cooperation and Development Guidelines for Multinational Enterprises [5], Eco Management and Audit Scheme III [6] and European Federation of Financial Analysts Societies [7] to overcome the necessity to use bridge documents will be shown. Further, ideas how to integrate the inter-organisational sustainability reporting approach will be discussed.

## 1. Sustainability Reporting Trends

The ongoing development and the alterations of sustainability reporting, like the change towards internet-based reporting which allows stakeholder orientation and integration of supply chain disclosure, will lead to an increased generation of sustainability reports (or corporate social responsibility reporting). By April 2012, 53% of the S&P 500 companies provide corporate sustainability reports and 63% are based on the Global Reporting Initiative guidelines, 5% are referencing towards GRI so that only 32% are non-GRI reports. This is a huge increase of sustainability reporting compared to 19%-20% in 2011. [1]

A proposed Directive of the Council of the European Communities [2] regarding the disclosure of nonfinancial and diversity information by certain large companies and groups, what will be realized by sustainability reports, will possible lead to mandatory reporting instead of voluntary reporting.

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Larger companies and groups will force their suppliers to report impacts of their processes and products in the supply chain due to supply chain disclosure. Therefore, companies are forced to reduce efforts in the process of generating a sustainability report, increase the value and accessibility of reports by machine readable reports using formats to exchange data which can be automatically used such as eXtensible Business Reporting Language (XBRL). XBRL offers several benefits due to its origin from eXtensible Markup Language (XML) it separate data from structural information, can be adopted by tags and other options towards any kind of required structure which will support enlarged structured of reports of companies due to change of boarders by including information of supply chains into the reporting. One other main benefit is the wide acceptance of XBRL. Due to its origin from the financial communication, company reports are generated in a XBRL format and are shared with public and other stakeholder groups.

The paper presents an inter-organizational sustainability reporting approach to enrich the current GRI G4 XBRL [3] version towards an inter-organisational reporting. It provides an harmonized approach including GRI G$ XBRL and further other guidelines, like United Nations Global Compact (UNGC) [4], Organization for Economic Cooperation and Development (OECD) Guidelines for Multinational Enterprises [5], Eco Management and Audit Scheme (EMAS) III [6] and European Federation of Financial Analysts Societies (EFFAS) [7] to overcome the necessity to use bridge documents. The approach is shown in Figure 1.


*Figure 1: Elements of a harmonized XBRL approach for inter-organizational sustainability reporting*

The further guidelines analysed to include elements into a harmonized XBRL approach are chosen due to different reasons: (1) principle oriented guideline such as UNGC from a non-governmental organization (bridge document to GRI exists), (2) principle oriented guideline such as OEC guidelines for Multinational Enterprises from a governmental organization (bridge document exists), (3) an environmental declaration such as EMAS III (to show how environmental declaration could be included), and the indicator oriented approach from the European Federation of Financial Analysts Societies for corporate responsibility reporting to include how approaches with different background can be included for later on an integrated reporting as outlook.

The aim is to overcome the current gap that bridge documents have to be used to indicate automatically missing content if a company has a sustainability report following GRI to prepare the report for a further guideline e.g. UNGC. The idea is to support the process of the generation of the sustainability report and to reduce efforts for companies and organisation using XBRL derived from XML which allows several techniques to verify documents concerning content.

## 2. Inter-organizational sustainability reporting

Current developments and trends, such as publishing not only information and impacts of one's own activities but integrating for example the emissions of the processes of all suppliers along the chain, will extend current reporting. The impact on sustainability of a company is the sum of all its activities and is influenced by the activities of all its suppliers. The suppliers are also taken into account in order to prevent companies from outsourcing not sustainable activities like productions with a high usage of natural resources or child labor. This situation asks for a reporting from two perspectives: the network and the member perspective. This kind of reporting is state-of-the-art in financial reporting. It will be transferred to the sustainability reporting domain with the inter-organizational approach (borrowed from Kasperzak [8]**Fehler! Verweisquelle konnte nicht gefunden werden.**).

The GRI guidelines G3 and G3.1 do not allow to report impacts of suppliers if the reporting company has no influence on the supplying company. Therefore the boundaries of sustainability reporting are discussed by several authors such as Lundie and Lenzen [9] or Bey [10]. The approach of Lundie and Lenzen reveals how sustainability reporting can be seen without boundaries and compares the impact of a company with the national economy **Fehler! Verweisquelle konnte nicht gefunden werden.**. Bey demands that setting boundaries of sustainability reporting will be one main research question concerning acceptance of sustainability reporting. The boundaries of sustainability reporting are not only discussed by researchers, Nestlé AG stated out in their non-financial report "Der Nestlé-Bericht zur gemeinsamen Wertschöpfung" of 2007 (roughly: Nestlé report about the creation of combined added value) [11] that Nestlé AG aims to include their suppliers and not wholly-owned subsidiaries in their ongoing reporting activities, but that they currently are not included in the sustainability reports due to missing guideline support. At that time, the quasi-standard for sustainability reports, GRI G3.1, covered only wholly-owned subsidiaries or any other company on which the reporting company has an influence. Joint reports could be quite useful for companies that are located in an industrial park and want to show how their joint activities of waste or energy management reduces their and the overall environmental impact. The scope of sustainability reporting including companies based on existing business processes and information exchanges without having a direct influence on them. The current state of sustainability reporting encloses only the reporting company and wholly-owned subsidiaries. The inter-organizational approach requires extending current guidelines by indicators and other aspects to specify the scope and kind of network. In addition, the approach has to handle the case of joining and leaving the network during the reporting phase. Therefore, current guidelines have to be extended. This must be handled appropriately, since the leaving of companies must not result in a breakup of the network. The inter-organizational sustainability reporting still requires several reporting cycles; with activities and next steps disclosed in a report, the outcome towards social, economic and environmental aspects will be obvious.

### 2.1. Approach

The inter-organizational sustainability reporting approach includes a procedural method shown in Fig. 2. Schaefer's method [12] for life cycling of strategic company networks is applied to inter-organizational sustainability reporting: decision phase divided into two phases: prephase (2) and preparation phase (3) and a return option from the prephase and cooperation phase towards initiation phase to adjust to changes in the prephase and prevent the phase-out of the company network. The new phases are needed to handle the complexity of sustainability reporting. The phase are used to prepare structure and content of the sustainability report, the return option allows to handle joining and leaving in the network without a phase-out due to that the main outcomes of sustainability reporting and the dialog with stakeholders require several reporting cycles. Further, the approach of inter-organizational sustainability reporting includes an adopted reporting framework based (document engineering) to handle a joint report from a company network.

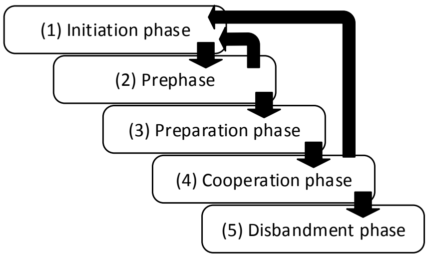


*Figure 2: Inter-organizational sustainability reporting procedural method (extends* [12]*)*

### 2.2. Added Values

The approach of inter-organizational sustainability reporting supports a company’s sustainability communication and enhanced the added values of sustainability reporting. Benefits are for example (1) competitive advantages (internally and externally) by reason of improved use of natural resources (e.g. usage of secondary raw materials, overview of material and energy inserts) to reduce costs; (2) increased reputation and transparency of reporting by covering-up outsourcing of material- and energy-intensive processes due to disclosure of supply chains (or in the network); (3) inclusion of external impacts (tri-partite reporting) without having an influence on each company; and (4) reduction of risks for the reporting company due to inclusion of sustainable activities of suppliers (preventing child labor or corruption).

## 3. Harmonized XBRL approach for inter-organizational sustainability reporting

### 3.1. GRI G4 XBRL

The Global Reporting Initiative has recently published the fourth version of their sustainability reporting guidelines called G4 **Fehler! Verweisquelle konnte nicht gefunden werden.**. The GRI G4 guideline is divided into two parts: (1) Reporting Principles and Standard Disclosure and (2) Implementation Manual. The first part discusses the content of sustainability reports when using the GRI G4 guideline and the second part shows how to preprocess information for including it in the report. The first part also documents very well, how much know how as well as information is needed when preparing a sustainability report. As further support the GRI published the reporting framework based on XBRL to increase the value as machine readable exchange format. [13] The GRI G4 XBRL guidelines include general standard disclosures (in total 58 disclosures), specific standard disclosures (in total 92 disclosures), and attachments if necessary.

The GRI guidelines are currently a quasi-standard for sustainability reporting and fulfill the requirements towards and extensible indicator-based guideline for an inter-organizational sustainability reporting in following criteria:

- Extensibility of the guideline (criteria, contact with guideline publisher necessary…)
- Transparency (criteria and weighting are described in the guideline)
- Acceptance of the guideline
- Coordination and communication efforts necessary for choice, weighting and reporting of criteria etc.

- Boundaries of reporting (minimize efforts and allowing adopting boundaries towards supply chains or a company network)

The GRI provides following documents (see Figure 3) for their GRI 4 XBRL guideline [14] using XBRL 2.1 [15] and Dimensions 1.0[16] specification:

- Entry point schema (defining and importing namespaces, namespace prefixes, and linkbases)
- Label linkbase (labelling of concepts e.g. in US English and further languages if necessary)
- Reference linkbase (reference towards the specific version, section etc. of the GRI 4 guideline of reportable concept)
- Definition linkbase (dimensions, domains and role types for hypercube)
- Presentation linkbase (extended link roles for general and specific standard disclosures)

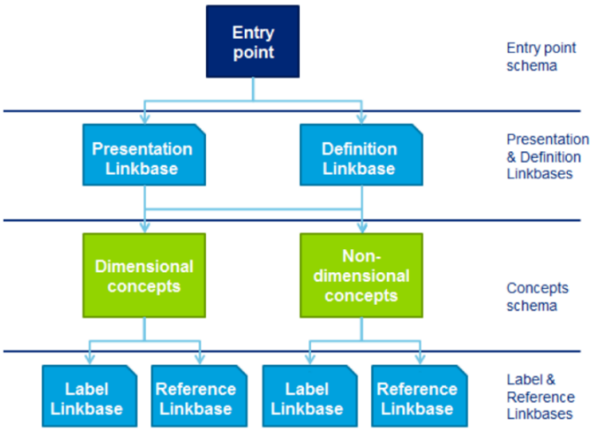


*Figure 3: GRI G4 XRBL structure* [14, p. 10]

### 3.2. Enrichment of GRI G4 XBRL content by further guidelines for inter-organizational sustainability reporting

To support the inter-organizational sustainability reporting guidelines have to support in particular following requirements:

- Support extensibility possibilities of the guideline with further indicators and principles required for a joint report of a network of reporting companies
- Support transparency to support network and member view of reporting companies
- Acceptance of the standard to decrease communication and coordination activities (therefore an indicator-based approach of guidelines is preferred)
- Decreased Coordination and communications efforts (e.g. indicators and statements are well described, no contact with external organizations or national contact point are required, and boarders of reporting can be adjusted towards network requirements)
- Support of adjustment of boarders of reporting (e.g. principle of materiality to include support chains, and value chains)

Therefore, several guidelines (Organisation for Economic Co-operation and Development (OECD) guidelines for Multinational Enterprises [5], United Nations Global Compact [17], GRI guidelines (G3, G3.1, G4, and High Five!) [18]–[21], KPIs for Environmental, Social & Governance Issues [7], International Network for Environmental Management Sustainability Reporting Guide [22]), environmental declaration such as Eco-Management and Audit Scheme III [6], and International Organization for Standardization (ISO) norm ISO 26000:2010 – Guidance on social responsibility [23] were analysed how they support an inter-organizational sustainability report. As result, the

GRI G4 guidelines with the XBRL were selected as basis guideline for the inter-organizational sustainability reporting approach due to:

- GRI G4 guidelines are indicator-based and allow extension such as sector supplements published for GRI G3.1 supporting the requirement of extensibility; indicator-based approach supports ratings and benchmarks due to that indicators are described in detail
- All disclosures are well described in the framework to decrease misunderstanding, by using the extension of XBRL the exchange of information can be annotated reducing misunderstanding in necessary communication activities in an company network
- The GRI guidelines are well known in the community and companies, organizations, and researcher were involved in the creating of the guidelines to increase acceptance; use of XBRL as accepted standard for business communication increase the acceptance in the field of environmental communication; European Union declares GRI as de-facto-standard by an declaration in the Greenbook for tripartite communication [24]
- Use of XBRL and an indicator-based guideline such as GRI G4 decrease communication processes due to call backs from companies requiring support in understanding the guidelines

The mentioned guidelines were analysed in the same kind of way and related approaches [25]and as result of the selection of GRI G4 as basis the guidelines and environmental declaration was chosen as shown in Figure 1. GRI G4 with the help of the disclosures allow the linkage of GRI G4 indicators and the principles of United Nations Global Compact (UNGC), exemplary G4-10 and G4-11 are linked with principle three of UNGC concerning labour issues. [3], [17], [20] The known linkages of GRI G4 and UNGC allows with existing bridge documents of GRI G3.1 and UNGC to estimate how much information is missing to have not only a full sustainability report following GRI G4 but also a report following UNGC. That estimation will allow to switch if necessary a reporting guideline. The linkage to OECD guidelines exists also in the G4 guidelines [3], [20], which support the use of the OECD guidelines for the enrichment of the GRI G4 XBRL. The OECD guidelines focus on extensibility by giving eleven topics as starting points for reporting by the support of national contact points of the member states which can be sued for extension of the GRI G4 guidelines. The OECD support the principle of disclosure of information but the required coordination with national contact points without having detailed indicators reveals that OECD guideline cannot be used as basis of our approach. [26] The Eco Management and Audit Scheme (EMAS) III, environmental declaration, shows how an established environmental management can be used for gathering environmental data as part of the sustainability reporting process. EMAS III requires an environmental management system and in the inter-organizational sustainability reporting approach data could be accessed via the environmental management system for the report. [6] The guidelines concerning KPIs for Environmental, Social & Governance Issues (ESG) are divided into two parts: (1) conceptual framework, and (2) KPIs by subsector. The conceptual framework includes preconditions for ESG reporting such as that the reporting should be based on a structured reporting which is fulfilled by GRI G4, for external reporting it should follow the DVFA Principles for Effective Financial Communication principles (relevance, transparency, continuity and recentness) [27, p. 11p], and reporting cycle (ones a year). Therefore, GRI G4 XBRL considerably supports the approach of inter-organizational sustainability reporting.

### 3.3. Proposal of a harmonized reporting framework based on GRI G4 and further guidelines using XBRL

A harmonized reporting framework using GRI G4 XBRL as basis will benefit by the open taxonomy of GRI which allows extensions to enrich the GRI standard and specific disclosures with required concepts and further elements such as:

- Reference from a concept such as EN1 indicator towards a company specific EN1 indicator for each reporting company (allowing network and members view)
- Use of a calculation linkbase to calculate e.g. the EN1 indicator on bases off all EN1 indicators' of reporting companies or alternatives
- Managing joining and leaving of companies to calculate correctly indicators by calculation linkbase or alternatives (exemplary, company A is a participating member in 2013 but in 2014 they leave; then in a comparison of 2013 and 2014 the data of company A should be excluded in the comparison or on the other hand if a company Z joins in 2014 their data should not be used for comparison of 2013 and 2014)
- The changing participating members requires the use of typed dimension to allow unknown members be integrated in the ongoing reporting process
- To support validation of different guidelines we currently analyse XBRL for using taxonomy extension for each guideline (resulting in five extension: one for each guideline and one for the inter-organizational sustainability reporting approach to include necessary elements for a network of companies which have not to be linked by a supply chain or value chain)

The research is currently focusing on the potential of XBRL and functionality to support the inter-organizational sustainability reporting approach. First results show that XRBL allows such an extension by the current supported functionality but the research is currently in the step to create a first version of such an XBRL document supporting GRI G4, the mentioned guidelines, environmental declaration, and the inter-organizational approach and has to be further specified.

## 4. Conclusions and Outlook

Consolidated, the paper describes the inter-organizational sustainability approach and current state-of-the-art in the field of XBRL. Also the carbon disclosure project focuses on supporting a reporting taxonomy to improve the way of reporting. Therefore, the approach to select a sustainability reporting guideline in XBRL as basis of these works looks promising and future papers a detailed semantic analysis of the guidelines will illustrate how such an approach can be realized. The approach could be a benefit for other environmental developments supported by IT such as the ongoing development of corporate environmental management information systems such as in the IT-for-Green project. [28]

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# Sustainability Management for Start-ups and Micro-Enterprises: Development of a Sustainability Quick-Check and Reporting Scheme

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## Abstract

For enterprises of all sizes, sustainability is becoming increasingly important. Accordingly, there has been a noticeable increase in academic literature in the field of sustainability management and related tools and approaches. While the academic and practical contributions are growing in this field, it appears that literature has overlooked certain type of enterprise, namely the micro-enterprises, including normal startup companies. Nonetheless, mounting evidence places emphasis for the inclusion of startups and micro-enterprises in the sustainability debate. Therefore, the aim of this paper is not only to close the theoretical gap on appropriate sustainability measures for startups and micro-enterprises, but also to propose a conceptual framework for an IT-supported analysis and reporting tool for sustainability in micro-enterprises and startups. Based on previous research on sustainability management tools in SMEs as well as sustainability software applications, the paper proposes the contents and layout of a web-based tool for startups.

***Keywords**: Sustainability Management; Start-ups; Micro-Enterprises; Software; Web-based tools.*

## 1. Introduction

For enterprises of all sizes, sustainability is becoming increasingly important. Accordingly, a noticeable increase in academic literature has emerged regarding effective management approaches and tools for business sustainability, also known as sustainability management [27]. While much of the focus of sustainability management research is placed on large enterprises, a shift has occurred to include small and medium-sized enterprises (SMEs) as well as social and sustainability entrepreneurs [12, 26].

Accordingly, there has also been an increase in scientific contributions for the development and implementation of IT-based environmental and social management applications in companies of all sizes (see [17] for an overview of various applications of IT-solutions for large companies and SMEs). However, most academic publications dealing with software and web-based applications are usually focused on particular aspects of sustainability, such as energy and resource efficiency [e.g. 1] or sustainability reporting [28]. A company-wide, holistic approach embracing all aspects of business sustainability has been practically observed in large companies [19], but not examined in the academic literature.

With few exceptions [e.g. 33], previous research has not proposed company-level tools for sustainability management in micro-enterprises and particularly start-ups. While some research does exist on sustainable business models and plans [e.g. 3], these models are more focused on sustainable innovations versus the core business itself. Such business models are difficult for most start-ups to implement because they mainly revolve around new business units than the core

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message of a new company. These business models also do not provide tools for a comprehensive sustainability evaluation and reporting system [21].

Furthermore, IT-solutions have not considered the early stages of business creation from the actual start-up of a company to its further development as a micro-enterprise. In fact, it appears that literature has overlooked certain category of businesses in the sustainability management context. According to the European Commission this category includes micro-enterprises with less than 10 employees and no more than 2 million Euro annual revenue.

However, mounting evidence suggests that start-ups and micro-enterprises should be considered in light of sustainable development for several reasons. First, sustainability is relevant for all companies in every industry of every economy [24]. Secondly, sustainability will never be achieved if the smallest companies do not get involved [10]. Not only do micro-enterprises constitute a majority of all registered businesses, e.g. 2.8 million enterprises (ca. 80%) in Germany fall into the micro-enterprise range, they also feed many products and services into the larger companies as suppliers and service-vendors. Thirdly, while it could be argued that individual micro-enterprises transmit a puny, insignificant burden on the environment, it is their collective impact and spill-over into larger enterprises that raises major concerns.

Fourthly, besides the direct burdens placed on society and the environment, indirect effects can be attributed to the exemplary roles that entrepreneurs and owner-managers of small businesses hold in economies and societies that desperately look for heroes to right the wrongs of environmental degradation and intra-generational injustices through sustainability-driven goals and measures. When considering the good examples set by social entrepreneurs, such as Muhammad Yunus, and ecopreneurs, such as Klaus Hipp, new business founders need not just inspirational stories, but effective operational means and devices to steer their business endeavors into future-oriented sustainability enterprises [26].

Last but not least, start-ups generally do not remain small but rather are growth-oriented [8; 16; 32]. As the size of the enterprise increases, so too does the relevance and motivations for sustainability management [29]. In addition to well-known management problems of fast-growing enterprises [12; 18], small business managers must be informed about the increasing environmental and social demands that rise with increasing size. For example, in the future it is plausible that medium-sized enterprises starting with 100 employees will be mandated by corporate law to state their environmental and social impacts through annual sustainability reports [14; 31]. Those owner-managers that have addressed with sustainability issues from the beginning might achieve a competitive advantage over those that decide to wait it out. The challenges of sustainability management in start-ups and fast growing companies should be integrated so to avoid a lengthy, costly period of playing catch-up.

Thus, the questions are raised: why should a start-up or micro-sized enterprise wait to reach a certain size in order to measure, manage and report on its sustainability activities? How could such a sustainability management program be conceptualized? What benefits would it bring the enterprise? Lastly, how might IT-solutions provide simple yet effective means to accomplishing these goals?

The aim of this paper is, therefore, not only to close the theoretical gap on appropriate sustainability measures for start-ups and micro-enterprises, but also to propose a conceptual framework for an IT-supported application that allows a company to easily assess and report its sustainability activities. This conceptual model will hopefully set the foundation for further practical developments. Based on previous research on sustainability management tools in SMEs [13] and private households, this conceptual paper proposes the contents and step-wise process of an IT-support tool for both start-ups and micro-enterprises. This tool, as we call the "Sustainability Quick-Check" (SQC) model, will be explained in the next section.

## 2. IT-supported Sustainability Quick-Check

Many of the existing processes for the preparation of sustainability assessments and reports are complex and contain a variety of indicators and metrics. In turn, this provides no clear path or structure for intuitive handling. One possible reason may be attribute to the fact that software applications were intended to be sold with additional consulting services. The aim of this paper is to develop a manageable and straightforward tool with a clear structure and based on understandable steps for a start-up and micro-enterprise.

The development of the SQC model is broken down into three complementary and sequential stages. In the first stage, a systematic analysis of the existing sustainability management tools and software and tools were examined. Based on Johnson (2013), it is established that not all management tools are applicable even in small and medium-sized enterprises (SMEs) with 10 or more employees [13]. The most applicable tools for small businesses are those that correspond with well-established management practices, such as a quality management system, training and education on sustainability management, risk analysis, supply chain management and even an environmental management system.

In the second stage of analysis, several SME-friendly software and web-based applications, such as Avanti GreenSoftware (www.avanti-greensoftware.com/de/), CR-Kompass (www.crkompass.de/), KIM-Software from Sustainum (www.sustainum.de/index.html), N-Kompass (www.n-kompass.de/) and 360 Report (www.360report.org/de/) were closely examined. These software not only offer user-friendly, cost effective ways to analyze and report on sustainability management in SMEs, combined they provide a good overview of what criteria and indicators should be considered for sustainability management in small businesses. While these various applications offer great insights applicable topics and indicators for SMEs, it is still uncertain if these software packages and web-applications will be adopted by very small enterprises and start-up companies.

In the third stage, a grid was developed that allows a structured overview of sustainability topics and corresponding indicators for start-ups and micro-enterprises. The idea behind this structure was to combine the results from both the first and second stage of analysis with the ideas from business model canvas [19]. Suitable sustainability key performance indicators and metrics were classified into various SQC-categories, such as production, supply chain management, sales and marketing and administration and supporting business functions (including strategy and human resources), and further broken down into key activities, key resources and key partners from both environmental and social perspectives. Table 1 below depicts example of possible categories, fields and aspects for the SQC model.

| **Basic Structure of the *Sustainability Quick Check (SQC)*** | | **Sustainability** | |
| --- | --- | --- | --- |
| | | **Ecological Aspects** | **Social Aspects** |
| ***SQC*-Category** | **Assessment field** | **Example Criteria** | |
| **Production of Product / Service** | Key Activities  | Energy and Water consumption in production (i.A.a. G4-EN3/ EN8) | Adherence to working hours and und guarantee of workplace safety (i.A.a. G4-LA5 und LA6) |

| | | | |
|---|---|---|---|
| | Key Resources  | Use of non-toxic and recycling materials and packaging (i.A.a. G4-EN1 und EN28) | Use of fair trade materials, incl. free from forced and child labor |
| | Key Partners  | Selection of regional, sustainable production partners, i.a. avoidance of long transport routes (i.A.a. G4-EN17 und EC9) | Support of the disadvantaged, e.g. collaboration with disabled persons |
| **Supply Chain Management, incl. Logistics and Procurement** | Key Activities | Shortening transport routes | Supply chain code of conduct and enforcement (audits); Supplier Training |
| | Key Resources | Environmentally conscious procurement (guidelines) for sustainable and environmentally safe materials (i.A.a. G4-EN2) | Purchasing requirements for fair products |
| | Key Partners | Selection of regional, environmentally friendly partners | Supplier selection and negotiations for fair and safe working practices |
| **Market incl. Sales and Marketing** | Key Activities | Market analysis and promotion of environmentally friendly products and services | Fair Marketing; Ensure transparency of social standards in own production and supply chain |
| | Key Resources | FSC- or PEFC-certified printed ads; paperless-advertising | Partnerships with NGOs (e.g. Cause-Related Marketing) |
| | Key Partners | Selection of environmentally conscious buyers and distribution points | Socially conscious buyers |
| **Firm Structure, Administration and Human Resources** | Key Activities | Training and support on the ecological performance of employees | Pay attention to equality in the workplace; Guidelines for recruitment (G4-LA1) |
| | Key Resources | Energy efficient Administration building (i.A.a. G4-EN3) | Employees with fair wages (i.A.a. G4-EC5) |
| | Key Partners | Employee participation in environmental activities | Employee participation in firm-internal decisions as well as firm-external community engagement projects |

The SQC model is based on some of the components of the aforementioned software, the value chain according to Porter [22]. and the business model canvas by Osterwalder et al. [20]. The value chain is the presentation and analysis of the primary (e.g. logistics, production or operations, sales and marketing) and secondary activities (e.g. administration, human resources, research and development) that support the primary activities, and together they bring value to a company's products and services [20; 22]. Similarly, this value chain has been used to assess environmental and social sustainability aspects along all these business activities [25]. Therefore, the value chain served as the basis for our selection of the four SQC categories, including production, supply chain, market and internal firm structure. Primary activities can be located in the first, second and their categories. For example, inbound and outbound logistics are combined with supply chain management and procurement into one category. The supporting activities provide an indirect but still supporting role in the production of products and/or services, and these are mostly located in the fourth category.

The business model canvas is a method of visualization of business models [19]. Business models describe the basic principles by which organizations create value, with the distinctions made between three aspects: the product-market combination, the configuration of value chains and main revenue mechanisms. For the SQC, the configuration of value chains is considered to be particularly important, since this the area where sustainability-related decision are made. Also, this part of the business model fits well with Porter's value chain [22]. A brief description of the product-market combination should precede the initial analysis, but it is actually not a part of the SQC since it is tailored for all kinds of startups and micro-enterprises. The environmental and social aspects of companies are already a part the business model, and they will be described separately in the product-market combination.

The business model canvas depicts a total of nine areas of a business model. The fields deemed particularly relevant for the SQC are the key activities, key resources and key partners. Key activities are those actions that are particularly important for a particular area of a business (in this case for each category, such as production of products and services). Key resources can be both physical and intellectual, human or financial resources. In addition, a sustainability management tool that carries information about desired sustainable processes, such as guidelines for environmentally conscious procurement and supply chains, can also be considered a key resource. Key partners considers essential partnerships into order to fulfill the key activities. Examples of partners are buyer-supplier relationships, and also strategic alliances with competitors and additional support organizations. This area ensure that sustainability issues are at the heart of cooperation, but partners must also be audited and consulted for conformity to an enterprises' sustainability goals.

These aspects should be monitored within each of the SQC categories to ensure that sustainability-related targets are meet, and that he enterprise has the proper resources and partnerships to fulfill these actions. The analyzed sustainability reports can then account on the three pillars of sustainability: economic, environmental and social aspects. Since the development and description of business models and the development of business plans – economic criteria are already involved with every environmental and social aspect of the SQC. Therefore, the economic aspects are not given an own column in the model.

By associating environmental and social areas of action in the SQC categories, each key area can be seen as an individual aspect that provides the basis for an overall combinative effort for sustainability in a start-up or micro-enterprise. These aspects are also related to core indicators found in the GRI reporting scheme. These indicators can thus be assessed within the framework of a software application as bullet points to cover or as questions that must be answered within a project to establish sustainability criteria within a very small business. These core indicators selected were mostly confirmed through an overview of the new G4-criteria [9].

## 3. Discussion and Further Developments

From this paper, the results provide both academic and practical implications. From an academic standpoint, the paper provides numerous points of departure for further interdisciplinary research. In the context of startup-related research, for instance, the IT-supported tool can be used as a basis for sustainability-centered business plans. From a practical perspective, this conceptual tool can encourage consultants of startups and software developers to include sustainability criteria in the creation of new software and further services. Based on this conceptual framework, mini-sustainability quick-checks and reports can be created as complementary parts of business plans and marketing-related activities.

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# ICT-based Sustainability Planning and Management Support for SME

Nils Giesen[1]

## Abstract

This contribution will give an insight on a methodical framework for ICT-Driven sustainability planning and management support with a focus on the needs and requirements of small and medium enterprises. In particular, the opportunities, influences and importance of modern SMEs are taken into account [1]. In those environments, sustainable planning processes and management support combined with a controlled economical, ecological but also social acting [9] are of increasing importance for all participating associations. A balanced and legitimated commitment plays an important role for environmental as well as for social orientations of those companies ([2]). In order to enable companies to act entrepreneurial in a way, that following generations can satisfy their own needs in the same dimensions as current generations, those companies need to be provided with assistance in management of processes, aggregation of information and conduction and communication of activities (s.f. [14], [5] and [15]) . In all of these activities ICT-based systems play an important role and can be of essential significance (e.g. [11], [12] or [4]), not only for disastrous and unwanted events (e.g. [10]), but also in order to manage different events with focus on sustainability.

## 1. Introduction

Even if sustainability nowadays is regarded by small and medium enterprises as a key competitive factor, individual measures are being implemented primarily due to customer wishes. In addition, most rules of conduct are not held or defined but mostly they be lived informally and unstructured [3]. By assisting and guiding SME towards a more sustainable development, different ICT-Methods and components can be combined to a powerful methodical framework. The major task of such a framework should be assisting in continuous activities and processes, realising the applicability of strategic instruments for sustainable development. The design and usage of (components of) the framework should not be an end in itself, rather it should be used to archive the self-set environmental and sustainable targets and politics of each SME Therefor a structured catalogue of suitable methods has been established [8].

With this contribution a detailed insight into the methodological and generic structure of the mentioned framework will be provided. Within the steady expansion of the framework several application scenarios have already been identified and validated by the implementation of corresponding prototypes. Here, the focus was always on the strategic aspects of decision support. A first prototype implemented aimed to support the planning phase of regional projects, under influence and considering sustainable development and mutual interactions of activities [7]. A further application was given in a corporate oriented support system for management control of SME, focused mainly on inside usage and implementation [13]. One of the underlying methodology was used to support decision making in the field of simulation and analysis of material flows ([6]). Furthermore the contribution will reflect the results of those different implementations in order to carry out an assessment of the individual elements of the framework to improve the usability for upcoming use-cases and scenarios.

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It is not intended to be create competitive situations, rather the (support of) elementary points as strategic management and internal goals should be prioritized than the additive activities of environmental certifications or sustainability reporting.

## 2. Sustainability for SME

Small and medium sized companies are not always able or willingly to implement a complete large scale (external driven) environmental policy or management and audit system. In addition, hosting and maintaining of complex environmental management information systems would blow up the existing financial framework for ICT-related investments. Nevertheless should they be able to measure their own sustainability related impact and development in order to obtain a reliable base for future decisions. This sets up the demand for a light-weighted, flexible and adaptable approach for a sustainability oriented decision support framework, based on existing ICT-Methods and components.

### 2.1. Sustainability Planning

Planning under the main principle of sustainability has to follow two major aspects in the planning activities: (open) communication and comprehensible and documented processes. While existing guidelines to planning and especially project planning activities are mainly focusing on support while already conducting the considered subject, sustainable planning needs an earlier and more strategic viewpoint on all upcoming activities to be conducted seriously.

In addition, there should be differentiated between sustainability planning and the planning of a project for a sustainable development. While the latter has already a focus on sustainability from itself and the initial activities, sustainability planning aims on guiding all planning decisions of any activities under the main principle of sustainability. An example for a better understanding could be the distinction between the planning for the constructions of a new harbour against the planning of a low emission industrial area. While both approaches have heavy influences on their surrounding environments and society as well as a heavy economic impact, an initial balancing between this criteria and the contemplated target course may heavily differ between these ideas.

For all possible planning activities, some common aspects can be summarized, to describe the initial outline as well as the targeted results. These aspects are relating on the activities as well as on the surroundings, in order to cover these activities in the sustainable development. Further existing frame conditions ("what should happen for whom and why") for the activity, temporal and spatial dependencies have to be included in the planning processes. These information give one part of the required base information. The second part is a clearly communicated set of requirements and indicators to rate the activity. Each individual indicator should be clearly connected to one of the overall fields of a sustainable development, to cover economic, ecologic and social aspects as well. Any given support can now use these information to lead to a, sustainable influenced, decision for the planning. The approach described in this contribution favours an ICT-driven approach using a multiple-criteria decision analysis (MCDA) for the planning process. A simplified overview of all mentioned aspects can be seen in figure 1.

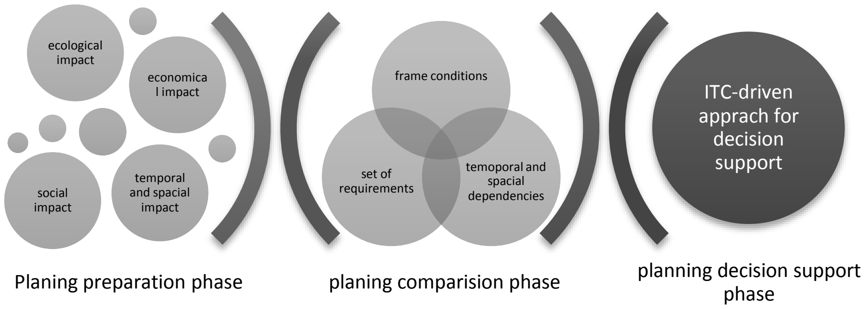


*Figure 1: planning aspects from different phases of the sustainable planning process*

## 2.2. Sustainability Management

Besides the sustainable planning of a given activity, an overall sustainability management should be considered of high importance for small and medium sized enterprises. While existing frameworks and management schemes are not only very complex, the often targeted at and for the demands of enterprises and require substantial input from different fields (e.g. required information, labour time, personal, licence costs, internal and external survey…) and are not suitable for small and medium enterprises. Instead of implementing new systems (technical or methodical), the existing potential should be used to "implement" a sustainability management with the use of well-known and controllable methods and systems of the SME. A guided selection of different strategic instruments can be used inside an activity flow for sustainability management. An excerpt of possible instruments and application spectrum listed in [8] can be seen in table 1.

| instrument | characteristics | | | Usable for criteria of… | | | Rate of Integration |
|---|---|---|---|---|---|---|---|
| | analytical | implementation | communication | ecological | social | economical | |
| ABC-Analysis | X | | | X | X | X | |
| Reporting | X | | X | X | X | X | X |
| EMIS | X | X | | X | | X | X |
| Environ. Accounting | | X | | X | | X | X |
| Cross-Impact Analysis | X | | | X | X | X | |
| DSS | X | X | | X | X | X | X |
| Risk-Analysis | X | | | X | X | X | |
| Social networks | | X | X | X | X | X | X |
| Supply chain management | X | X | | X | X | X | X |
| Suggestion scheme | | X | | X | X | X | X |
| Wiki | X | X | X | X | X | X | X |
| Workflow management system | | X | | X | | X | X |

*Table 1: analytical, implementation and communication aspects of existing instruments for a sustainability management*

## 2.3. ICT-driven Approach for decision support

To conduct the planning process in a comparable and comprehensible way, a generic methodology is needed. The used PRECC methodology is taking into account the concept of having different independent groups of stakeholders taking part in the decision process as well as an focus in ICT-driven or ICT-supported methodologies [6].

Such an ICT-driven approach for decision support can be divided in five activity phases, which should be conducted sequentially and furthermore in an iterative manner. Figure 2 gives an overview of the five phases of PRECC:

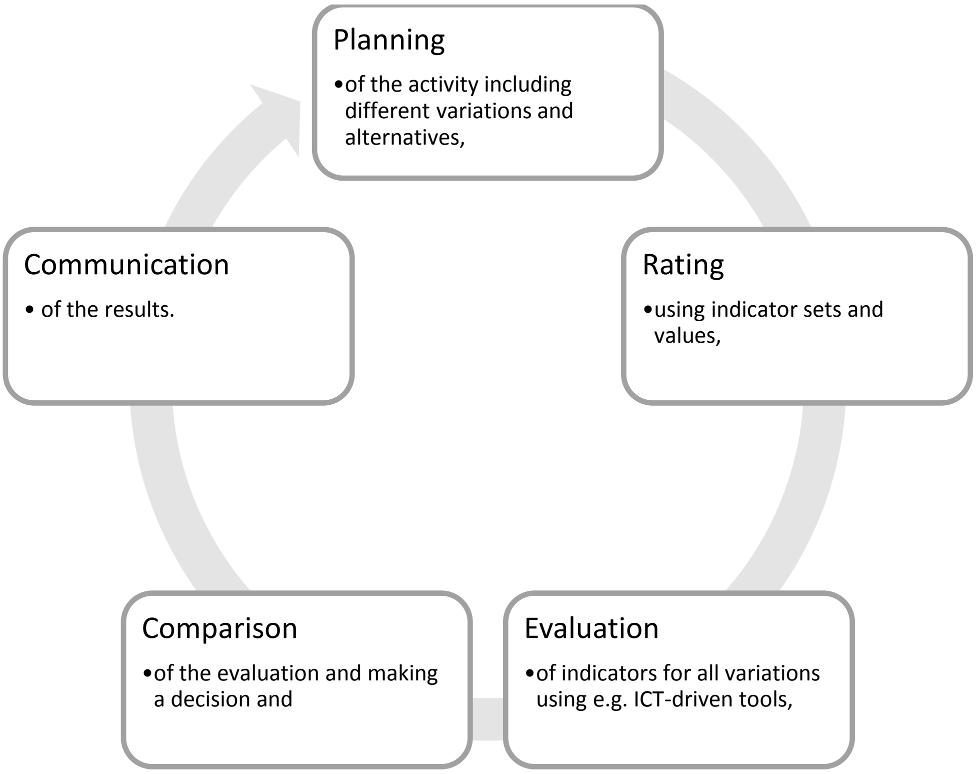


*Figure 2: iterative approach of the PRECC principle*

The planning phase as initial phase of PRECC covers the basic foundations of all following phases. By defining the activity with the aspects in figure 1 an ICT-driven implementation can be set up following the planning phase. The second phase, rating, can be implemented open in a way, where different rating schemes and different weighted sets can be used by different stakeholders, showing the importance and impact of different indicators and values. The evaluation phase provides a view into the results of different MCDA-based approaches and provide a first ranking and possible action fields for the planned activity. The iterative approach of PRECC is closed by a comparison and a communication phase. While the first is mainly targeted for all involved decision manager, the second one is aimed at all involved stakeholder. The results of the comparison and communication phases should be used to start the iteration process and influence the planning of further activities.

## 3. Methodical Framework

Figure 3 gives an insight on the methodical framework which was used to develop the software prototypes for ICT-based sustainability planning and management support systems:

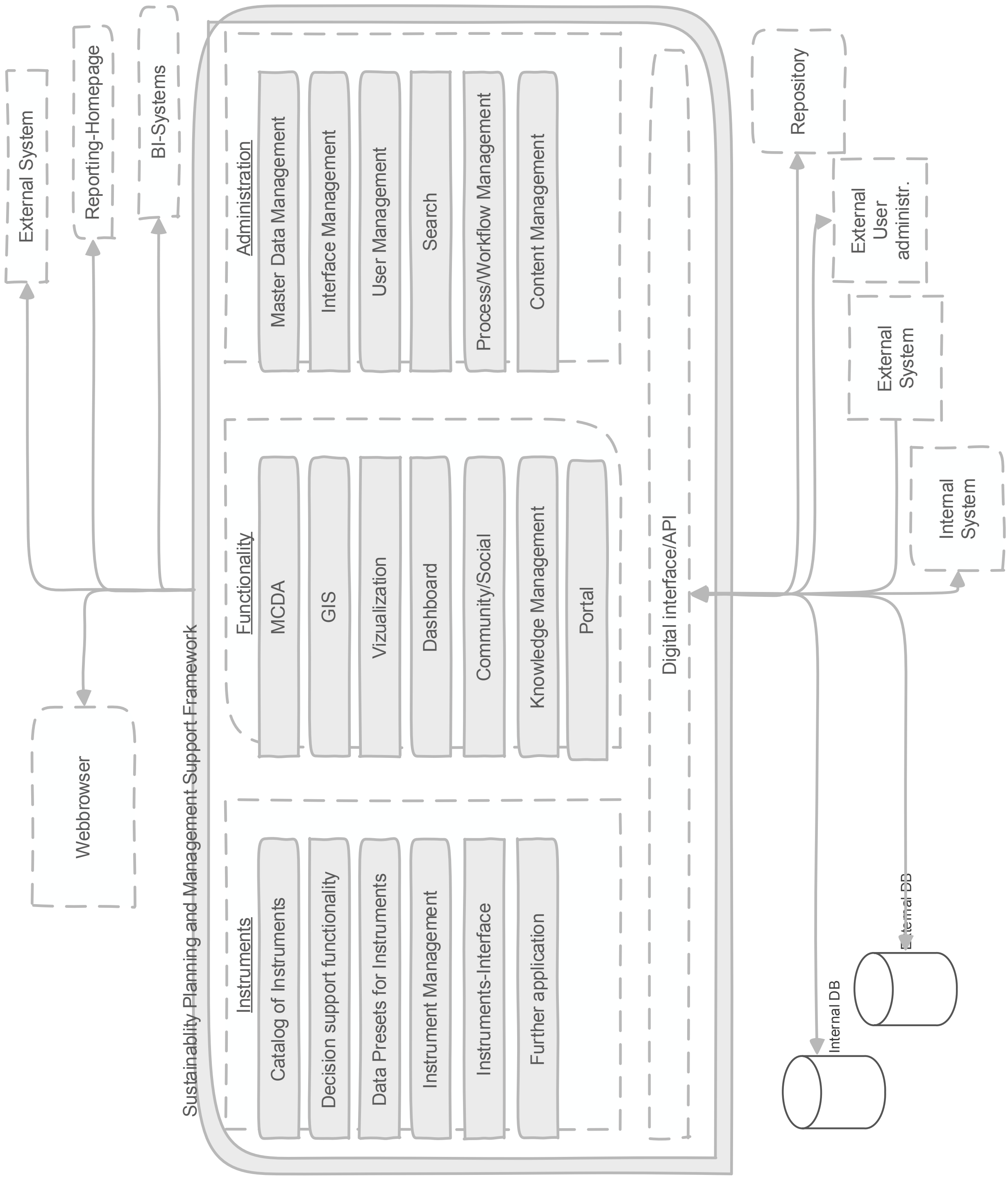


*Figure 3: Sustainablity Planning and Management Support Framework*

The framework includes three major areas: Instruments, Functionality and Administration. Each Area has subitems to be used either from existing software or from easy to adapt and mantain external providers. The mixture of ICT-based and methology based elements aims to reduce the overall amount for an implementation. This will allow an integration to the existing corporate information system landscape over the interfaces, making all available information usable. Combinend single-sign-on/user administration functionality also aides in this process. Further external processing can be used for industry wide comparison (e.g. categorization/grading) if stakeholder demands are existing.

## 4. Prototypes

The methodical framework was used to and extended by two different prototypes, who will be described shortly in the following chapter. More details and access to the prototypes can be given on request by the authors.

### 4.1. ProPlaNet

ProPlaNet is an example for a web based software system which includes a project planning tool, the public interest, using a multi-criteria-decision-analysis (MCDA) to support the decision making process, for the rating of regional projects – Under consideration of the credo of a sustainable development.

The fundamental aspects of the approach are measuring sustainability (indicator based), the current state and development of a region, the effects of projects and comparison of project alternatives with a focus on quality management for data integration and user management as well as e-participation for the overall process.

ProPlaNet was one of the first derivations of the framework, proving the general possibility of technical implementation and been applied to several use cases for regional impact projects. Realized use-cases have been tested from large-scale activities (e.g. identifying renaturation areas for mangrove woods) over regional-scale (impacts of different highway lines) to small-scale activities (e.g. building renovation / room use scenarios) – depending on the available data sources. One impact for the framework from ProPlaNet was the goal to reduce the dependency from external data sources for planning activities.

### 4.2. Sinister

Sinister is a prototype to develop a strategic instrument for developing a sustainable enterprise and aims at small and medium sized enterprises (s.f. [13]). Under consideration of the core areas of supporting strategic decisions, including sustainable supply chains and to raise the efficiency of production processes this prototype supports with ICT-based tools for visual analysis, reporting, decision support, data and system integration and geographic analysis and information systems. Sinister is a proof-of-concept for a light-weighted stand-alone software solution with interfaces to external and internal data sources. Possible scenarios include the integration of external data (e.g. via web service from of federal statistical offices) and internal data (e.g. from an ERP-system) to combine these information to identify new production or market possibilities. While the technical implementation was successful, the usability and process running need to be improved. Nevertheless, the results could be used to further improve the framework.

## 5. Outlook and Conclusions

By providing a framework with low “resource” and complexity requirements, a major benefit for SME could be provided. By applying one of the prototypes or a further implementation of the framework, the companies benefit from direct visible and usable information and decision support for all sustainability related issues. They can combine internal and external data and adapt to a sustainable development without investing critical resources (personal, time, money…) to large-scale software or management installations without knowing what output could be used. Further development on the framework will be conducted as well as a more detailed information of the framework and its details itself will be published.

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# A Maturity Model for Green ICT: The case of the SURF Green ICT Maturity Model

Albert Hankel[1], Lisa Oud[2], Maiko Saan[2], Patricia Lago[2]

## Abstract

This paper discusses the development and evaluation of a maturity model for Green ICT. We describe how the model was developed with the input of a number of Green ICT experts before it was released to the general public. The model consists of three domains with attributes on Green ICT that encompass both Greening of ICT as well as Greening by ICT. The quality of the model and its accuracy to capture the full scope of Green ICT has been evaluated through an online survey. We evaluated the quality of the model on relevancy of attributes, whether the attributes were well defined and whether the domains were complete. Twenty participants contributed meaningfully. Two attributes were considered to be irrelevant and six new attributes were suggested. With these results the quality of the maturity model can be improved. Our next step is to test the usefulness of the model by seeing how it is used in practice. We hope this paper inspires more work on testing the quality and usefulness of models and frameworks on Green ICT.

## 1. Introduction and motivation

There is a clear need to transform our society into one that is environmentally sustainable. One of the factors in this transformation is avoiding too much global warming, which is associated with the amount of $CO_2$-particles in the air. To avoid a higher than 2° C warming, we need to reduce our Greenhouse Gas (GHG) emissions to zero before 2050 and maybe even earlier.

The field of Green ICT is associated with minimizing the negative environmental impacts of ICT and optimizing the positive impacts of ICT. However, most Green ICT activities are often only focused on reducing the negative impacts of ICT. Even within these activities there is a narrow focus: data centers receive disproportionate attention because these are such large energy consumers; yet, data centers are only responsible for 20% of the total ICT footprint with end user devices being responsible for the largest part (60%) [1]. In addition, from a lifecycle perspective, most efforts in Green ICT reduce the impact of the use phase and its associated energy consumption, but for many ICT devices and components, the largest part of their footprint is in production [2].

The main reason for this narrow focus is that such Green ICT actions are the most visible and most easy to take. In addition, optimizing the positive impacts of ICT often leads to disassociated benefits and split incentives, between organizations and within organizations: a common case is that ICT departments must make the investments while others, such as Facilities departments, reap the benefits, both from an economic and environmental perspective. To overcome the narrow focus on both the solution space and collaboration options, organizations need to have insight into how Green ICT actions affect a wider scope of environmental impact and a way to understand their progress in opening up the narrow focus.

This paper describes and evaluates the SURF Green ICT Maturity Model (SGIMM) that has been designed for the purpose of giving organizations insights in and understanding of the total

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environmental impact of Green ICT. We will describe how the model was created with the input of a number of Green ICT experts before it was released to the general public. The quality of the model and its accuracy to capture the full scope of Green ICT has been evaluated through an online survey.

## 2. Methods used to create the maturity model

SURF, the Dutch higher education and research partnership for ICT, decided to develop a maturity model on Green ICT after interviewing a number of Dutch higher education and research institutions. In these interviews the institutions expressed a clear need for some way to know how well they are doing in terms of Green ICT. SURF wanted to develop a maturity model based on expert views and opinions and validate this through a survey spread amongst practitioners. The SGIMM was developed by SURF and a number of Green ICT experts, both from the Dutch higher education and research community as well as outside it. Responsibility for ICT in organizations part of this community is typically delegated to an ICT department. The SGIMM was therefore designed from the ICT department’s perspective

The outline of the model was created in a workshop with nine Green ICT experts. During this workshop domains were set and attributes were discussed (see section 3 for a detailed description of the maturity model). Based on this input we designed a first draft model that was evaluated by the expert group in an elaborate survey. The draft that followed on the feedback from the survey was tested in a pilot with a higher education institution, the Hogeschool van Arnhem en Nijmegen. The results were discussed again with the expert group leading to a maturity model that was published after this discussion[3].

## 3. Description of the SURF Green ICT Maturity Model

The concept of the maturity model is based on the Capability Maturity Model, representing a framework with five maturity levels for quality and process improvements. The five levels are (1) initial, (2) repeatable, (3) defined, (4) managed and (5) optimizing. At the lowest level, the initial level, the organization does not provide a stable environment for the activity. At this level the process is ad hoc. However, at the highest level, which is the optimizing level, the entire organization is focused on continuous process improvement [3].

The SGIMM conceptually consists of four domains covering negative and positive impacts and aspects of ICT. Each domain consists of attributes that have a definition and a description of a level five maturity. Three domains and attributes are summarized in Table 1.

The three domains mentioned in Table 1 are generically applicable to any organization. The fourth domain is sector specific and covers ‘Greening of primary processes with ICT’. For the higher education sector, the primary processes would relate to education and research. This domain is not yet included in the currently published model.

The SGIMM is designed to give organizations insights into the maturity of Green ICT of the organization. It is set-up as a self-assessment and enables organizations to have an internal dialogue, to gain agreement on the status quo and to define actions for improvement. By letting several individuals within an organization score the attributes and discussing theses scores with the participants (average, minimum, maximum scores, etc.), an organization can identify weak and strong Green ICT aspects. SURF published a manual that guides users through this process of self-assessment together with the model itself.

[3] http://www.surf.nl/en/knowledge-and-innovation/knowledge-base/2014/surf-green-ict-maturity-model.html

| Green ICT in the organization | Greening of ICT | Greening of operations with ICT |
|---|---|---|
| Green ICT Strategy | Computing Infrastructure | Travel Reductions with ICT |
| ICT Governance | Network Infrastructure | Space Reductions with ICT |
| Green ICT Procurement | Storage Infrastructure | Energy Reductions with ICT |
| E-waste policy | Housing | Paper Reductions with ICT |
| Green ICT Architecture Principles | End User ICT Equipment | Other Reductions with ICT |
| Information Management | ICT Services | Environmental Awareness and Decision Support |
| Community Collaboration | Green Software Development | |
| Green ICT Supply Chain Management | | |

*Table 1. The domains and attributes of the SURF Green ICT Maturity Model.*

## 4. Evaluation of the SURF Green ICT Maturity Model

While the SGIMM was grounded in the opinions of the Green ICT experts and should therefore theoretically be of sufficient quality, this needed to be validated by practitioners. In order to validate the model, we designed an online survey[4] in which questions were asked on the quality of the model. These questions were based on Wand and Wang [4], who identified four generic dimensions to evaluate Intrinsic Data Quality using the most cited quality dimensions in their literature study: (1) complete, (2) unambiguous, (3) meaningful and (4) correct. They defined complete as a set of data that includes all necessary values; unambiguous (accuracy and precision) as representing the correct data; meaningful was defined as being able to use data in a useable way; and correct as containing the right information. To apply these dimensions to the questions we wanted to ask we chose to ask about the relevancy of attributes (meaningfulness), whether they were well-defined (correct and unambiguous) and whether a domain was complete or missing an attribute (complete).

The survey was set-up online and spread mainly amongst people from the Dutch higher education sector. It was also promoted outside of the sector and internationally (mainly UK higher education) for comparison purposes, but this was only a small part of the response. Because the entire survey was time consuming participants could choose one or more domains (Table 1) to answer questions about. Motivation was required for most answers. In addition we collected information on each participant on where they were from (country, sector) and whether they were familiar with Green ICT, their maturity.

We did a trial run with the survey amongst the Green ICT experts who helped us with the maturity model. Their feedback, such as to add an ‘I don’t know’ option to each question, was incorporated in the published version of the survey which was available for four weeks during February 2014.

[4] The survey content is available upon request at the authors.

## 5. Results of the evaluation

In total, 68 participants started the survey but only 20 of them contributed meaningfully. 80% of the participants were working in the Netherlands. The response for each domain was as follows:

- Green ICT in the organization 8
- Greening of ICT 13
- Greening of operations with ICT 8

Because the response was so low, it was hard to draw any quantitative-based, representative conclusions. Nevertheless, we found some interesting results.

First, we used the self-rated maturity on Green ICT of participants and of their organizations as a weighting factor to calculate relevancy scores. As can be seen in Figure 1, more than half of the participants rated themselves mature, whereas they rated their organization of lower maturity than themselves. We assumed opinions of mature participants and/or working for mature organizations are more important than opinions of immature participants and/or working for immature organizations. The maturity levels were converted to a 1-5 scale and each participant's relevancy score on an attribute was weighted by their fraction of the sum of maturity levels of all participants who scored that attribute.

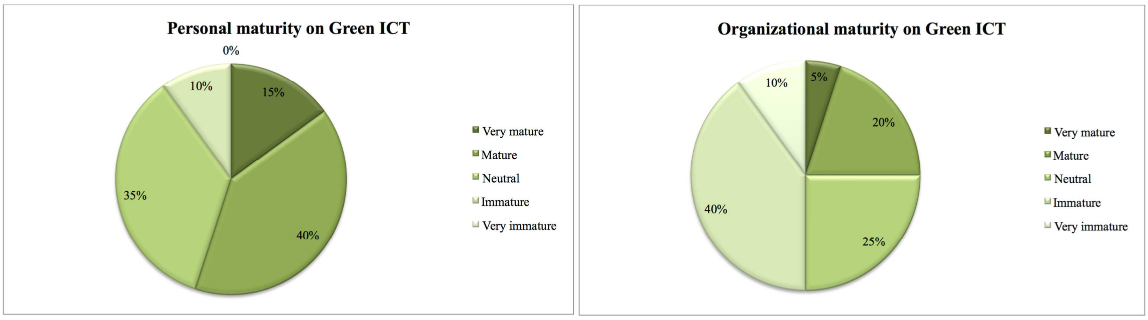


*Figure 1. Personal and organizational maturity of the survey participants.*

By weighting the average relevancy of attributes we amplified differences between attributes that were difficult to see otherwise. Participants had to agree or disagree with the relevancy of an attribute on a Likert scale of 1 to 5, where a score of 5 was the highest relevancy option. A neutral position towards relevancy was indicated by a score of 3. We considered an attribute relevant if its weighted average relevancy is 3 or higher. Figure 2 shows the results for all attributes of the model. Almost all attributes are considered relevant except two, being: 'Information Management' and 'Other reductions with ICT'.

We also asked participants to motivate their score. If we just zoom in on the two low-scoring attributes we see for 'Information Management' that the participants were triggered by the use of the word *redundancy* in the attribute description: they do not believe information management can be used to reduce excessive redundancy in ICT resources. For 'Other reductions with ICT' it seems that this attribute does not appeal to participants because it is too broadly defined: it is described as a catchall, covering everything not mentioned by the other five attributes in the domain 'Greening of operations with ICT'.

The second quality aspect we were interested in was whether attributes were well defined. In the survey this was a yes/no question where participants had to motivate if they disagreed. The results are shown in Table 2.

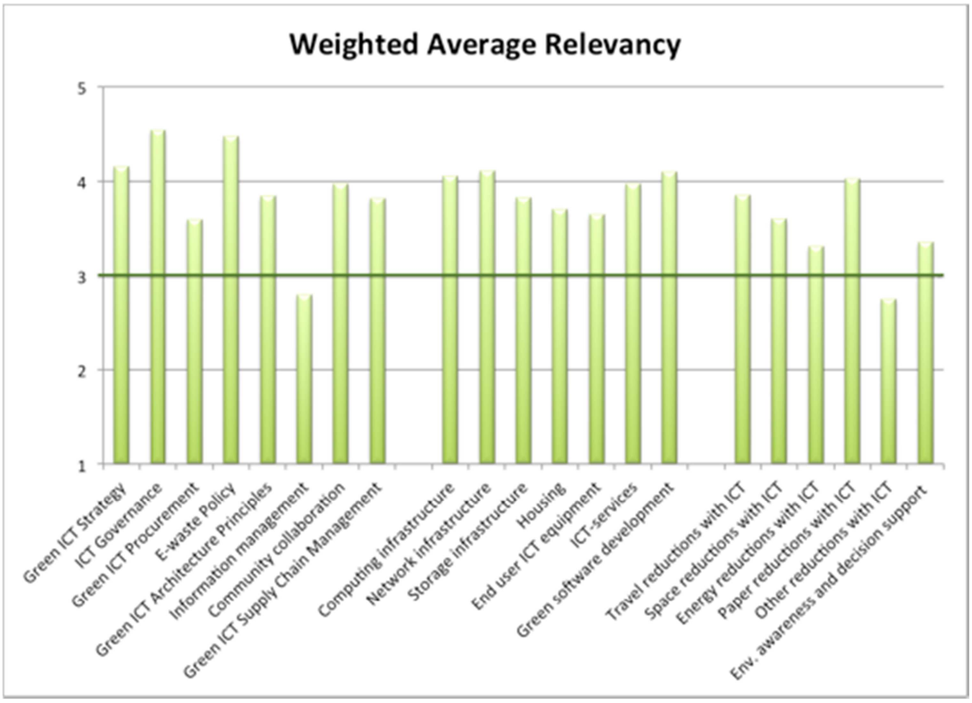


*Figure 2. Weighted average relevancy scores for all attributes of the maturity model.*

| Attribute | Participants | Agreement | IDK: Participant does not know | Agreement excluding IDK |
|---|---|---|---|---|
| **Green ICT in the organization** | | | | |
| Green ICT Strategy | 8 | 6 | 1 | 85,71% |
| ICT Governance | 8 | 6 | 0 | 75,00% |
| Green ICT Procurement | 8 | 6 | 1 | 85,71% |
| E-waste Policy | 8 | 5 | 1 | 71,43% |
| Green ICT Architecture Principles | 8 | 4 | 1 | 57,14% |
| Information management | 8 | 2 | 3 | 40,00% |
| Community collaboration | 8 | 4 | 2 | 66,67% |
| Green ICT Supply Chain Management | 8 | 4 | 3 | 80,00% |
| **Greening of ICT** | | | | |
| Computing infrastructure | 13 | 10 | 2 | 90,91% |
| Network infrastructure | 13 | 10 | 1 | 83,33% |
| Storage infrastructure | 13 | 7 | 4 | 77,78% |
| Housing | 13 | 10 | 1 | 83,33% |
| End user ICT equipment | 13 | 9 | 1 | 75,00% |
| ICT-services | 13 | 7 | 2 | 63,64% |
| Green software development | 13 | 8 | 1 | 66,67% |
| **Greening of operations with ICT** | | | | |
| Travel reductions with ICT | 8 | 4 | 1 | 57,14% |
| Space reductions with ICT | 8 | 7 | 1 | 100,00% |
| Energy reductions with ICT | 8 | 7 | 0 | 87,50% |
| Paper reductions with ICT | 8 | 7 | 1 | 100,00% |
| Other reductions with ICT | 8 | 6 | 1 | 85,71% |
| Env. awareness and decision support | 8 | 7 | 0 | 87,50% |
| Green ICT Strategy | 8 | 6 | 1 | 85,71% |

*Table 2. This table shows whether participants agreed with the definition of attributes.*

A strict definition of being well defined would be that all participants agreed with the definition of an attribute. This would translate into a 100% score in the last column of Table 2 and the observation that only two attributes are well defined. If we look into the motivation participants gave us, we see a clear difference between high scores (above 80%) and low scores. In general the high scores have small comments for improvement often adding something local from their own experience. The low scores show comments relating to the need for more examples (too abstract), ambiguousness and scoping and focus issues.

The final aspect of the survey concerned completeness of the maturity model. We asked participants whether they were missing an attribute in a domain. In each domain two participants made suggestions. These were: Maintenance management; People and culture; Mind-set and experience of staff; Sustainable offices; Savings in productions and logistics; Improving work inefficiencies with ICT. As participants were often only evaluating one domain, some suggestions do overlap with each other or attributes were already present in the model. Second, for the domains ‘Green ICT in the organization’ and ‘Greening of ICT’ a high percentage of participants answered “I don’t know”; three out of eight and five out of thirteen respectively. It seems that this question was difficult to answer.

While it is difficult to draw any definitive conclusions from this survey, overall it seems that the maturity model is covering most aspects of Green ICT within the three domains. The results suggest that two attributes can be removed and six suggestions for new attributes are offered. Most descriptions of the attributes need small revisions, whereas some need more work, based on the feedback from the participants.

## 6. Related work

Many models, frameworks and tools on assessing the environmental impact of ICT have been released over the past years from both research and practice. In addition, there are general impact assessment tools that can also be applied to ICT, such as life cycle analysis or green house gasses audits (see Ecofys et al. [5] for an overview of general tools applied to ICT).

Most of the specific models and tools focus on energy efficiency and reducing the negative impacts of ICT, such as those developed by the Green Grid[5] and the OpenDCME model[6]. While these are mostly focused on data centres, others such as those developed by Gartner [6] and Molla et al. [7] capture the entirety of ICT but are still only limited to the direct impacts in scope or are very general/abstract. A few tools have been developed that also include the positive impacts of ICT, such as those by UK HM Government [8], deMonsabert et al. [9] and Donnellan et al. [10]. Still those mostly focus on the negative impacts, too. From a system perspective or the total global footprint of human society this seems strange since the negative impacts are responsible for 2% of that footprint, while the positive impacts have the potential to reduce the global footprint by 16% [1].

As far as we can derive from research literature and practice, there is a lack of works on assessing the quality of the tools, if and how they are being used and whether they achieve their intended effects. While such questions might be trivial for other assessment topics, as it will quickly follow from use, this is not the case for the environmental impact of ICT. Environmental sustainability is typically multi-dimensional and prone to local optimizations and it is therefore complex to assess progress.

[5] www.thegreengrid.org

[6] www.opendcme.org

| Model | Problem description | Goal | Target audience | Comparison with SGIMM |
|---|---|---|---|---|
| Data Center Energy Efficiency Maturity Model [11] | Organizations have problems managing data centers due to complexity and rapid evolution. | Help to improve the energy efficiency management in data centers. | Organization who manage data centers. | Both are maturity models. Limited scope – only data centers. |
| ICT Capability Maturity Framework [10] | ICT is responsible for a major percentage of the organizational footprint. | Manage sustainable ICT within an organization to reduce the organizational footprint. | Organization who would like to reduce their ICT footprint. | Both are maturity models. Focus is more on strategic level (similar to [6]). |
| SustainaBits [9] | Challenges to define and achieve sustainability goals. | Provide a reliable and industry accepted framework to guide organizations within the IT sector to a sustainable future. | Organizations within the IT sector. | Not a maturity model but a broad set of criteria. Focus is on comparison between IT organizations. |
| UK HM Government Green ICT Maturity Model [8] | ICT has a key role both as a contributor to the government's carbon footprint and as an enabler for the business and behaviour changes required to meet the significant Greening Government targets. | This model provides the means for UK government to demonstrate the progress being made with embedding Green ICT into its business processes and practices. | All UK public sector bodies. | Very similar to SGIMM, but targeted at governmental organizations. Seems based on practice alone (vs. research). |
| Green IT Readiness Framework [7] | Pressure on organizations to implement sustainable business practices. Critical capability of organizations to measure their G-readiness. | Help organizations to evaluate their maturity on Green ICT based on their Green IT readiness. | Researcher to establish cause-and-effect relationship models. Practitioners to use as a decision tool. | Focus on Greening of ICT. Uses five components (similar to SGIMM domains) that can be scored 1-7. Based mainly on literature. |
| Gartner Green and Sustainable IT Infrastructure and Operations Maturity Model [6] | Many organizations do not necessarily acknowledge sustainable development priorities explicitly. This model focuses on these priorities from an IT I&O perspective. | The model is intended to help identify where your organization is on the maturity curve, and how to get to where you want to be. | CIOs | High level descriptions (aimed at strategic & tactical level), few examples, little attention for enabling aspects. |

*Table 3. A comparison of Green ICT models and frameworks.*

## 7. Conclusion

In this paper we have explained how we have developed a Green ICT maturity model that goes beyond the energy efficiency of ICT. To evaluate the quality of the model, we defined three quality aspects: relevancy of attributes, well-defined attribute descriptions and completeness of the domains. We created a survey where participants had to evaluate these aspects. Twenty participants contributed meaningfully to the survey.

From the participants' response, it seems that the maturity model is covering most aspects of Green ICT within the three domains. Two attributes were considered not relevant and six suggestions were made for new attributes. Most descriptions of the attributes need small revisions, whereas some need more work, based on the feedback from the participants. While it is difficult to draw any definitive conclusions from this survey, with these results the maturity model can still be improved.

## 8. Discussion

The results of the survey are indicative on the quality of the model, but they are not conclusive. We will continue to find ways to assess the quality, because we think it is important to ground this in science and in practice. This is not only useful for the model itself, but conclusions can also be used in other models. Similarly, we want to learn from other work as well and we think it would be good to see more work on quality assessment of Green ICT models.

One of the quality aspects we did not look at is whether the model is actually used and how it is used. Our next step is therefore to continue the evaluation of SGIMM through following its use in practice. We want to see how organizations use the model as a baseline, what they do with the results and if anything has changed in the organization after a period of time.

While the survey results can be used to improve the maturity model, the response was too low to draw any quantitative conclusions that can be generalized to meaningful statements for other Green ICT models or statements on attitudes towards Green ICT. For example, it would be interesting to find out what aspect of Green ICT is found most relevant in the Dutch Higher Education sector compared to those in the UK. The high dropout of participants (20 out of 68 completed the survey) indicates that it was difficult to complete the survey, probably because of its length and depth. It would be interesting to do a shorter survey to find out more about what aspect of Green ICT is considered important, based on topics such as the attributes in the SGIMM.

We hope the way we approached the development and evaluation of the SGIMM will attract follow-up for research on other Green ICT models and frameworks, as we believe it is necessary to ground these models in practice and to evaluate these scientifically. In the end, the goal of such models is that they are used in practice and that will only happen if they are of sufficient quality.

## Acknowledgements

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# Upgrading Reporting, Communication and Benchmarking Tools of IT-for-Green Project

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## Abstract

Corporate sustainability and sustainability management have become key issues in modern organizations to achieve a more balanced and sustainable development. The IT development has increasing increased drastically in recent years and in the same way how IT can support the environmental and sustainability behaviours in business processes it can be part of the solutions to improve the sustainability performance in organizations. In the last years different projects had been working in this area, to guide and provide tools for decision makers and stakeholders. IT-for-Green is one of this projects that propose a new generation of CEMIS that permit to incorporate the strategic sustainability integration. Another solution, the System of Sustainability Performance Evaluation supports social, economic and environmental indicators related directly with organization's performance distributed over key areas. This paper explores the possibility to upgrade and integrate those two systems that actually run in different technologies and pattern designs using web services to facilitate application integration reducing application's heterogeneity. A first GET_INDICATORS web service definition and implementation was made, taking advantage of one of the facilities of IT-for-Green as an open platform.


## 1. Introduction

The recent growth in corporate sustainability made organizations consider this area as a key success factor that must be managed. IT plays an important role in sustainability management, specifically in sustainability performance evaluation. Although IT has environmental impacts during its lifecycle, as a positive part, IT supports eco-controlling and efficiency in organizations.

The last fifteen years have raised the idea of how IT can support the environmental and sustainability behaviour in business processes. Different concepts have been popularized through the academic and business world, e.g. Green Information Systems (IS), Green IS & IT, Green computing, Green IT and IT-for-Green. All are related to first-order effects (negative environmental impact of IT) and second-order effects (positive impact of IT in business processes). IT-for-Green is one of the newest concepts of the second-order effects and refers to the positive impact of using IT on business and economic processes. This perspective considers IT as part of the solutions to eco-sustainability. Thus using IT to make enterprises greener refers to IT-for-Green [1].

Established tools for the strengthening of IT support are Corporate Environmental Management Information Systems (CEMIS), but those are not sufficient yet to achieve the strategic sustainability integration [2, 3]. For that reason, the project IT-for-Green started in 2011. IT-for-Green will cover the complete product life cycle from input to transformation to output. It proposes a new generation of more strategic CEMIS, which should be able to support the company's decision makers in all stages of product life cycle. Organizations need to track in a continuous way their sustainability goals and the goals of all their branches. The sustainability indicators are a good tool to compare sustainability business performance in different branches, setting an internal

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sustainability benchmarking. Managers prefer the condensed information for a quick understanding of the whole business picture, identifying setbacks and progress related to the overall performance. The main objective of this paper is to propose an upgrade to the IT-for-Green project, specifically to the component, which is related to sustainability reporting and dialogue (called Module 3).

Communication and reporting are key elements of an organization's sustainability management. For that reason the idea of System of Sustainability Performance Evaluation (SySPE) developed for Cuban organizations, can be included as a future extension as a collection of web services for the IT-for-Green project to strengthen and upgrade the reporting functionalities and to contribute to the internal benchmarking of organizations.

SySPE is a tool to support the storage, retrieval management and integration of different sustainability indicators. SySPE helps to calculate the Corporate Index of Sustainability Performance (CISP), this index helps managers to discover which is the overall compliant of sustainability business goals and include the perception of different stakeholders. The application allows the graphical representation of CISP and visualizes the improvement potentials of indicators to redirect the business managers' efforts.

All these functionalities can help to track business sustainability behaviour continuously and to reduce environmental business impacts. The paper exposes the different technologies used for the integration and how to effectively integrate two systems that actually run with different design patterns through a web service definition and implementation, taking advantage of one of the facilities of IT-for-Green as an open platform.

## 2. IT Support for corporate environmental management and sustainability

The business has great responsibility in the process of transition to a more sustainable development (SD). The SD is a social concept , and is being increasingly applied as a business concept under the name of corporate sustainability [4]. The first definitions of corporate sustainability were a faithful translation of the concept given in "Our common future" at business level. Others like SAP defines sustainability in a business environment. Sustainability requires us to consider environmental, social and economic aspects at the same time. If you are able to manage the risks and the opportunities holistically, it will lead to increased business success in turn [5]. The main objective of corporate sustainability management is balancing the organizational performance in the economic, social and environmental improvement opportunities identified simultaneously [6, 7].

In recent years, some tools had been developed to help organizations in the long path of sustainability. Decision Support Systems are emerging as a suitable solution in the field of sustainability planning and control of complex systems [8]. Some of the most prominent specialized tools are: SAP Sustainability Performance Management (SuPM), Enablon SD-CSR, SoFicredit360 and STORM. All presented tools offer similar possibilities regarding their reporting capabilities [9]. Other important tools is OEPI related environmental performance indicators; a fundamental goal of OEPI is to bridge the gap between various sources and types of environmental information and users of different backgrounds by providing an integrated information source [10].

## 3. IT-for-Green project as a CEMIS solution

IT-for-Green is a project coordinated by the Carl von Ossietzky University of Oldenburg joined with other German universities and business organizations. It is financed by the European Research and Transfer Network for Environmental Management Information Systems (ERTEMIS). The principal aim of this project is "increasing the environmental friendliness of companies and their processes by means of ICT" [11]. The project proposes to research and create a new generation of

Corporate Environmental Management Information Systems (CEMIS) which is able to support the company's decision makers.

The system has different functionalities clustered in three modules [11-13]:

- *Green-IT:* Organizations have to deal with energy efficiency as a relevant element to reduce their IT infrastructure carbon footprint and the potential of their climate change impact, through the optimization of their electricity grid. This module is oriented to support energy efficiency and data modelling; it helps to calculate the energy requirements of a data center and compares the results with reference data to optimize energy use and costs.
- *Green Production and logistics:* This module gives insight on two basic CO2 producing systems, namely production and logistics. For both systems there is a subsystem that models the existing processes and non-existing processes, so both can be compared to each other and to those of other companies.
- *Sustainability reporting and communication:* This module's goal is to collect and manage information about the real contribution of companies to sustainable development and stakeholders' interaction. The module handles economic, social and environmental information, necessary to current and future stakeholder demands. Reports are elaborated with the accepted guidelines GRI G3, but also other kind of reports can be transformed into a schema to be generated by the application.

IT-for-Green Next Generation CEMIS is built in a modular way and it follows the Service-Oriented Architecture (SOA). The CEMIS is a service-oriented platform that allows for loose coupling and bundling of necessary methods [12]. The platform is designed to be open and extensible for new nodules and services through a workflow-based and service-oriented platform [12, 13]. The architecture is shown in the figure 1, Green Service Mall is the component that deals with web services, specifically it is a service repository where the web services can be published and discovered by consumers to satisfy their necessities.

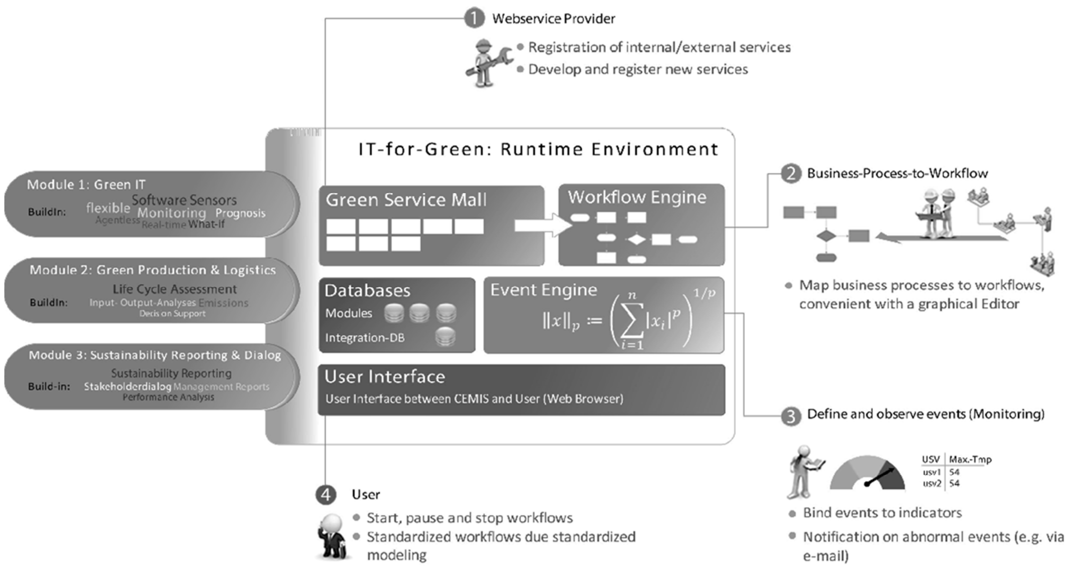


*Figure 1: Next Generation CEMIS Architecture.[13]*

The *Workflow Engine* is oriented to map the business process and it allows different tasks such as adding, updating, and deleting workflows; it is responsible for the system workflow execution and management, interacting with the service consumer and the workflow editor.

The Event Engine is a component of the CEMIS with the main task to compare pre-established (environmental) requirements (e.g. water consumption, CO 2 emissions, etc.) with the current variables' performance and to detect possible violations and generate warnings and alarm messages automatically. The *Event Engine* is composed by different subcomponents like: management, executor, timer, condition model and Data Access Objects (DAO). The *User Interface* is the layer between the CEMIS and the users and can be operated using any kind of web browsers.

Actually IT-for-Green is moving forward to achieve more ambitious goals. The next steps will be to integrate the prototypes into the surrounding web service infrastructure and the import of sustainability indicators and the generation of schemes [14]. The integration of IT-for-Green with other applications is a near future objective.

## 4. System of Sustainability Performance Evaluation

*SySPE* is an informatics solution born in 2012, impelled by the necessity of the Cuban energy sector as representation of Cuban business organizations to respond to internal and external pressures derived of the inclusion of Sustainable Development concept at business levels, to support decisions associated to sustainability performance and provide an internal benchmark and report tool to satisfy stakeholders information requirements. *SySPE* supports social, economic and environmental indicators related directly with organization performance distributed over key areas. For this the idea of the Sustainability Balanced Scorecard (SBSC) was used, to pursuit the balance among the perspectives and the economic, environmental and social pillars.

SySPE has three main modules (Figure 2. a). *Data collection:* is related to the collection and storage of indicators information defined by business managers and regulatory standards. The BSC perspectives definitions belong to this module. Other actions are the update and elimination of information, those actions will be restricted to a small group of users that could interact with the module system.

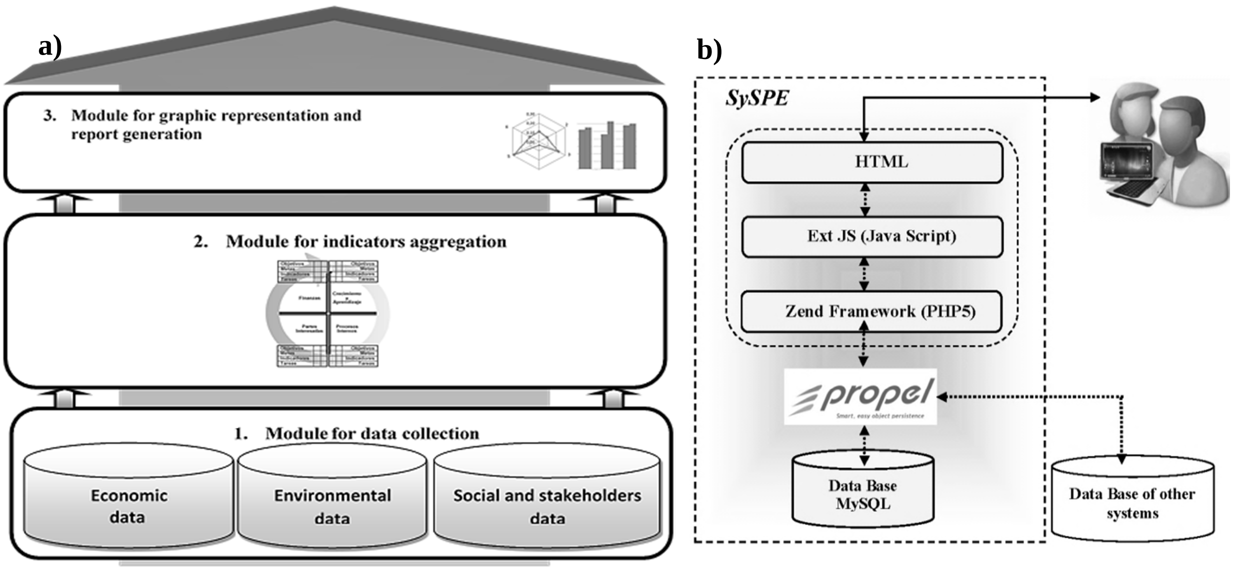


*Figure 2: SySPE architecture.[15]*

*Indicators aggregation:* this module allows setting the sustainability indicators defined over the SBSC perspectives and assign weights for indicators and perspectives to calculate the Corporate Index of Sustainability Performance (CISP). The CISP idea is synthesized in an index of the progress or setbacks in corporate sustainability performance, to verify simple and continuously if the managerial efforts, organizational management instruments and environmental training are translated into a better or worse sustainability performance. The third module for *Graphic representation and report generation*, allows users and stakeholders to visualize the behaviour of CISP and sustainability indicators in a period and represent graphically the behaviour of indicators and indexes.

The technologies used for application development were various (Figure 2. b), the MySQL, Propel as Object Relational Mapping, Zend Framework (ZF) was used as rapid web development framework of PHP 5 implementing the Model-View-Controller (MVC) design pattern, which is the best current practice to develop modern web applications. [16]. The graphic representation of reports was implemented using the Business Intelligence and Reporting Tools (BIRT).

*SySPE* solution intents to cover a poor explored area in Cuban organizations; linked to the support of IT to sustainability performance management and business sustainability benchmark. The main goal is to support sustainability data and indicators to guide business managers and stakeholders to redirect sustainability issues efforts.

## 5. Integrating SySPE with IT-for-Green

SySPE and IT-for-Green are two solutions that actually run in different technologies and pattern designs, IT-for-Green uses a Service Oriented Architecture design pattern and SySPE implements a Model-View-Controller pattern. In order to upgrade the IT-for-Green solution sustainability reporting and dialogue module, it is proposed to take advantage of SySPE functionalities and reporting capabilities. To achieve this goal one question should be answered: How to integrate effectively two systems that actually run with different design patterns and technologies? A method of data exchange is needed, that doesn't depend upon a particular programming language or design pattern.

An effective solution is a web service as a way to expose the SySPE functionalities and make it available through standard web technologies to facilitating application integration reducing applications heterogeneity. Web services have become a widely used form of adding depth to online applications and allow developers write applications that are interoperable with external services located anywhere in the world [17]. Web services use different web standards like XML and SOAP to tag and transfer the data, Web Services Description Language (WSDL) is used for describing the services available and the Universal Description, Discovery and Integration (UDDI) is used for list what services are available [18].

To establish a real integration between those applications, web services architecture was defined (see Figure 3).

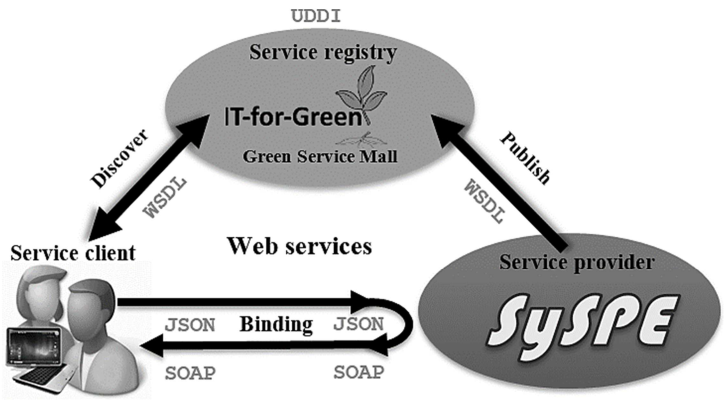


*Figure 3: Web services architecture.*

Its shows how a service client contacts and discovers the web service in service registry (Green service mall), the service registry answers with a service description indicating where to locate the service and how to invoke it. The service provider, SySPE, similarly has to generate service descriptions for those services and will make its services known by publishing the corresponding service descriptions in a service registry. The service description is used by the service registry to catalog each service and search for it when requests arrive from service clients. SySPE validates the service request and sends structured data in an XML file, using the SOAP protocol. This XML file would be validated again by the service requester using an XSD file.

To create the web service Zend Framework will be used, the framework of PHP was used to develop SySPE application and provide components to work with web services. The components provided by the framework, for web service creation, are mature and well-designed, they offer good integration with the rest of the framework and are comprehensively documented; the entire code is unit-tested and peer-reviewed and there is no licensing fuss around Zend Framework [19]. ZF includes a number of components that enable work with existing web services as well as creating your own. Zend_Service provides a straightforward interface to a number of popular web services like: Amazon, Twitter, Yahoo and Google's services [20].

As a practical example the web service called GET_INDICATORS was defined, to orient the example in one of the future directions identified by [14] (import of sustainability indicators) as base of business sustainability performance, to upgrade module three. GET_INDICATORS web service allows obtaining all the indicators with their respective fields stored in SySPE. For this was created a PHP class named Services with one function GET_ INDICATORS (Figure 4). This function establishes the connection with the database executes the query and returns the result in JSON (JavaScript Object Notation) format.

```
<?php
class Services {
   function  GET_INDICATORS(){
            $path = realpath(dirname(__FILE__).'/../../config.ini');
      $config = new Zend_Config_Ini($path, 'database');
      $con = new Myapp_SQLDBCONNECTION();
      $con->selectdb($config->database, $con->connect($config->server, $config->user, $config->passw
      $query = "SELECT indicadores.idindicador AS id, indicadores.nombre AS `name`,indicadores.descr
      $result = $con->createquery($query);
      $information = $con->getarrayobject($result);
      $json = "{".'"'.'rows'.'"'.':'.json_encode($information).'}';
      return $json;   //INDICATORS
```

*Figure 4: Class services.*

ZF allow you to automagically generate a WSDL file based on existing code. To test the WSDL file a PHP class called client was created (Figure 5). The class defines a function WSDL_call and use a Zend_Soap_Client by pointing a Zend Soap Client instance at the URL, returning the WSDL in an XML format to test the service.

```
<?php
class client {
        function WSDL_call() {
        $path = realpath(dirname(__FILE__).'/../config.ini');
        $config = new Zend_Config_Ini($path, 'webservice');
        $client = new Zend_Soap_Client($config->service_url);
        $ca =  $client->GET_INDICATORS();
        echo $ca;   } }
$C = new client();
$C->WSDL_call();
```

*Figure 5: Class client to test GET_INDICATORS web service.*

The services description (WSDL) was generated for the service created using the class client (Figure 6). This web service should be published at Green Service Mall, this component is responsible for the registration of external and internal services offered by IT-for-Green solution to be discovered by the consumers. This web service is an initial approach to demonstrate the possible integration of those platforms trough a first example GET_INDICATORS. The web services are a powerful tool to achieve the real integration and communication between those systems.

```
– <definitions name="Services" targetNamespace="http://localhost/siedawebservices/webservices/servicecontroller.php">
  – <types>
      <xsd:schema targetNamespace="http://localhost/siedawebservices/webservices/servicecontroller.php"/>
    </types>
  – <portType name="ServicesPort">
    – <operation name="GET_INDICATORS">
        <documentation>This method return indicators fields</documentation>
        <input message="tns:GET_INDICATORSIn"/>
        <output message="tns:GET_INDICATORSOut"/>
      </operation>
    </portType>
  – <binding name="ServicesBinding" type="tns:ServicesPort">
      <soap:binding style="rpc" transport="http://schemas.xmlsoap.org/soap/http"/>
    – <operation name="GET_INDICATORS">
        <soap:operation soapAction="http://localhost/siedawebservices/webservices/servicecontroller.php#GET_INDICATORS"/>
      – <input>
          <soap:body use="encoded" encodingStyle="http://schemas.xmlsoap.org/soap/encoding/" namespace="http://localhost/sie
        </input>
      – <output>
          <soap:body use="encoded" encodingStyle="http://schemas.xmlsoap.org/soap/encoding/" namespace="http://localhost/sie
        </output>
      </operation>
    </binding>
  – <service name="ServicesService">
    – <port name="ServicesPort" binding="tns:ServicesBinding">
        <soap:address location="http://localhost/siedawebservices/webservices/servicecontroller.php"/>
      </port>
    </service>
    <message name="GET_INDICATORSIn"/>
  – <message name="GET_INDICATORSOut">
      <part name="return" type="xsd:string"/>
    </message>
  </definitions>
```


*Figure 6: XML of GET_INDICATORS WSDL.*

## 6. Conclusion/Outlook

Nowadays business need support of IT resources to monitoring, controlling and support decisions making process as a real imperative in organizations. In the last years different solutions were developed with diverse functionalities oriented to corporate environmental management and sustainability. IT-for-Green and SySPE are two solutions emerged of this needs, the first covers the complete product life cycle and the second allows tracking business sustainability indicators to help managers to discover which is the overall compliant of sustainability business goals using CISP and include the perception of the different stakeholders.

The communication and integration between those solutions that run in different technologies and design patterns to complement and upgrade IT-for-Green solution is possible through the web services implementation. To partially achieve this goal a web services architecture was defined among services clients, IT-for-Green and SySPE. A web service GET_INDICATORS was defined using a bottom-up model were it is possible to implement classes first, and then use a WSDL generating tool to expose methods from these classes as a web service. ZF was used as WSDL automatically generating tool based on existing code.

The future direction of this research is oriented to implement the key functionalities of SySPE, the calculus of Corporate Index of Sustainability Performance and graphic generation as a web service to be used by consumers of IT-for-Green to analyze the indicators associated to production process, products or services as internal benchmarking of organizations.

## Acknowledgment

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# Sustainability training for SMEs

Meike Cordts[1], Karsten Uphoff[2], Barbara Rapp[3]

## Abstract

This paper discusses essential results of a research project at the University of Oldenburg. Under the supervision of the Centre for Lifelong Learning (C3L), the department of Business Informatics/ Very Large Business Application (VLBA) and the ecco consultancy, SME training needs in the context of sustainable management were evaluated and translated into a SME-related qualification concept. Although the topic of sustainability is particularly important for SMEs, it is an enormous challenge for the majority to develop their employees' skills and competencies in this area. As yet, the external education to support sustainability management in SMEs is hardly developed – this includes specific training needs for various sustainable management aspects.

## 1. Sustainability in SMEs – a topic for part-time qualification

Profound socio-ecological changes compel companies to deal with strategies that enable them to face current and future social challenges. In this context, sustainable management plays a crucial role as a key prerequisite of sustainable design and orientation of companies. While large companies create specialized positions to work on these topics – know how, financial and human resources are missing in small and medium-sized enterprises (SMEs). In addition, precise and practical ideas on how to transfer sustainable management into SME-business reality are rare and, if existent, more of a theoretical and abstract nature – all in all the practical implementation is still an enormous challenge especially for SMEs.

One of the latest studies exploring training needs of SMEs is [1]. Nearly all responding SMEs mentioned a lack of knowledge on how to change and adapt their business model including their competencies, the attached processes and activities in changing markets and economies.

Facing such challenges, SMEs are in the urgent need of dealing with long-term-sustainable business strategies and the implementation of sustainable structures and processes. Nevertheless, the external education supporting an appropriate sustainability management in SMEs is a, so far, surprisingly untapped instrument (see [2]). Internal SME qualification- and training-options are very limited and the external provision of skills is insufficiently developed. From a current perspective, specific training needs e.g. for different aspects of corporate governance (such as the efficient use of energy, the promotion of cultural diversity and tolerance within the company or the socially and environmentally responsible management of the value chain) cannot be satisfied.

Existing pre-employment education offers for sustainable management in SMEs only focus on solitary aspects. Innovative, practicable, part-time and integrated qualification offers that put their attention to a complete, integrated and SME-compatible sustainability management are currently not available.

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## 2. Background and objectives of the proposed model project

The project “Sustainability Learning Lab” (SLL) under the supervision of the Center for Lifelong Learning (C3L), the department of Business Informatics/ Very Large Business Application (VLBA) at the University of Oldenburg as well as the ecco consultancy wants to give an answer to the sketched qualification gap in SMEs. Therefore relevant qualification needs were evaluated and, as a result, translated into a corresponding educational concept. In the long run, the project focuses additionally on two long-term goals: the development of a holistic innovative education offer in the field of sustainability for SMEs and for the short term the development of innovative methods of IT-based learning (e.g. simulations and scenarios).

The initial question of the project was: How can sustainability be established and implemented in SMEs in a long-term perspective? In this context, the employees’ qualification plays an important role as it influences the companies’ processes and culture for a long time – this is in clear contrast to the only superficial and short-lasting concepts that can be found in most of the companies that deal with this subject by now. A serious challenge for companies is the transfer of knowledge and competences to employees at different hierarchy levels with heterogeneous qualifications and backgrounds that form the basis for an integrated sustainability management. For this reason, the key qualification elements in this project focus on different target groups:

- Management/the strategic level (‘the big picture’): The SME-Management should understand the key sustainability drivers and opportunities for the organization. The correct targets must be set and effective sustainable steps must be initiated.
- Execution and alignment through quality, energy or environmental managers (ISO 9001; 14001; 50001, etc.): The transformation to a more sustainable company is usually a process of evolution in management systems. By using the existing infrastructure and processes of these systems, significant changes can be achieved.
- Operational Departments, such as purchasing, manufacturing or sales: In these departments “everyday business decisions” are being made. On this level, decisions about the detailed content and design of sustainable processes are in the focus.

Especially small companies do not have time and knowledge to provide the qualification necessary for all these employees by themselves. This is why the project SLL focuses on a tool that was rather neglected in the area of sustainability by now: the demand-oriented external training of employees with a focus on practice. Therefore, the project aims at establishing a holistic qualification system, which supports the implementation of an integrated sustainability management and keeps the specific needs of SMEs (with all its different actors) in focus.

On the project level the early integration of companies in workshops and events guarantees the active participation of the major target group of SMEs in the project and supports the practical relevance of the project results. In this context the project does not only focus on the content but also the design and structure of a possible qualification program. This includes didactical elements as well as tools (e.g. IT-support) and learning locations which can be found inside as well as outside of a company.

## 3. Some obstacles and success factors

As one overall conclusion we can assume that successful sustainability needs generalists who bring their expertise to sustainable development in a holistic approach (e.g. to give orientation) and specialists who contribute concrete sustainable-related ideas into enterprise department-units. Corresponding processes are not running without resistance and require specific implementation expertise. Required qualification offers providing these skills, should be able to deal with these hurdles and success factors.

### 3.1. The right content

In the sustainability related competence discussion, the distinction between core (cross-) competencies and domain or job specific skills can be found (see [3], page 8). What skills to be addressed, how they can be taught by teachers and how to use them, raises a wide range of development tasks and research questions.

An important (qualification) success factor is the finding of relevant sustainable tasks for different levels of action:

- Cognitive, reflexive and communicative actions: e.g. understanding significant developments relevant to enterprise sustainability, the development of entrepreneurial concepts and decision-making processes; goal-setting processes, creative thinking processes.
- Instrumental actions (implementation of closed-end workflows): e.g. compliance with sustainability in procurement and product development, performing control procedures in the supply chain etc.

A knowledge of both levels (process and content knowhow) should be provided. The main challenge is to provide an adequate qualification concept that is integrating the knowledge of different perspectives on the topic of sustainability.

### 3.2. Organization of qualification

Unsuitability and hence a lack of use of qualification for sustainable management in SME-business is the status quo. In functional areas such as controlling, R&D, human resources or marketing, sustainable qualification isn’t perceived and used as a tool to solve future challenges.

As a consequence it is important to ensure that the qualification concept fits the formal booking requirements of SMEs’ functional organization units: last minute booking, close location of the venues, reasonable costs etc. Furthermore SMEs are requiring in particular a good (academic) care during and after the qualification events.

### 3.3. Methods

The success of qualification offers ultimately depends on the design of the qualification arrangements, used methods and the nature of the learning situations and case studies. So the competence-enhancing qualification arrangement has to answer different questions:

- Qualification arrangements and the used methods should be aligned action-oriented. In what way succeeds an action-oriented qualification offer that fits the (reciprocal) relationship between strategic level know how and concrete action?
- It should be learned in the course of concrete entrepreneurial tasks. In what – at best holistic – way should different levels (in the sense of knowledge integration) of the qualification concept map relevant processes and fit them with necessary knowledge transfers?
- Because of lengthy and complex decision contexts subjects should be taught in forms of self-regulated and collaborative learning arrangements. Which forms of learning meet these self-organizational and social requirements?

The essential, often in literature discussed pros and cons of blended learning approaches (cf. [4] or [5]) will not be discussed here.

## 4. Concept and methods of the sustainability training approach

Large companies already deal with sustainable challenges, albeit in a very superficial way; SMEs rarely cope with it. For small companies, transforming the very abstract and theoretically discussed topic of sustainability into practical use with realizable objectives and actions is quite difficult.

Additional obstacles SMEs are facing in the daily business are the limited time and restricted financial resources. Developed qualification concepts and methods should be able to deal with these restrictions.

In view of the already outlined conditions under which SMEs act and taking the identified hurdles and success factors of necessary qualification concepts into account, specific solutions are required. A further special challenge is the diversity of the target group, which consists of employees from staff or management departments as well as operating departments, e.g. purchase or marketing (cf. chapter 2). All of them should be involved in a sustainability concept claiming a holistic approach. All potential participants bring in different levels of knowledge as well as personal qualities and preconditions into the learning situation. Additionally, the individual goals connected with a qualification program differ extremely between these groups. This leads to the assumption that a flexible organization and design is a major necessity of the project results which need to meet the requirements of a strongly heterogeneous target group. Another central challenge relates to the curriculum and its' adequate design regarding the content. It shouldn't be overloaded with content and the flexible integration of the planned modules should be ensured. Furthermore, there should be time for joint discussions, as this is one the main success factors of successful blended learning concepts.

In order to meet these conditions, a qualification concept for SMEs should be developed, which contains the important environmental, social and economic issues, uses existing educational opportunities and potentials and considers general requirements of SME learning situations (places, times, shapes etc.). These requirements should meet with the following technical and methodological ideas, inter alia:

- Transfer of skills supported by simulation games: Simulation games are one of the most applied training methods in the area of economic qualification. They highly meet the afore stated requirements: multidisciplinary and cross-functional transfer of knowledge, individual training and experiencing sustainable management as well as the demonstration of the cross-linked character of sustainability in different operational areas and markets.
- Learning labs with real data, topics etc.: This very specific instrument offers the possibility to model, test and reflect sustainable processes. Amongst others, sustainability strategies, scenarios and decisions on how to design business processes can be tested by simulations and be reviewed regarding their sustainability related consequences. For this purpose the corporate environmental information systems, developed at the department of Business Informatics I/ Very Large Business Applications (VLBA) at the Carl von Ossietzky University of Oldenburg are being systematically adapted.[4]
- Technological education design: Currently, e-learning technologies and web-based applications enjoy a high degree of attention in the transfer of qualifications and knowledge. At this point it is important to state, that e-learning-concepts must not replace but complement human interaction.[5] Nevertheless most contents can be displayed perfectly in the way of e-learning. Main advantages are that learners can work on modules and tasks in their own pace, modules and lections can be designed interactively and less attendance days can reduce individual inhibitions. As a total effect, e-learning can lead to a higher quality of learning. This is why in this project special assessment technologies (for the evaluation of individual and corporate

[4] At the University of Oldenburg new solutions for corporate environmental information systems in the project IT-for-Green are being developed. These systems are able to depict interdependencies of economic, ecological and social goals. They are an important base of the software used in the project. Cf. www.it-for-green.eu.

[5] A main challenge lies in the task to not overloading the curriculum, to create space for common discussion despite of the blended learning concept and to guarantee the intended interlocking of the modules.

qualification demands in the field of sustainability) to be used in combination with intelligent e-learning offers and tutorial learning systems.

- To offer studies independent of time and place, qualification programs are to be designed according to blended-learning concepts. This means that phases of independent learning are to be combined with phases of attendance and web-based cooperative learning in a way that permits flexible and participant-oriented studies.
- Arranged exchange of experience: To confirm attained knowledge and reflect the experiences made, an exchange among learners and between learners and teachers is an indispensable element of a blended-learning concept. At this stage, the critical debate on the subject of sustainability and the transferred knowledge is a crucial factor.
- Attendance by mentors: Throughout the whole learning process and especially the phases of independent learning the attendance of a mentor that contributes methodical know-how and expertise is to be ensured by the provider of sustainability education.

The central project idea is the development of the above outlined learning lab, which will be discussed in more detail in the following. Learning labs are innovative places of learning, in which problem-solving-skills can be proved in a practical way. Therefore, individual trying, experiencing and reflecting is in the focus, similar to a workshop. The main idea is that theoretical or abstract knowledge is being translated into management practice which in the end leads to the development of new competences of the employees. The sustainable learning lab offers the chance to model decisions and processes in the company, to put them to a test and to reflect them. Sustainability strategies can be tested, business process creation may be simulated and its impacts are examined. To this purpose, IT-simulation- and scenario-planning-tools have to be designed. These give the opportunity to reduce the complexity of processes and to make them more transparent. Therefore, important instruments are e.g. the CEMIS developed in the research project IT-for-Green that can be used specifically for the required purpose.

The purpose of a learning lab is to prepare participants for decision making in complex surroundings and to arouse skills for the handling of complex decision making processes. Some features of the mentioned Learning Lab tool are outlined exemplarily in the following:

- Main purpose is to simulate decisions and strategies, comparable to corporate strategic planning simulations. This can be done individually or in small teams to understand the dynamics of interconnected elements (e.g. sustainability, consumption of energy and resources, employee’s behaviour or similar) and to find solutions in a systematical way. Furthermore, the concept is supposed to provide opportunities to reflect self-made decisions and to initiate learning processes on this basis. In connection with the new CEMIS technologies and their possibilities of simulating and building scenarios, the subject of sustainability management and strategy can be communicated on a concrete database.
- The learning lab is an innovative combination of technologies and methods to simulate decision making processes in complex systems. By means of special software-based miniature copies of reality, learning labs reproduce surroundings of complex decision making processes and enables learners to experience the consequences of their decisions and strategies in virtual simulations.
- A learning lab process is of a circular nature and consists of three phases: conception, testing and reflection. Participants have the possibility to experiment in this this surrounding to understand the dynamic of interconnected elements (e.g. sustainability, energy and resource consumption, behavior of employees) and to develop systemic solutions.

## 5. Conclusion

SMEs have to deal with long-term sustainable business strategies and concrete operational sustainability tasks. External SME based qualification offers are a relatively untapped instrument, as internal SME qualification- and training-options are very limited. All in all there is a lack of use of qualification for sustainable management in SME-business.

Against this background, the project's objective is to create a qualification offer, which contains (SME focused) lifelong learning aspects, interdisciplinarity as well as diversity in the choice of methods and (as a result) provides concepts for problem-solving knowledge, systematic-cross-linked thinking and concrete domain specific skills.

The currently developed SLL is a qualification concept which can reflect the effects of sustainable management by an IT-based simulation and scenario technique. The SLL closes the existing gap between necessary reflexive and communicative (decision-making) and concrete action (performance) know how.

To the end, it is important to highlight that there does not exist the optimal way or embodiment of a sustainability concept in enterprises, but an individual way has to be found by employees themselves. Therefore, a qualification program should prepare the participants to make decisions in complex situations and teach them necessary skills and attitudes.

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# Preparation of a Biomass Potential Map

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## Abstract

Achieving a fossil-resources-free power supply requires an exploration of alternative, renewable energy sources. Over the last years, biomass has become an important component of this endeavour and its consumption is rising steadily. Common sources of biomass are agricultural production and forestry but the production of these sources is stagnating due to limited space. To explore new sources of biomass, for example in the field of landscape conservation, the location and available amount of biomass must be obtained. Normally, there are no reliable data sources that give information about the objects of interest like hedges and vegetation along streets, railways, rivers and field margins. There is a great demand for an inventory of these biomass sources which could be answered by applying remote sensing technology.

To generate that kind of spatial information, satellite imagery is used in combination with area-wide available GIS and elevation data. The multispectral satellite images are assumed to have a low spatial resolution of 10-20 m and spectral bands corresponding to the Sentinel-2 spatial and spectral configurations. For GIS data, the German Digital Landscape Model (ATKIS Base-DLM), containing roads, field boundaries and waterways, supports the mapping allowing for deduction of potential biomass objects located beside GIS objects. To allow a quantitative estimation of the biomass volume, a digital surface model (DSM), produced from raw LIDAR data, is utilized.

## 1. Introduction

Renewable energy sources are key components in reducing the consumption of limited fossil fuels. As opposed to coal and gas, the generation of power through solar energy, water, wind or biomass does not unlock carbon dioxide ($CO_2$) that has been buried in the ground for the last millions of years and, hence, does not effectively add $CO_2$ to the atmosphere in the medium to long term. Because of this lack of net-created $CO_2$, research has focused on exploitation of such energy sources over the past years ([3], [5], [6], [8]).

Biomass is a key player is this suite of renewable energies as it is abundant on most land areas and has the potential to re-grow in a few months to years. Prime targets for biomass production are forests and agricultural areas but due to a limited extend of these, alternative vegetation sources need to be identified.

The biomass objects of interest are vegetation stripes alongside streets, railways and waterways, unploughed stripes that separate fields and in general hedgerows (see Figure 1 for examples). The objects have elongated shapes with a limited width in the range of 5 to 20m and can be found in a range of places resulting in a great potential as biomass energy source.

We further separate these types into ligneous, graminaceous and herbaceous vegetation. These sub-categories have an inherent consequence for the growth pattern, hedge type and size of the respective plants and the amount of biomass produced in a given temporal interval.

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The maintenance of these biomass objects works normally as follows: vegetation alongside streets is trimmed to keep a special shape that allows traffic to pass while vegetation alongside fields is sometimes maintained by farmers but in most cases very irregular. A central collection system of the accruing biomass only exists in few areas. The approach presented here will address that point.

To estimate the biomass potential of these areas, a detailed map of the amounts of vegetation is required. As no local information is available, we use a combination of low-cost data sources to calculate the necessary information. First, a vegetation height map is created utilising LIDAR data. This map will then be compared to aerial imagery (AISA Eagle), which we have as a substitute for the upcoming Sentinel-2 data. A spectral unmixing of the comparably large pixels (10 to 60 m) is done using the Sequential Maximum Angle Convex Cone (SMACC) approach. With the endmember specifications and the determined vegetation height, we are able to derive the biomass volume. This data, in turn, will allow the analysis of potential regions where the usage of the existing biomass is feasible for energy production.

Our test site is located close to the city of Bottrop in North Rhine-Westphalia, Germany. It comprised a rural area with intensive agricultural use but also contains parts of a natural preserve.

*Figure 1: Examples of target objects in test site: vegetation alongside streets (left and middle), unploughed strips (right).*

## 2. Related Work

Normally only agricultural crops and forest vegetation are considered in remote sensing approaches that deal with biomass feedstock production. A good overview about these approaches can be found in [1] where concepts, methods and commercial software are reviewed for the monitoring of energy crops.

However a few approaches are existing that deal with small biomass units in contrast to the common agricultural crop production and forestry. In most cases, additional information is used for these approaches in form of height information in order to increase the recognition rates. In the following some ideas of approaches that deal with small biomass units are reviewed.

A combination of LIDAR data and airborne images to estimate biomass and volume of shrub vegetation is used in [5]. Features of both data sources serve here as input to a regression model. The results show good accordance of the estimations and ground truth data.

The application of a two-stage approach based on spectral information from SPOT satellite images to retrieve an estimation of woody biomass can be found in [6]. In the first stage the author classifies the images with a Maximum Likelihood classifier to find regions of arboreal, shrub and herbaceous vegetation. The second stage of the approach is aimed at finding an analytical model representing the relationship between vegetation parameters like tree height and stem diameter and the spectral SPOT information by correlation analysis.

An existing known model that estimates the carbon content of single pine trees with tree height and crown diameter as parameters is applied in [8]. In airborne LIDAR data tree crowns are identified with an adaptive technique of Local Maximum Focal Filtering resulting in the two variables necessary for the carbon model.

Considering SAR data, the potential of TerraSAR-X High Resolution Spotlight images to classify grasslands, herbaceous, trees, shrubs and flower strips into different classes is investigated in [3]. The author processes a time series of six images of one year and successfully applies a Random Forest classifier. For woody structures the approach delivers producer's accuracies above 80 %.

## 3. Strategy and Data Description

### 3.1. Strategy

In our work, we present an approach dealing with small units of biomass that can be detected using a combination of two data sources. For the first data source, the spectral information, we assume low spatial resolution satellite data of about 10-20 m Ground Sampling Distance (GSD) which has the advantage of being cost-effective and nearly area-wide available. This data source will provide the qualitative identification of vegetated areas.

Although data in the range of 10-20 m GSD exists, our approach aims at using Sentinel-2 data that will be freely available from 2015 and has a setup of 13 spectral bands. Therefore, we simulate corresponding data using measurements from an airborne line scanner with similar spectral bands.

The second source of data is height information in form of digital surface models (DSM). This data can be derived directly from LIDAR acquisitions or through stereo matching of aerial images that are normally widely available. In this secondary data, we are able to quantitatively analyse the vegetation detected earlier in terms of height, volume and mass. For our test site, we use LIDAR data that was acquired synchronously to the line scanner flight.

Both data sources are processed to indicate biomass potential: Spectral unmixing is applied to the spectral data to generate qualitative biomass indicators while the LIDAR data is used to produce a digital surface model as quantitative biomass indicator. Both processing steps are described in detail in the next chapter. The result of the processing is an information layer stack that enables an exact estimation of the biomass amount. In this part of the study, we build the biomass potential map to outline the vegetated areas that can be considered for energy production. The amount estimation, the amount prediction and an economic analysis including logistic aspects will be the topic of follow-up research.

### 3.2. AISA Eagle

The AISA Eagle sensor is a passive hyperspectral airborne line scanner that works in a spectral range of 400-970 nm and separates, depending on the image rate [images per second], up to 488 spectral bands. For our experiments, a configuration of 107 spectral bands in a range of 431-926 nm with a spatial resolution of 0.5 m is used. The bandwidths in our test dataset of the single bands lie between 4.27 nm and 4.81 nm. The single strips for our test site are preprocessed by the data provider to an image mosaic. The flight height was at 800 m above ground. Sample data is illustrated in Figure 2a.

### 3.3. LIDAR

Synchronously to the recording of hyperspectral information, a RIEGL LMS-Q680i full waveform laser scanner was used to acquire height information. The height information is delivered in binary LAS file format, a public file format for the interchange of 3-dimensional point cloud data (see [2]). The LAS file format supports up to 15 return pulses per outgoing pulse. The differentiation of the return pulses is important for dealing with vegetation, because vegetation objects typically deliver more than a single return pulse due to the intertwined leaf and branch structure. Sample data is illustrated in Figure 2b.

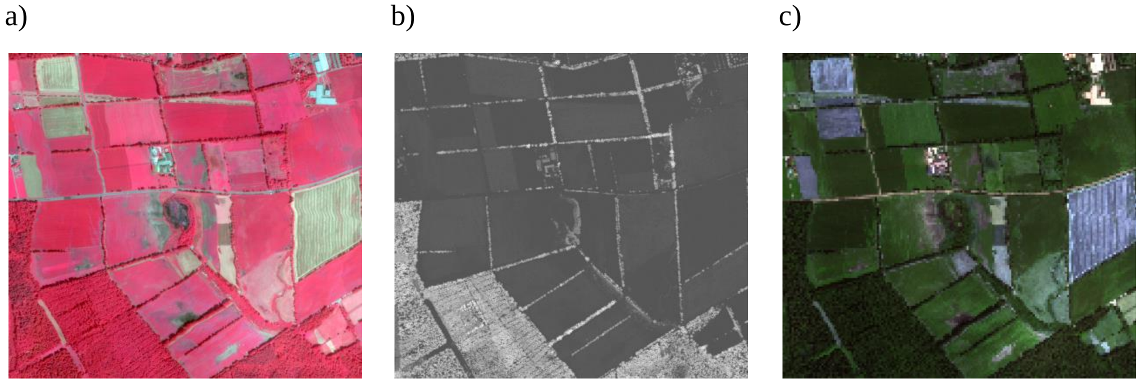


*Figure 2: a) CIR bands of AISA Eagle input data b) LIDAR input data c) simulated Sentinel-2 data, 10m GSD*

## 4. Methods

### 4.1. Vegetation height map

To generate vegetation height information from the raw LIDAR data, a classification into ground and non-ground points on the basis of the recorded return pulses is applied. The procedure works as follows: If the return signal of a single LIDAR point contains more than one return, the first return represents the surface of vegetation and the last pulse represents the ground. If vegetation exists, the height above ground is calculated by building the difference between the first and the last pulse. If a LIDAR point lies on soil or sealed areas the height is set to zero.

Normally LIDAR points are acquired in an irregular distribution, but, for our application, a regular distributed vegetation height is needed to assign a vegetation height to each pixel. To achieve this, all existing LIDAR points are utilised to span a TIN (triangulated irregular network). At the positions of a regular raster, the height values are linearly interpolated to the TIN data set. The LIDAR point cloud we use at our test site is very dense compared to the spectral data, resulting in a negligible interpolation error.

### 4.2. Sentinel-2 simulation

Sentinel-2 (see [4]) will be a pair of two satellites with the start of the first satellite planned for 2015. Sentinel-2 will deliver data in the visible, near infrared and shortwave infrared spectrum comprising 13 spectral bands: 4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m spatial resolution, with a swath width of 290 km. Sentinel-2 will be placed in a 5 day repeat-cycle orbit what guarantees a high degree of data availability.

In the following, the simulation procedure of Sentinel-2 data based on a hyperspectral AISA Eagle dataset is described. In comparison to other data simulation approaches (see [9]), where complex sensor models are known and used, a simplified method is applied here.

Firstly, corresponding bands between the source (AISA Eagle) and target dataset (Sentinel-2) are determined. For example, band 1 of Sentinel-2 covers a bandwidth between 433 nm and 453 nm. All AISA Eagle bands that lie in this range, bands 2 to 6, form the basis for the simulation. The complete band mapping is shown in Table 1.

Secondly, pixel values (digital numbers, *DN)* are calculated for each of the 9 Sentinel-2 simulation bands according to Equation 1, where $t_i$ is the band number of the target dataset, $s_n$ the band number of the source (AISA Eagle) dataset. Afterwards all *DN* values are normalised to a range between 0 and 1 to compensate the different amount of AISA Eagle bands that lie in the range between 3 and 24 bands.

$$DN_{t_i} = \sum_{n=n_{min}}^{n_{max}} DN_{s_n} \tag{1}$$

Thirdly, a spatial resampling of the simulated bands is done to get the desired target resolution of 10 m, 20 m or 60 m. In Figure 2c, the simulation results for bands 2-4 with a spatial resolution of 10 m are illustrated.

| Sentinel-2 simulation data band number | Accumulated AISA Eagle bands | Amount of AISA Eagle bands | Target spatial resolution [m] |
|---|---|---|---|
| 1 | 2-6 | 5 | 60 |
| 2 | 8-21 | 14 | 10 |
| 3 | 26-33 | 8 | 10 |
| 4 | 49-55 | 7 | 10 |
| 5 | 60-62 | 3 | 20 |
| 6 | 67-69 | 3 | 20 |
| 7 | 76-79 | 4 | 20 |
| 8 | 78-101 | 24 | 10 |
| 8b | 93-96 | 4 | 20 |

*Table 1: Corresponding AISA Eagle bands for Sentinel-2 simulation.*

### 4.3. Spectral unmixing

Due to the limited spatial resolution of the Sentinel-2 simulation data and objects of interest that are smaller than pixel size, the application of multispectral classification at sub-pixel level is limited or difficult. The smallest objects of interest, for example vegetation alongside streets and unploughed strips, have a width of no more than 3 to 5 m. Thus, a single image pixel represents a mixture of reflectance values of several materials.

In contrast to classification methods that assign the most probable class to each pixel, spectral unmixing decomposes a mixed pixel spectrum into a collection of constituent spectra, called endmembers, and a set of corresponding fractions, or abundances. Endmembers represent the reflectance characteristics of pure material reflectances, for example water, soil, vegetation and street surfaces. Spectral unmixing works in two steps: An initial endmember detection followed by the spectral unmixing itself.

For our experiments, a powerful endmember detection approach called Sequential Maximum Angle Convex Cone (SMACC), that is available in the software ENVI, is used. SMACC ([7]) works with a convex cone model (residual minimization) and selects unsupervised existing endmembers in image data.

SMACC starts with a single endmember and increases incrementally in dimension. The data vector that builds the maximum angle with the existing endmember is taken as additional new endmember and extends the endmember set. The algorithm ends, if the maximum number of found endmembers is reached or if the maximum relative error is below a specific threshold. In Figure 3 on the left hand side, the development of the maximum relative error in relation to the number of endmembers is illustrated. It can be seen that the maximum relative error converges starting from an amount of 4 endmembers.

For the second step, linear spectral unmixing (LSU) is applied that works with a linear mixture model according to Equation 2, where $DN$ is a pixel value, N the number of endmembers, $a_i$ the abundance of endmember $i$ and $s_i$ the spectrum of endmember $i$. According to Equation 3, the sum of all abundances for a unique pixel has to be 1.

$$DN = \sum_{i=1}^{N} a_i s_i \tag{2}$$

$$\sum_{i=1}^{N} a_i = 1 \tag{3}$$

This approach results in abundance maps, the extracted endmember spectra (Figure 3 right) and mapping information about single endmember locations in the image.

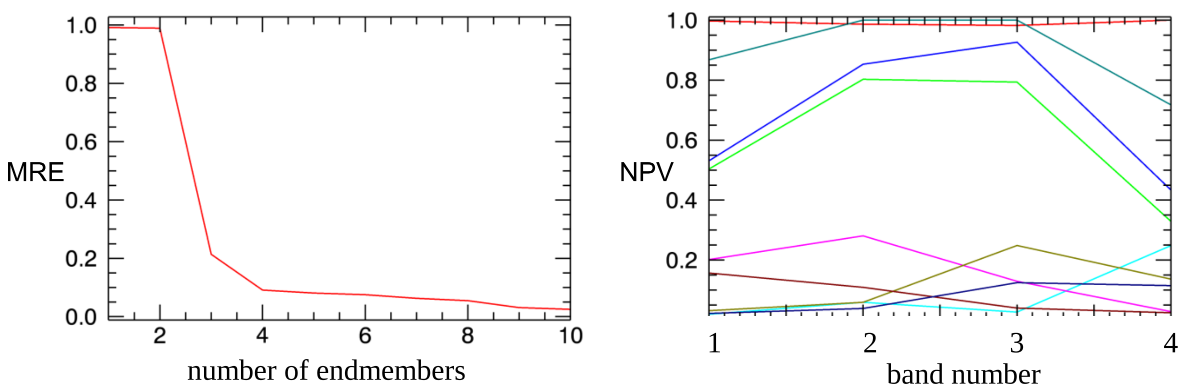


*Figure 3: SMACC output, behaviour of the maximum relative error (MRE) according to the number of endmembers (left) normalized pixel values (NPV) of endmember spectra (right).*

### 4.4. Potential map

As final step, the biomass potential map is set up as a multi-layer image of biomass indication information. The map is based on the result of the spectral unmixing and the DSM. Other additional spatial information like GIS data about streets, railways and waterways can also be used as hint for the existence of biomass objects of interest in our definition.

Since the spectral unmixing works unsupervised, all abundance maps have to be manually checked if vegetation relevant for our objects of interest is represented. In Figure 4a and b two abundance maps indicating relevant biomass are illustrated where dark pixels correspond to 0 % and white pixel to 100 % of endmember membership of a pixel.

The vegetation map that is calculated from the LIDAR data is taken directly as biomass indicator, as illustrated in Figure 4c. Dark pixels correspond to no vegetation, white pixels represent the height of vegetation.

a) b) c)

*Figure 4: a) Endmember 4 representing vegetation and trees b) endmember 8 representing vegetation on fields c) vegetation height map.*

## 5. Evaluation

The proposed approach is applied to test data from a test site in Germany, close to the city of Bottrop in North Rhine-Westphalia. The test site is located in a rural area with intensive agricultural use but contains also parts of a natural preserve.

To evaluate our approach, a vegetation map based only on the spectral unmixing results without use of height information is compared to a vegetation reference map based on LIDAR data. The vegetation map is a binary map considering all relevant abundance maps that are selected manually as described before. A pixel of the vegetation map is set to 1 if one or more abundance maps contain values > 50 % at this position.

The vegetation reference map also contains binary information of pixels containing vegetation larger than 0.3 m. Both maps are compared pixel-wise and 74.5 % of the reference vegetation pixels are recognized by spectral unmixing (cp. Figure 5). Considering the vegetation map 69.8 % of all pixel are correct vegetation compared to the reference, while 30.2 % are no vegetation in the reference.

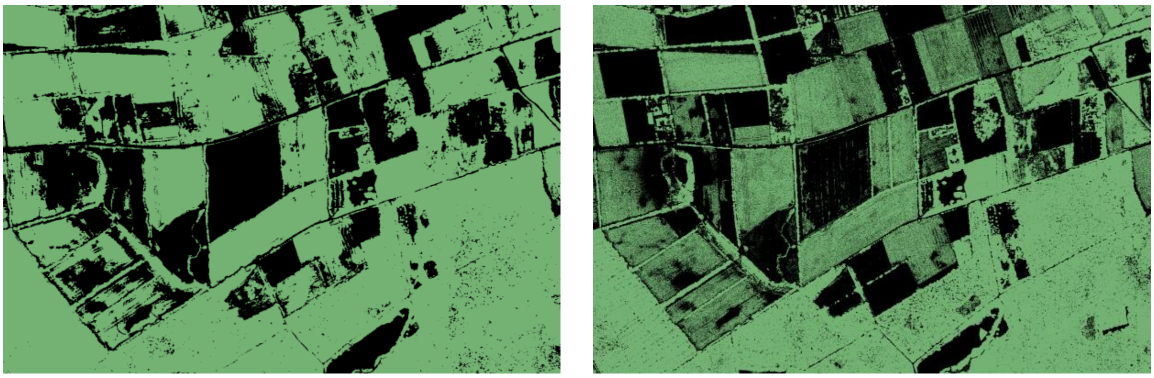

*Figure 5: Vegetation map as result of spectral unmixing (left) vegetation reference map (right)*

In terms of single biomass objects of interest, an evaluation is difficult because of rare reference data. The vegetation height map (Fig. 4c) is a very precise and valuable data source and nearly each biomass landscape conservation object is contained in the data. By combining all information in a biomass potential map, to be done in a follow-up study, it will be possible to enable the detection of most landscape conservation objects of interest.

## 6. Conclusions

Our approach aims at mapping new alternative sources of biomass for energy production in contrast to common renewable energy sources. Exploring landscape conservation elements for energy production has a great potential. Some existing running pioneering projects work already with great success. To reduce data costs for the mapping task, a combination of Sentinel-2 satellite data, that will be freely provided in combination with height data, is proposed. Realistic sources to generate height information are widely available orthophotos and LIDAR data. Our result, a collection of biomass potential layers, builds a stable basis for a subsequent biomass amount estimation that is necessary to enable the harvest of biomass landscape elements.

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# Wind Power Prediction with Cross-Correlation Weighted Nearest Neighbors

Nils André Treiber, Oliver Kramer[1]

## Abstract

A precise wind power prediction is important for the integration of wind energy into the power grid. Besides numerical weather models for short-term predictions, there is a trend towards the development of statistical data-driven models that can outperform the classical forecast models [1]. In this paper, we improve a statistical prediction model proposed by Kramer and Gieseke [5], by employing a cross-correlation weighted k-nearest neighbor regression model (x-kNN). We demonstrate its superior performance by the comparison with the standard u-kNN method. Even if different pre-processing steps are considered, our regression technique achieves a comparably high accuracy.

## 1. Introduction

In the past, Kramer and Gieseke developed a prediction model that is exclusively based on wind power time series measurements [5]. In this model the predictions task is formulated as multivariate regression problem that considers the time series of neighboring turbines for a particular target turbine. In this line of research, we employed linear regression, support vector regression and k-nearest neighbor (kNN) regression. The main result is that there is in general no regression technique, which provides the highest accuracy for all cases. Rather, it depends on the surrounding terrain and the wind conditions, which method provides the most accurate prediction. In addition, the selection of appropriate features has an important part to play [7].

In this paper, we introduce a new method, called x-kNN model. The cross-correlation between the particular neighboring and the target turbine defines its contribution to the prediction in kNN regression. We compare our model with the uniform kNN method (here called u-kNN), whose most appropriate features have been found by testing all possible pattern combinations. Moreover, the exclusive consideration of the cross-correlation of the turbines is discussed. In addition, we show that our model is also superior if the inputs of the classical regression model have been reduced by a principle component analysis (PCA).

## 2. Related Work

In his thesis, M. Hall demonstrates that an appropriate feature selection can be performed via a correlation analysis [3]. Thereby, features should be highly correlated with the label, but uncorrelated with the label. A correlation-based kNN algorithm for classification tasks is introduced by Xinran and Xiang [6]. In a more general way, the contribution of the neighbors for classification and regression tasks can be weighted with regard to the distance in feature space, so that nearer neighbors contribute more than more distant ones. This implementation is discussed in the paper written by Dudani [2].

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## 3. Wind Data Set and Prediction Model

### 3.1. General Time Series Model and u-kNN Regression

We formulate the prediction as regression problem. Let us first assume we want to predict the power production of a target turbine only with its time series: The wind power measurement $\boldsymbol{x}^i = p_t(t^i)$ (pattern) is mapped to the power production at target time $y^i = p_t(t^i + \lambda)$ (label). For our regression model, we assume to have $N$ of such pattern label pairs that are basis of our training set T={$(\boldsymbol{x}^1, y^1)$, …, $(\boldsymbol{x}^N, y^N)$} and allow via a regression to predict the label for unknown patterns. One can assume that this model generates better predictions, if more information of the time series is used. For this reason, we extend the pattern by adding past measurements $p(t-1), \dots, p(t-\mu)$ with $\mu \in \mathbb{N}^+$.

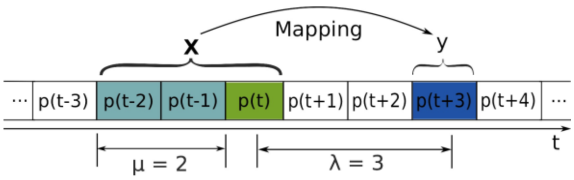


*Figure 1: General time series model. The parameter $\lambda$ describes the time horizon of the prediction.*

To catch some spatial-temporal dependencies, we also take the features of the times series of $m$ neighboring turbines into account, which are generated in the same way as for the target turbine.

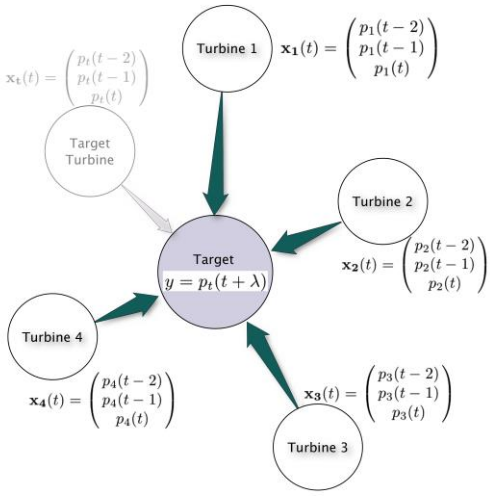


*Figure 2: Setup with 4 neighboring turbines and 3 past measurements. This results in a $15-$dimensional pattern $[(4+1)\cdot 3 = 15]$.*

After defining the mapping, the goal is now to find a regression function $f$ that provides good predictions to an unseen pattern $\boldsymbol{x}'$. In the u-kNN regression method, the output of $\boldsymbol{x}'$ depends on the k-nearest patterns in the training set, found by calculating the Euclidian distance $dist(\boldsymbol{x}^i, \boldsymbol{x}')$ to all existing patterns. Finally, the label is given as arithmetic average of the corresponding $k$ labels:

$$f_{kNN}(\boldsymbol{x}') = \frac{1}{k}\sum_{i \in \mathcal{N}_k(\boldsymbol{x}')} y_i$$

with the set $\mathcal{N}_k(\boldsymbol{x}')$ that contains the k-nearest neighbors of $\boldsymbol{x}'$.

### 3.2. Data Set

For our experiments, we use the freely available wind data set of the National Renewable Energy Laboratory (NREL), which is part of an integration study for wind and solar energy in the western part of the United States [8]. On the NREL website, a GUI allows to download the time series of the generated power with a time resolution of 10 minutes for 32,043 turbines. In this paper, we decide to predict the output of three arbitrarily selected wind turbines near Casper (WY, ID: 23167), Comanche (WY, ID: 8419) and Tehachapi (CA, ID: 4155).

## 4. Cross-Correlation Weighted kNN

Before we go into detail, it is worth mentioning that the measured power measurements $p_k$ of all turbines are in the same interval $p_k \in [0\,MW,\ 30MW]$. Therefore, a normalization preprocessing has not to be done, regardless of the particular kNN implementation. In our x-kNN variant, the inputs do not contribute equally to the label, but are weighted according to the cross-correlation with the target:

$$x_{corr}(p_t, p_k) = \frac{\sum_{i=1}^{N} p_k\left(t^i\right) p_t(t^i + \lambda)}{\sqrt{\sum_{i=1}^{N}\left(p_k(t^i)\right)^2 \cdot \sum_{i=1}^{N}\left(p_t(t^i + \lambda)\right)^2}}$$

If the cross-correlation coefficient is high, the turbine gets a major influence for the prediction by expanding the corresponding dimension in the regression model. Each feature of the pattern is weighted with the cross-correlation coefficient to the power of $l$:

$$x_k = p_k \cdot |x_{corr}(p_t, p_k)|^l$$

with an index $k$ representing a neighboring turbine $j = 1, 2, \ldots, m$ or the target itself. The power $l$ controls the strength of the cross-correlation weighting.

## 5. Experimental Details and Results

### 5.1. Training and Evaluation Details

Every tested kNN model is trained by using data from the year 2004. To speed up the training process, only every fourth time step is taken into account. Despite a smaller training set it is guaranteed that wind conditions at different seasons are included. For finding an appropriate value of the parameter $k$, we implement a two fold cross validation and test values of $k$ in the interval *k=[10, 20, 30, …, 130]*. For the evaluation, we test our models on the year 2005 and determine the mean square error (MSE) of the forecasts $y^i$ with the measured power outputs $p_t(t^i)$ for the N forecasts:

$$MSE = L_2\left(p_t(t^i) - y^i\right) = \frac{1}{N} \sum_{i=t_{start}}^{t_{end}} \left(p_t(t^i) - y^i\right)^2$$

We compare the MSE of our prediction models with the persistence model assuming that the wind speed does not change in the forecast horizon. This naïve model is quite successful for short time horizon predictions and not easy to beat [9].

In the experiments, we do not include past measurements, i.d. $\mu = 0$. The additional neighboring turbines are selected with an automatic algorithm that determines turbines around the target, which are spatially well distributed. With a focus on one hour predictions and given mean wind speeds of about 8.5 m/s, we consider neighboring turbines in a distance of 30 km from the target turbine. Finally, we determine *m=12* neighboring turbines for each target.

### 5.2. Measurement of the Cross-Correlation between Target and Neighboring Turbines and the Target Itself

Before we compare the different regression models, we determine the cross-correlation coefficient $x_{corr} \in [-1, 1]$ between the time series of the target and the neighboring turbines $x_{corr}(p_t, p_j)$ and between the target itself $x_{corr}(p_t, p_t)$ for all measurements in year 2004.

Table 1 shows that there are high correlations $x_{corr}(p_t, p_j)$ for the turbines in Comanche. In contrast, the correlation in Tehachapi varies quite strongly.

| turbine | $x_{corr}(p_t, p_t)$ | $x_{corr}(p_t, p_j)$ min | $x_{corr}(p_t, p_j)$ max | $x_{corr}(p_t, p_j)$ mean |
|---|---|---|---|---|
| Casper | 0.902 | 0.529 | 0.800 | 0.678 |
| Tehachapi | 0.930 | -0.029 | 0.775 | 0.555 |
| Comanche | 0.873 | 0.785 | 0.826 | 0.815 |

Table 1: Cross-correlation coefficient for the target itself $x_{corr}(p_t, p_t)$ and for the target and the neighboring turbine $x_{corr}(p_t, p_j)$. The coefficient is shown for the turbine *j* with the lowest/highest correlation. The last column includes the average correlation coefficient.

### 5.3. Results for x-kNN Regression

After computing the cross-correlation coefficient, we employ our x-kNN implementation and MSE of an one hour ahead prediction for the three target turbines. Hereby, the pattern includes the features of all 12 available neighboring turbines. Table 2 shows the results, achieved with a cross-correlation weighting parameter of $l = 5$.

| | Casper | Tehachapi | Comanche |
|---|---|---|---|
| x-kNN: MSE $[MW]^2$ | 22.963 | 17.803 | 17.525 |
| Pers.: MSE $[MW]^2$ | 26.066 | 20.715 | 24.274 |

*Table 2: Results for the introduced x-kNN regression. For comparison, the results of the persistence model are also shown.*

One can observe that the x-kNN prediction achieves a considerably higher accuracy than the persistence model. The increase in accuracy for the turbine near Comanche is very high (27.8%). In the following, we compare x-kNN to three further approaches: (1) u-kNN with naïve input set tuning, (2) u-kNN with input sets tuned with regard to cross-correlation, and (3) dimensionality reduction as pre-processing for u-kNN.

### 5.4. Results for u-kNN Regression with Naïve Input Set Tuning

Table 3 shows the MSE achieved with the u-kNN regression and with a) no neighboring turbine, b) all 12 turbines, and c) with the best subset of turbines determined with an exhaustive search of all possible input combinations, i.e. $\sum_{m=0}^{12} \binom{12}{m} = 4096$.

| u-knn | Casper | Tehachapi | Comanche |
|---|---|---|---|
| MSE $[MW]^2$: a) | 24.884 | 20.006 | 22.869 |
| MSE $[MW]^2$: b) | 24.948 | 20.226 | 17.673 |
| MSE $[MW]^2$: c) | 23.258 | 17.588 | 17.501 |

*Table 3: Results for the u-kNN regression with particular input sets: a) univariate times series model (no neighboring turbines), b) multivariate model considering all additional turbines in the neighborhood and c) multivariate model with most appropriate inputs.*

One can observe that taking into account a particular subset of neighboring turbines is useful for the prediction. But even with the best subset the u-kNN method only achieves in mean a comparable high accuracy with our x-kNN.

### 5.5. Results for u-kNN Regression with Inputs Selected with Regard to Cross-Correlation

In the following experiments, we analyze the accuracy of the u-kNN when taking into account only the turbines with a high cross-correlation with the target. The results are given in Table 4.

| turbine | l=1 | l=3 | l=5 | l=7 | l=9 | l=11 |
|---|---|---|---|---|---|---|
| Casper | 23.905 | 23.538 | 24.030 | 24.424 | 24.889 | 24.917 |
| Tehachapi | 19.625 | 18.970 | 18.806 | 19.759 | 20.515 | 20.217 |
| Comanche | 19.539 | 18.627 | 18.549 | 18.482 | 17.637 | 17.649 |

*Table 4: MSE in $[MW]^2$ for the u-kNN regression with the l highest cross-correlated neighboring turbines. The target turbine measurement is always part of the pattern, because it has the highest correlation with the prediction value, see Table 1.*

It can be seen that this u-kNN variant does not allow good predictions. In particular, for the turbines in Casper and Tehachapi, the accuracy is much worse in comparison to the results achieved with x-kNN.

### 5.6. Results for u-kNN Regression with Various Numbers of Principle Components

In further experiments, we employ PCA [9] as preprocessing method and test a different number of components for the u-kNN prediction model. We determine the principle components of the measurements corresponding to the year 2004 and train the regression model with these features. In the evaluation part, we have to transform the measurements according to the principle components we computed on the train set, before we make the prediction on the test set. Table 5 shows the results.

| turbine | c=1 | c=3 | c=5 | c=7 | c=9 | c=11 |
|---|---|---|---|---|---|---|
| Casper | 42.345 | 30.478 | 25.658 | 24.556 | 24.702 | 24.836 |
| Tehachapi | 39.029 | 29.578 | 24.964 | 24.784 | 20.558 | 20.004 |
| Comanche | 18.199 | 17.842 | 17.648 | 17.680 | 17.671 | 17.677 |

*Table 5: MSE in $[MW]^2$ for the u-kNN regression with PCA reduced features. Parameter c identifies the number of components taken into account.*

It can be observed that the PCA in general does not yield competitive results. While the results for Comanche are still quite accurate, they are comparable for Casper and Tehachapi with the relatively inaccurate results achieved with the univariate u-kNN model. For both turbines the forecast fails completely, if only few components are taken into account.

## 6. Conclusion

Wind power prediction is a key technology for the successful integration of wind energy into the grid, because it allows to plan reserve plants, battery loading strategies and scheduling of the different authorities. In this paper, we present a special kNN regression method based on a weighting of inputs with regard to the cross-correlation between neighboring turbines and the target turbine.

We demonstrate that the exclusive consideration of the cross-correlation for u-kNN is not sufficient for a good prediction. In contrast, our efficient implementation provides robust and precise predictions, which can only be achieved for equally weighted inputs after an extensive pre-selection of turbines.

## Acknowledgements

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# Different horizons of the application of Weibull distribution for Wind resource assessment: a case study for the Brazilian Northeast region

Tatiane Carneiro[1], Paulo Carvalho[1]


## Abstract

This paper aims to apply the Weibull distribution in the annual and semiannual horizons to contribute to the assessment of wind energy potential in three cities located in Northeastern Brazil (BRNER) region. The potential for wind power in a period can be evaluated by a probability density function such as the Weibull distribution. Different methods for calculating these parameters, including the method of equivalent energy, developed to optimize the application of this frequency distribution to the data collected in northeastern Brazil, were tested. This research seeks to optimize the fit to the data of wind speed and contribute to the reduction of errors in the analysis of wind potential of cities located in the Brazilian Northeast. According to the analysis, it was found that the reduction of the horizon of application provides better efficiency in the adjustment of calculated and observed frequencies. It was also observed that the Weibull distribution applies satisfactorily to the data collected in coastal cities and its efficiency is reduced when applied to distant cities on the coast. Among all analyzed methods for calculating the parameters (k and c) of Weibull distribution, the method of equivalent energy was the one which performed better.


## 1. Introduction

The use of frequency distributions as a tool for data representation of local wind speed is a very common practice in the wind industry, because they can aggregate the numerous variants that influence the behavior of the wind. According to Silva (2003), a good measure to evaluate the wind energy potential of a site is through the use of frequency distributions.

As noted in the literature, the function of the Weibull distribution is the most used in the description of the behavior of the values of wind speed at a given location (Maceira*etal.*, 2011). The Weibull distribution has been shown as a convenient method of characterizing wind resources. With the two factors (k and c) and the average air density is usually possible to estimate the annual output of a wind turbine with good accuracy.

Northeastern Brazil (BRNER) is a region that has a well-defined seasonal pattern in relation to the behavior of wind speed data, with a first half of the year with low values of speed and a second half that features high velocity values.

Apart from analyzing the distribution parameters and the way to calculate them, it is necessary to analyze the horizons of adjustment. When apply in the Weibull distribution function for annual data, the curve should be adjusted every observed month, therefore, the estimations of (k and c) must represent the low-speed data (first semester) and also the high-speed data (second semester). Besides the improvement in getting the Weibull parameters, the application of the Weibull distribution at different horizons could improve the fit to the data analysis and contribute to the reduction of errors in time to estimate the produced electricity and the analysis of potential of wind city in BRNERlocated cities.

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This paper aims to apply the Weibull distribution of the annual and half-yearly horizons, using different numerical methods for the calculation of this distribution. This application seeks to improve the data fit and reduce the estimation errors of wind power generation in the analyzed cities.

## 2. ApplicationsandResults

### 2.1. StudyAreaand Data Description

The BRNER has an area of 1.5 million km2 (18% of Brazilian territory), equivalent to the size of France, Italy, United Kingdom and Germany combined, with an estimated population of 53 million inhabitants, or in other words, 28% of the Brazilian population (IBGE, 2010). Wind speed data was collected by 80 metres high measurement towers, installed on three sites in three separate states of the BRNER: Parnaíba (state of Piauí), Maracanaú (state of Ceará) and Petrolina (state of Pernambuco) (Figure 1). The measurement periods for the three sites were: February 2012 to January 2013 for Maracanaú, August 2012 to July 2013 for Parnaíba and May 2012 to March 2013 for Petrolina.

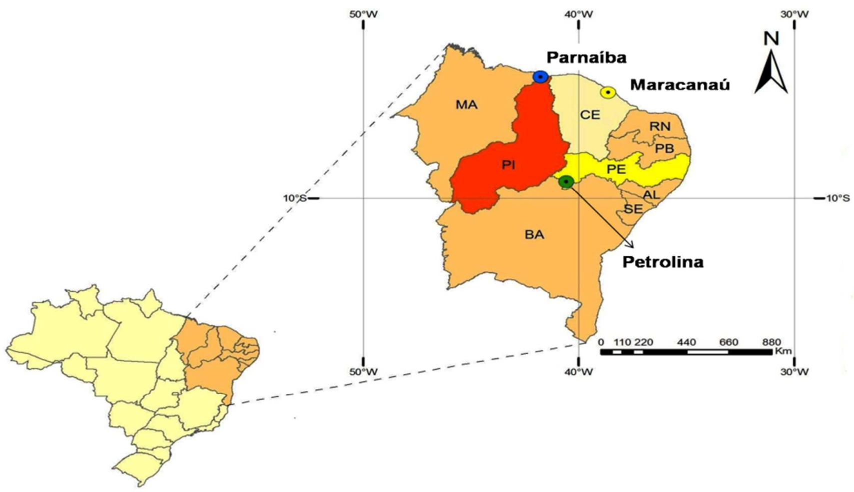



*Figure 1: Localization of the measurement towers in the states of Piauí (PI), Ceará (CE) and Pernambuco (PE).*

### 2.2. Investigation of numerical methods for estimation of Weibull parameters

The wind energy potential in a period may be evaluated by a probability density function, such as the Weibull distribution. This distribution is characterized by two variables: k, the dimensionless shape parameter, and c, the scale parameter, both having the same wind speed unit(Borges; Carvalho, 2012). Several numerical methods for the calculation of the Weibull parameters, observed from a wind speed set, are found in the relevant literature. Thus, in this way, investigations into the accuracy of the numerical methods for a specific site should be considered.

Six variants of numerical methods for estimating Weibull parameters are viewed in Chang (2011), and are categorized as: moment (M), empirical (E), graphical (G), maximum likelihood (ML), modified maximum likelihood (MML) and energy pattern factor (EPF).The ML method performed the best fit and the G had the lowest performance.

A new method for the estimation of Weibull parameters, called the equivalent energy (EE) method, is considered in Silva et al. (2004). It was found that errors between 2% and 7% in the energy content could occur on half of the tested sites. Therefore, the research objective was to develop a method that should present a mean error of 1% in the energy content of the wind analysis.

An analysis and comparison of the seven aforementioned numerical methods, using wind speed data collected on two sites along the coastline of Ceará, Brazil, can be found in Rocha et al. (2012).The EE method had the best performance.

Five numerical methods for the calculation of Weibull parameters are utilized in Abdel-Hady et al. (2012). These methods are categorized as: Mean Wind Speed (MWS), G, ML, MML and Power Density (PD). The best performances are found for MWS and ML methods.

Based upon the observed wind speed data, the Weibull distribution can be described as

$$f_{Weibull}(v) = \frac{k}{c} \cdot \left(\frac{v}{c}\right)^{k-1} \cdot e^{-\left(\frac{v}{c}\right)^{k}} \tag{1}$$

$k$and$c$ are the shape and scale parameters of the Weibull distribution and $v$ is the wind speed.

To estimate the Weibull distribution parameters, four numerical methods are used in the present research: Moment Method (M), Empirical Method (E), Energy Pattern Factor Method (EPF) and Equivalent Energy Method (EE).

The M method determines the k and c parameters with the use of Eqs.(2)and(3)(Chang, 2011).

$$\bar{v} = c\Gamma\left(1 + \frac{1}{k}\right) \tag{2}$$

$$\sigma = c\left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{2}{k}\right)\right]^{1/2} \tag{3}$$

$\bar{v}$and$\sigma$ are the mean wind speed and the standard deviation of the observed data, respectively.

$\Gamma$ represents the gamma function.

The E method is considered a special case of the M method, determined by using Eqs (4) and (5) (Chang, 2011).

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1{,}086} \tag{4}$$

$$\bar{v} = c\Gamma\left(1 + \frac{1}{k}\right) \tag{5}$$

The EPF Method is related to the mean wind speed, and is defined by Eqs.(6), (7) and (8) (Akdag;Dinler, 2009).

$$E_{pf} = \frac{\overline{v^3}}{(\bar{v})^3} \tag{6}$$

$$k = 1 + \frac{3{,}69}{\left(E_{pf}\right)^2} \tag{7}$$

$$\bar{v} = c\Gamma\left(1 + \frac{1}{k}\right) \tag{8}$$

$\boldsymbol{E_{pf}}$is the Energy Pattern Factor.

The EE method was developed by Silva (2003), aiming to identify a methodology for estimation of Weibull parameters with an adequate adjustment to the wind resource found in the BRNER (wind data with relatively high shape factor values). The name comes from the fact that it is based upon the equivalence between the energy density of the Weibull curve and the energy density of the observed data. The Weibull parameters are determined with the use of Eqs.(9) and (10).

$$\sum_{i=1}^{n}\left[W_{v_i} - e^{-\left\{\frac{(v_i-1)\left[\Gamma\left(1+\frac{3}{k}\right)\right]^{1/3}}{\overline{v^3}^{1/3}}\right\}^{k}} + e^{-\left\{\frac{(v_i)\left[\Gamma\left(1+\frac{3}{k}\right)\right]^{1/3}}{\overline{v^3}^{1/3}}\right\}^{k}}\right]^{2} = \sum_{i=1}^{n}\varepsilon_{v_i}^{\;2} \qquad (9)$$

$$c = \frac{(\overline{v})^3}{\Gamma\left(1+\frac{3}{k}\right)} \qquad (10)$$

$\boldsymbol{W_{v_i}}$is the frequency of occurrence of each interval, $\overline{\boldsymbol{v^3}}$ the mean of the cubic wind speed and $\boldsymbol{\varepsilon_{v_i}}$ the approximation error.

The method efficiency is determined by using the statistical tests: RMSE (root mean square error), $X^2$ (chi-square) and $R^2$ (analysis of variance or efficiency of the method), as described in Eqs.(11), (12) and (14).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(X_i - Y_i)^2}{N}} \qquad (11)$$

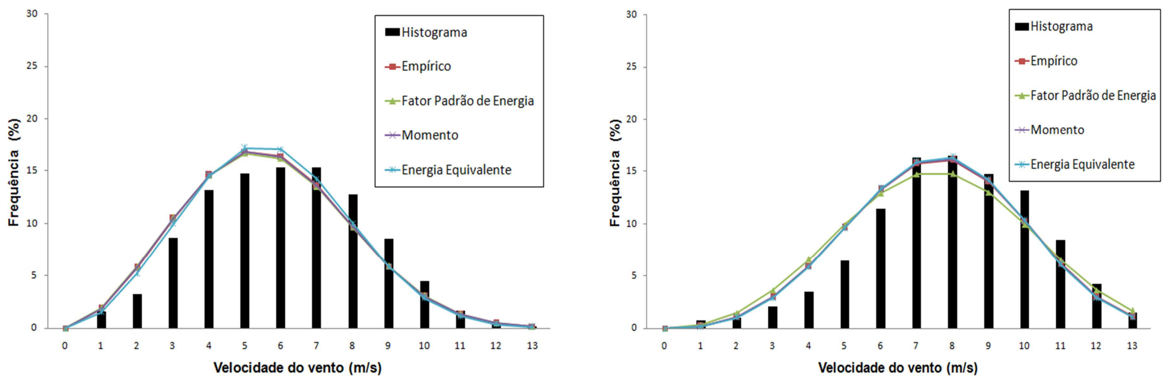
$$X^2 = \sqrt{\frac{\sum_{i=1}^{N}(Y_i - X_i)^2}{N-n}} \qquad (12)$$

$$R^2 = \frac{\sum_{i=1}^{N}(Y_i - Z_i)^2 - \sum_{i=1}^{N}(Y_i - X_i)^2}{\sum_{i=1}^{N}(Y_i - Z_i)^2} \qquad (13)$$

$N$ is the number of observations, $Y_i$ the frequency of observations, $X_i$ the frequency of Weibull and $Z_i$ the mean wind speed.

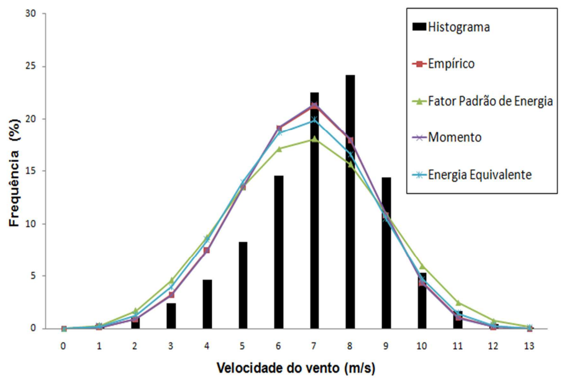
## 2.3. Results

Figure 2, 3 e 4 illustrate Weibull curves for each of the four utilized numerical methods for Maracanaú, Parnaíba and Petrolina, the different horizons (annual, first semester and second semester).




a)

b)




c)

*Figure 2: a)Weibull distribution –Maracanaú;b)Weibull distribution –Parnaíba; b) Weibull distribution –Petrolina.*

According to Figure 2, Weibull curves for each of the four numerical methods considered in the analysis have different coincidence levels with the histograms.The best adjustments are found in Figures2a and 2b, representing Weibull adjustment to the wind data obtained on coastal sites. Lower adjustments are found in Figure2c, representing wind data from a site far from the coast. Tables 1, 2 and 3 show the application of the statistical tests (RMSE, $X^2$ e $R^2$) for Maracanaú, Parnaíba and Petrolina, respectively, using a measurement height of 78 metres.

| Methods | Statistical tests | | |
|---|---|---|---|
| | RMSE | $X^2$ | $R^2$ |
| **EE** | 0.008714 | 0.000075 | 0.929075 |
| **M** | 0.018224 | 0.000439 | 0.925308 |
| **E** | 0.017216 | 0.000296 | 0.925795 |
| **EPF** | 0.020956 | 0.000439 | 0.925308 |

*Table 1. Applicationof statistical tests for Maracanaú – CE.*

| Methods | Statistical tests | | |
|---|---|---|---|
| | **RMSE** | **$X^2$** | **$R^2$** |
| **EE** | 0.094722 | 0.008972 | 0.921334 |
| **M** | 0.107416 | 0.011538 | 0.926805 |
| **E** | 0.111639 | 0.012463 | 0.926314 |
| **EPF** | 0.247164 | 0.06109 | 0.900961 |

*Table 2.Applicationof statistical tests for Parnaíba – PI.*

| Methods | Statistical tests | | |
|---|---|---|---|
| | **RMSE** | **$X^2$** | **$R^2$** |
| **EE** | 0.000125 | 0.000156 | 0.833267 |
| **M** | 0.001272 | 0.000160 | 0.880779 |
| **E** | 0.001232 | 0.000152 | 0.879844 |
| **EPF** | 0.006303 | 0.003972 | 0.824999 |

*Table 3.Applicationof statistical tests for Petrolina - PE.*

According to the statistical tests, the EE method has a good performance, since it shows the best fit in tables 1 and 2, and the second best in table 3. Considering the variations in the calculation of the parameters k and c of the Weibull distribution, the same four numeric values for both semesters of the year was implemented methods, as shown in Figures 3 and 4.

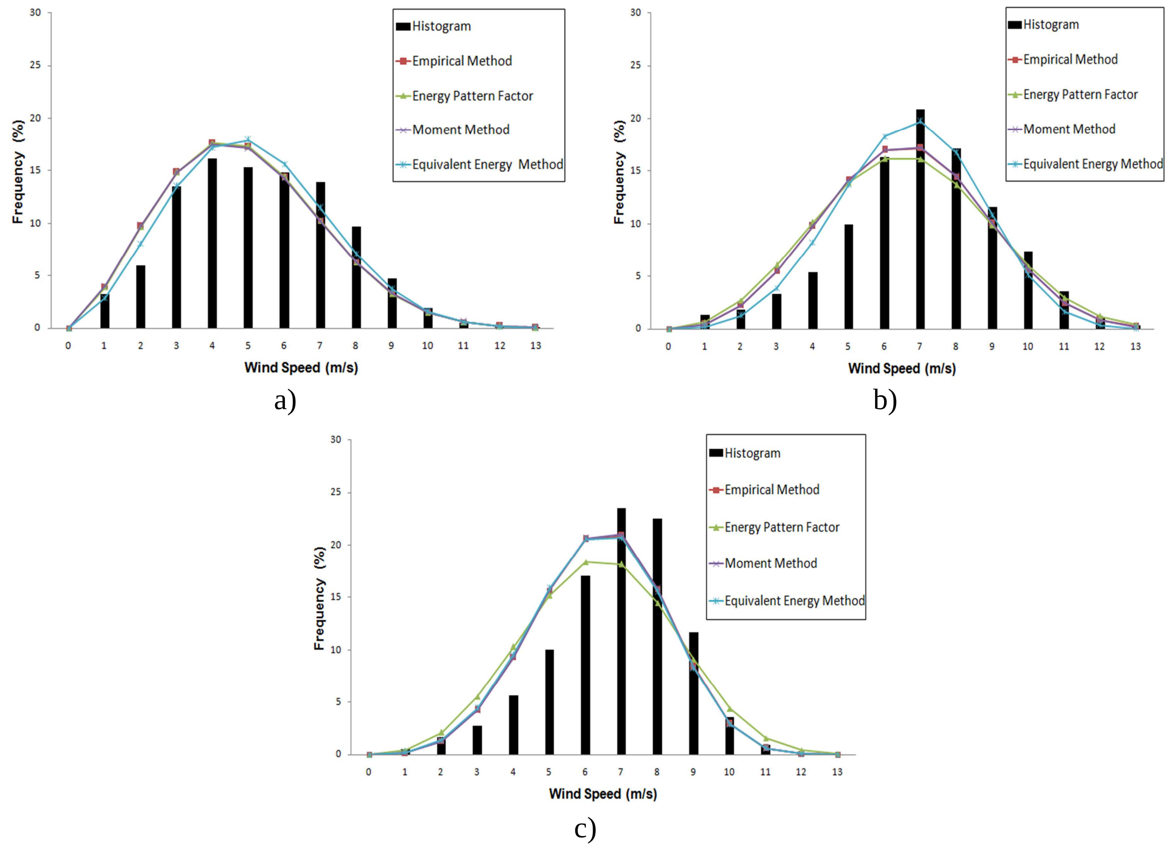



*Figure 3: a) Weibull distribution –Maracanaú(first semester);b) Weibull distribution - Parnaíba (first semester); c) Weibull distribution - Petrolina (first semester).*

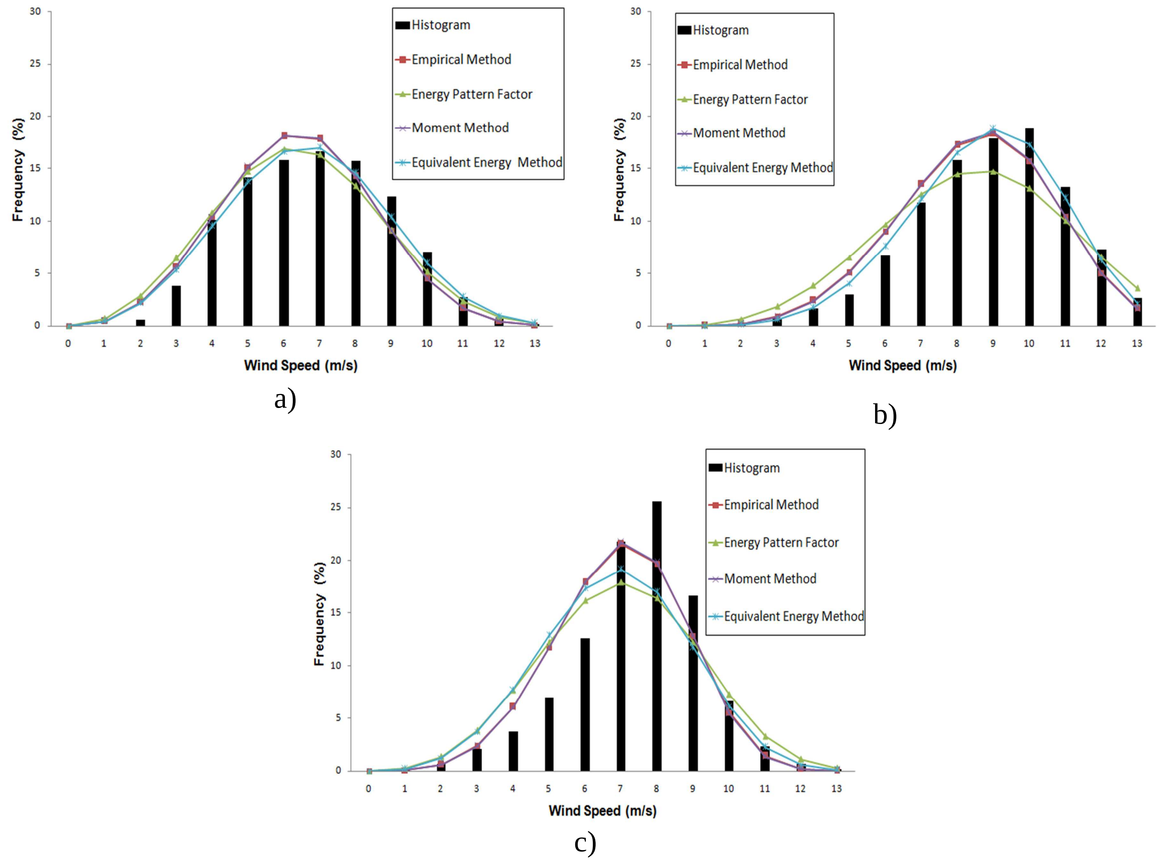



*Figure 4: a) Weibull distribution –Maracanaú(second semester); b) Weibull distribution - Parnaíba (second semester); c) Weibull distribution - Petrolina (second semester).*

According to Figures 3 and 4, the optimal settings were found when applied to Maracanaú and Parnaíba (coastal zones) and a lower setting has been found to Petrolina (city far from the coast). In Tables 4 to 9 show the statistical tests (RMSE, $X^2$ and $R^2$) to evaluate the implementation of different numerical methods for semesters.

| Methods | Statistical tests | | |
|---|---|---|---|
| | RMSE | $X^2$ | $R^2$ |
| **EE** | 0.018758 | 0.000351 | 0.954162 |
| **M** | 0.043527 | 0.001895 | 0.918983 |
| **E** | 0.040858 | 0.001669 | 0.918661 |
| **EPF** | 0.038651 | 0.001494 | 0.918836 |

*Table 4. Applications of statistical tests for Maracanaú .CE (first semester).*

| Methods | Statistical tests | | |
|---|---|---|---|
| | RMSE | $X^2$ | $R^2$ |
| **EE** | 0.000441 | 0.000019 | 0.934093 |
| **M** | 0.011233 | 0.000126 | 0.889658 |
| **E** | 0.011687 | 0.000137 | 0.889023 |
| **EPF** | 0.032806 | 0.001076 | 0.863718 |

*Table 5. Applications of statistical tests for Parnaíba-PI (first semester).*

| Methods | Statistical tests | | |
|---|---|---|---|
| | RMSE | $X^2$ | $R^2$ |
| **EE** | 0.000388 | 0.000015 | 0.851544 |
| **M** | 0.000334 | 0.000011 | 0.869615 |
| **E** | 0.000348 | 0.000012 | 0.869059 |
| **EPF** | 0.001408 | 0.000198 | 0.830615 |

*Table 6. Applications of statistical tests for Petrolina - PE (first semester).*

| Methods | Statistical tests | | |
|---|---|---|---|
| | RMSE | $X^2$ | $R^2$ |
| **EE** | 0.001680 | 0.000282 | 0.976802 |
| **M** | 0.002330 | 0.000543 | 0.952098 |
| **E** | 0.002516 | 0.000633 | 0.942526 |
| **EPF** | 0.016639 | 0.000268 | 0.941909 |

*Table 7. Applications of statistical tests for Maracanaú .CE (second semester).*

| Methods | Statistical tests | | |
|---|---|---|---|
| | RMSE | $X^2$ | $R^2$ |
| **EE** | 0.013626 | 0.018567 | 0.986711 |
| **M** | 0.097462 | 0.009498 | 0.940495 |
| **E** | 0.106931 | 0.011434 | 0.940675 |
| **EPF** | 0.628612 | 0.395152 | 0.873212 |

*Table 8. Applications of statistical tests for Parnaíba-PI (second semester).*

| Methods | Statistical tests | | |
|---|---|---|---|
| | RMSE | $X^2$ | $R^2$ |
| **EE** | 0.002160 | 0.004664 | 0.803604 |
| **M** | 0.000156 | 0.000243 | 0.889602 |
| **E** | 0.000371 | 0.000138 | 0.888433 |
| **EPF** | 0.012454 | 0.001551 | 0.815431 |

*Table 9.Applications of statical tests for Petrolina – PE (second semester).*

Analyzing Tables 4 - 9, it can be noticed that in the two semesters, the method of equivalent energy shows the best fit adjustment to Maracanaú and Parnaíba (coastal cities); the moment method and empirical method have the best adjustment to Petrolina (far from the coast).

Considering the statistical tests values for Maracanau and Parnaiba, it was observed that the reduction of the Weibull application horizon provides better adjustment efficiency of the calculated and observed frequencies ($R^2$ - over 97% and RMSE – lower 0.00168, for a 6 months period). However, using the Weibull distribution fit for Petrolina no significant improvement was observed.

## 3. Conclusion

Taking into account the four numerical methods used for the estimation of the Weibull distribution parameters, the Equivalent Energy Method (EE) shows the best results for sites near the coast. For Petrolina, ca. 650 km from the coast, Moment Method (M) and Empirical Method (E) show the best results.

For all the considered sites, k and c monthly values vary considerably throughout the year, with a peak occurring in the second semester. Taking this local characteristic into account, namely the difference between monthly and annual k and c parameters, the wind speed potential analysis based only on annual values can lead to false estimations.

Independent of the used numerical method, the Weibull distribution analysis for a 6 months period has a better performance than the analysis for a year, especially for the second semester of Maracanau and Parnaiba, with adjustment above 97% and RMSE lower than 0.00168.

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# Multi-Actor Urban Energy Planning Support: Building refurbishment & Building-integrated Solar PV

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## Abstract

Considering the large amount of energy consumption in cities, two-thirds of the overall consumption, these latter have an important potential in terms of $CO_2$ emissions reduction. Therefore, energy strategies are needed at a city level and consequently, adequate planning tools are required to support urban energy planners in assessing their decisions (e.g. which buildings are the best to refurbish). This paper presents an ontology based approach for urban energy planning support applied to building refurbishment and building-integrated solar PV planning. The adopted methodology is an iterative, incremental process, where each iteration leads to the integration of a new planning decision. The process starts by the identification of the actors whose interests are affected by the decision, then developing/ re-using computation models that provide answers for their questions. The different models are integrated using an ontology that models the parts of the city within the scope of the questions to be answered. The system is applied in a district (about 1200 buildings) in the city of Vienna. The adopted approach provides different actors with specific information to their points of view. Furthermore, the output is aggregated to a common level of abstraction, to be understood by all the actors. This approach is applicable to different cities, as the ontology also integrates extension and upgrade mechanisms that provide flexibility to cope with different data-availability contexts.

## 1. Introduction

More than two-thirds of primary energy in the world is consumed in urban settlements [1]. This energy consumption results in approximately 71% of all energy-related direct greenhouse gas (GHG) emissions [2]. Therefore, cities represent a rich ground for taking action to reduce the amount of GHG emissions. Therefore, decision makers, namely city administrations and governments, are developing strategies for energy planning at various spatial scales that clearly state what measures to be taken, where and in what quantities and in which time horizons.

However, cities are complex systems regarding the amount of components and interactions they comprise. The components the city covers can be: (i) physical components, such as buildings, streets, facilities, etc. (ii) human components, whose interests are to be considered or even (iii) regulations and laws that regulate the city. All these components, as well as their interactions, are to be taken into consideration by the decision makers in order to develop energy strategies. Moreover, these energy strategies have to be integrated, considering the impact of each decision on other decisions, besides their impact on the city.

To cope with the complexity of cities, adequate planning support systems are needed to formalize this complexity and automate the interactions that cannot be handled manually, by urban energy planners.

This paper presents an ontology-based approach for urban energy planning support. The ontology comprises information and knowledge to support an urban energy planning process that deals with both solar PV and building refurbishment planning, answering questions such as: what locations

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are the best to install solar PV systems or to refurbish for better thermal insulation. The proposed approach considers the multiple perspectives of all the stakeholders that are involved in the planning and decision making process.

A large variety of tools exist already and they address different aspects of energy planning with a variance of scopes and fields of interest. A more comprehensive list is defined in [3]. However, in this paper, we focus on tools that have a comparable scope to the one of this work i.e. supporting energy planners in developing energy strategies. Such tools include, EnerGis [4] that aims to calculates the minimum annual heat demands of buildings within a geo-referenced context. SUNtool [5] and its later successor CitySim [6] are more on the energy simulation side and attempt to model and simulate energy flows of buildings, considering the individual properties of each building. SynCity [7] is considered as a scenario development, simulation, and optimization tool, at city level. It focuses on urban energy systems and it attempts to discover where large reductions of energy intensity can be achieved within the city. UrbanSim [8][9] is an open source framework that allows constructing scenarios and simulations that can be used at a city scale. It has GIS interface and addresses not only energy in the city but also other aspects. CommunityViz [10] is a scenario development and decision support tool for land-use planning. It is has a GIS interface and offers simple wizards to create different scenarios of land-use as well as calculations of different user-defined indicators. It is an extensions of the GIS software ArcGIS [11]. Semergy [12] supports decision making concerning building refurbishment. It offers a simple interface to users to define and optimize the best building configuration, in terms of refurbishment components, considering both energy efficiency and cost.

The above tools fill specific gaps in urban energy planning that they have been designed for. However, there are four main objectives that have been set in this research that they do not fulfill all together. These four main objectives are actually necessary conditions for urban energy planning support that we describe in the next section.

## 2. Objectives

The objectives that are set represent the necessary conditions in urban energy planning support systems that have been defined in a previous related work[13]. They are mainly based on the analysis of an energy planning process and a data availability analysis in different cities.

The sustainable energy action plan (SEAP) process [14] is used as a reference process in urban energy planning, with more than 5000 cities and municipalities as users [15]. A data availability analysis was performed [13] in the cities of Vienna, Linz, Amstetten in Austria and Nanchang in China, in the context of smart city projects [16], where data have been collected to develop energy strategies for the respective cities. The following conclusion applied: (i) the more detailed data are, the les available they become. (ii) The level-of-detail (LOD) of available data significantly impacts the precision of the developed energy strategies. (iii) Data availability and LODs of data are significantly different, varying from a city to another.

The resulting conditions in urban energy planning support software are defined as the following:

1) **Supporting the perspectives of different actors**: the decision making process must involve all the stakeholders that have potentially affected interests and provide them with specific information, from their different perspectives.
2) **Shared understanding and quantifiable impact of decisions**: the assessment of the impact of energy strategies must be quantifiable. The output results must be aggregated to a level of abstraction that is understandable by all the different actors (i.e. stakeholders).
3) **Measures integration and resources negotiation**: the assessment of the impact of energy strategies must consider the interdependencies between different components and calculations

e.g. installing solar PV reduces the surface areas where solar thermal collectors can be installed.

4) **System viability through robustness against data availability problems**: The system must be flexible to be used within different conditions of data availability and levels of detail.

We note that these objectives have been used also as an assessment basis for the state-of-the-art tools that we have listed in the previous section.

## 3. Methodology and application

The presented methodology in this section is based on a general framework (meta-methodology), the design science in information systems research [17]. This framework sets guidelines that have to be considered within the research process. These guidelines have all been explicitly or implicitly addressed by the adopted methodology.

The methodology is presented in this section with a running application of each of its steps, in modelling solar PV planning in a district in the city of Vienna (about 1200 buildings).

The methodology is an iterative incremental process, as shown in Figure 1, where each iteration starts by the scoping phase. In this specific work, this process has been run twice: once for considering solar PV planning, then another time for building refurbishment.

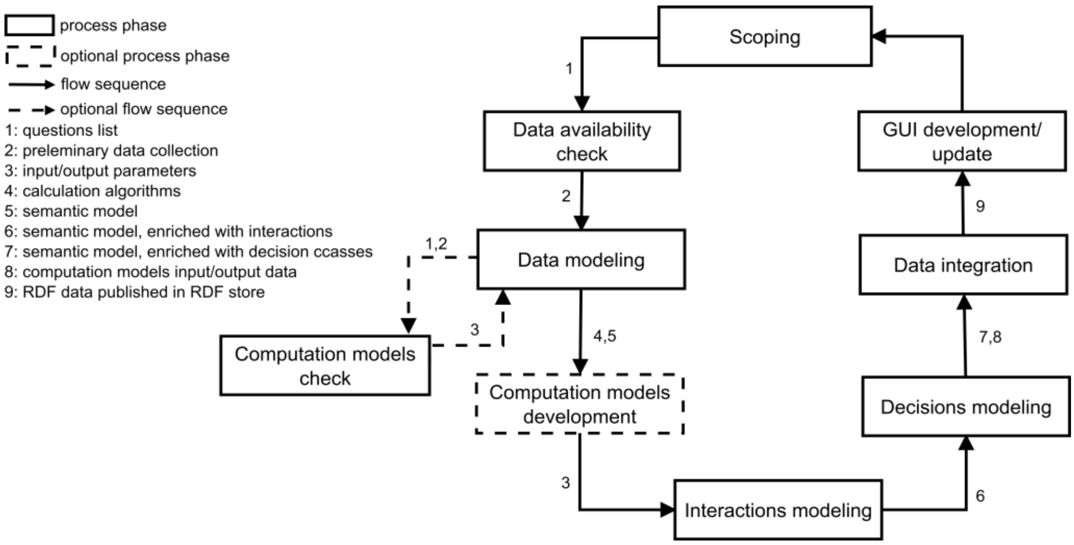


*Figure 1: Main phases of the development methodology*

**Scoping phase**, the actors (stakeholders) that are involved in the decision making process are identified. Then, for each actor, a list of questions that are of interest is established followed by a breakdown of the questions to a set of quantifiable expected answers, as shown in Table 1.

| Actor | Question |
|---|---|
| **Building owner** | -What is the net present value of my investment?<br>-What is my investment Break-even duration?<br>-How much investment costs are required? |
| **City Administration** | -How much subsidies are to be paid to PV installations?<br>-How much electricity is produced from subsidized PV installation?<br>-How much CO2 emissions are saved with subsidized PV installations?<br>-What is the CO2-emissions-saved-equivalent in terms of trees carbon sequestering? |
| **Grid operator** | -What transformers are overloaded because of PV installations?<br>-What is the peak feed-in power at the transformers?<br>-How long does the overload occur?<br>-What is the electricity feed in Quantity?<br>-How much is the direct use of the generated electricity? |

*Table 1: competency questions of the ontology-Solar PV planning*

**Data availability check:** it is performed to understand what datasets exist and what their levels of detail are. The data availability (and un-availability) significantly impacts the rest of the process i.e. it is possible that some of the questions formulated in the scoping phase have answers of a low LOD.

The main information provider in this case was the city of Vienna. An initial data collection has been performed and it included a solar cadaster of the city [18], building stock data, standard electricity demand profiles, demographic data, solar PV funding schemes, etc. In brief, the acquired data was not detailed enough to aim at going in the direction of simulations but rather in making assumptions and generalizations, such as assuming that all residential buildings have the same electricity demand profile and correcting this assumption by using a diversity factor [19] where it is necessary.

**Computation models check / data modelling:** for each expected answer, in alignment with the available data, calculation methods are defined, by domain experts, listing all the intermediary steps. Then, semantics extraction is performed based on calculation methods, questions, expected answers, and actors. Then an ontology is developed as described in [20]. In the case that existing computation models can be reused, the data modeling phase considers the input and output parameters of these models as a basis for the semantics extraction and classification.

The final outcome represents an ontology of an urban energy system (UES), that includes concepts regarding solar PV planning and that is open to include more measures, and therefore making the UES be more and more general. The example in **Fehler! Verweisquelle konnte nicht gefunden werden.** shows a fragment of the concepts of the UES, which deals with solar PV planning and that will grow later on to include more concepts the more measures are integrated.

**Computation models development:** computation models are developed (if no existing ones can be re-used) according to the calculation methods that have been identified in the data modeling phase, by domain experts. There are no restrictions in this phase on which programming languages or technologies to use.

For solar PV planning, Java computation models have been developed, while their data management has been performed by MySQL, PostGIS, and PostgreSQL databases. We note that some data preparation tasks have been performed in spreadsheets. The goal of the computation models is to calculate answers for the questions that are listed in the scoping phase.

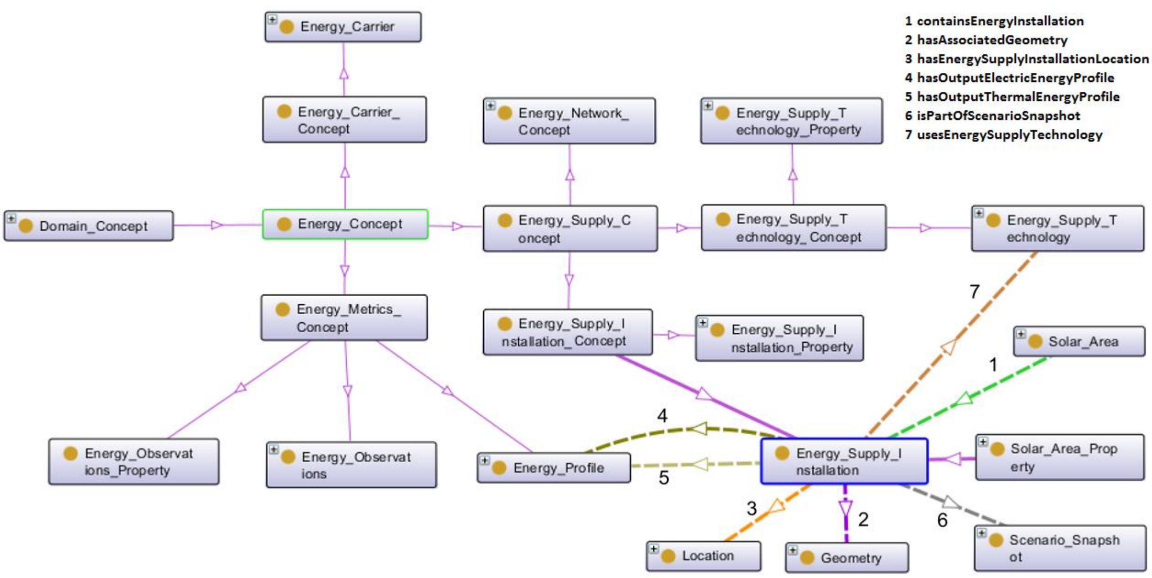


*Figure 2: Ontology fragment- main solar PV planning concepts*

**Interaction modeling:** in this phase, we capture the interactions between the different modeled components, showing which components are affecting which others through which data properties, as shown in Figure 3. The main goal of this phase is to keep the different calculation models integrated. In other words, it adds a part to the ontology so that it becomes aware about how every calculation model influences the others.

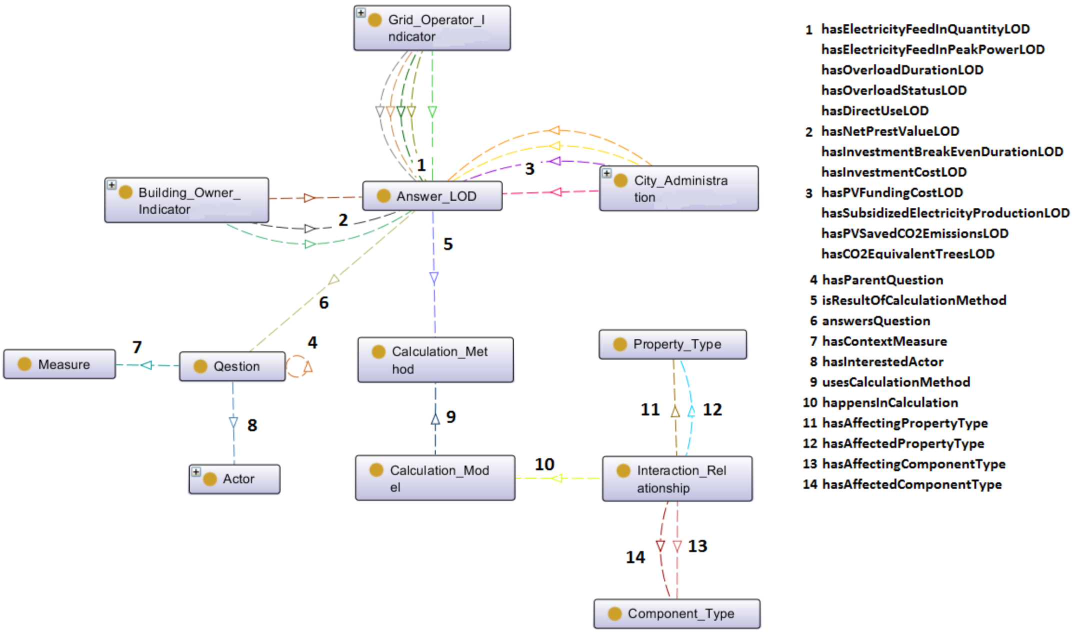


*Figure 3: Ontology fragment- interactions of computation models*

**Decision modeling**: in this phase, the knowledge of the actors regarding their interpretations of the values of the expected answers is captured. Rules are formalized to classify buildings (or groups of buildings) as having high or medium potential from each actor´s perspective. Then more rules are formalized to classify buildings as having high or medium potential for all the actors together. For example, a building is interpreted as having a very good potential for solar PV, by the building owner if the net present value of the investment is higher than 25000€. From a multi-actor perspective, it is considered as having very good potential for solar PV, if it does not overload the transformer within the low voltage grid and it has very good potential from one of the perspectives of the building owner or city administration.

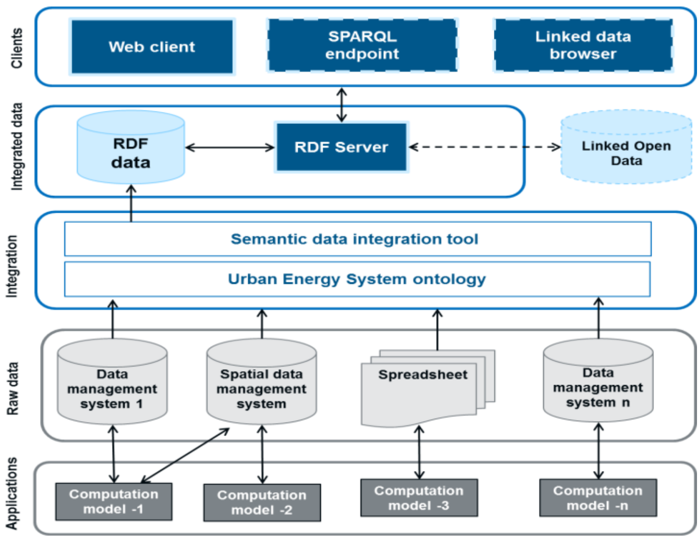


*Figure 4: data integration architecture*

**Data integration:** in this phase, the ontology is populated by data from the databases (or possibly spreadsheets) of the different computation models that have been used, using an existing data integration tool, Karma [21]. The integrated data are then served in a Resource Description Framework (RDF) format [22], as depicted in Figure 4.

**GUI development:** a light web interface is developed according to the workflow that energy planners prefer to adopt. The interface uses google maps to display the RDF data in a geo-referenced context. It is possible as well that the data are accessed through a SPARQL endpoint or a linked data browser. A sample preview of a potential interface is show in Figure 5.

The GUI development is still under progress and open for discussion with energy planners/urban planners: how to present the integrated data and under which workflow, or maybe even in a decentralized participative way, where different stakeholder are involved and all having access to the interface.

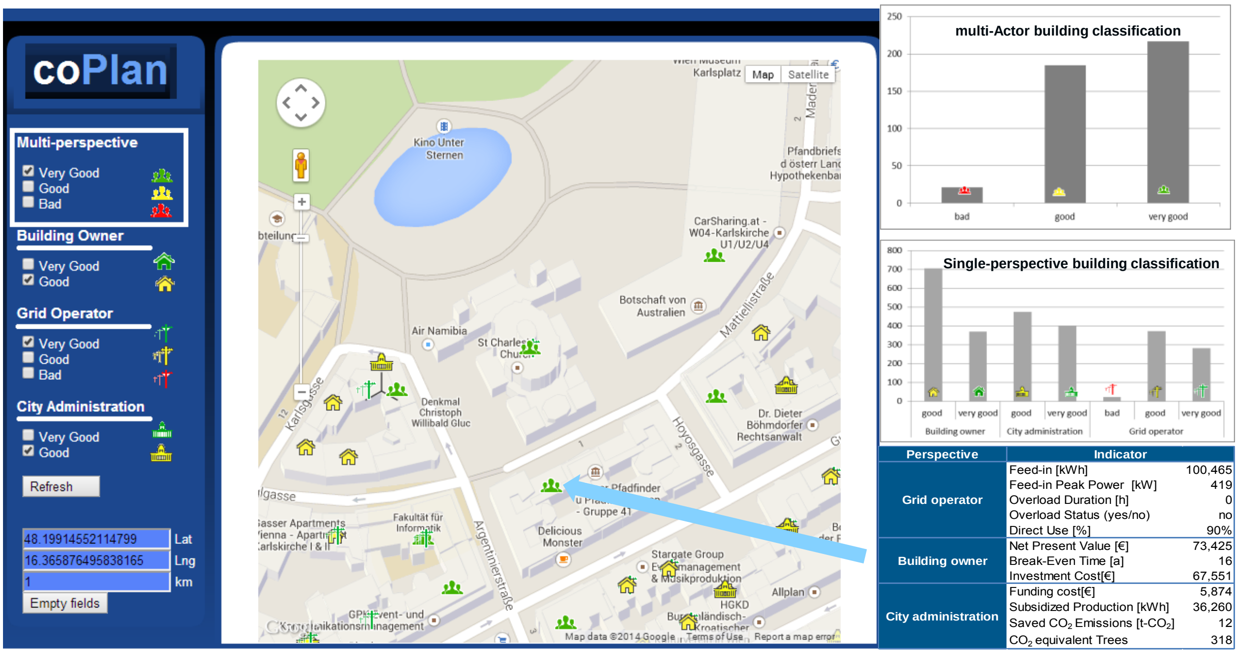


*Figure 5: Sample interface preview*

## 4. Building refurbishment planning integration

Similarly applying the same methodology as above, building refurbishment planning has also been modelled. The different stakeholders and their respective questions (which are answered by the ontology) are shown in Table 2. Given the LOD of the available data in building refurbishment planning, it was only possible to model at a census level instead of having more detailed calculations at single buildings level as it was the case in solar PV planning. Thus, computation models have been developed based on the number of square meters per census and their distribution in terms of percentages over different building-uses and used-heating technologies.

| Actor | Question |
|---|---|
| **Building owner** | -What is the net present value of my investment?<br>-What is my investment Break-even duration?<br>-How much investment costs are required? |
| **City Administration** | -How much subsidies are to be paid to refurbish buildings?<br>-How much energy is saved by subsidizing building refurbishment?<br>-How much CO2 emissions are saved by subsidizing building refurbishment?<br>-What is the CO2 emissions-saved-equivalent in terms of carbon sequestering by trees? |

*Table 2: competency questions of the ontology-Building refurbishment planning*

The integration of building refurbishment planning with solar PV planning was ensured through: (a) the integration of their data, by sharing the same ontology that represents an UES that contains concepts that are part of solar PV and building refurbishment planning. (b) Ensuring the consistency of data that are shared and calculated by the different heterogeneous computation models. This is achieved in the interactions modelling phase: the output data parameters of the building refurbishment computation models were checked if they are shared as input data parameters in the solar PV planning computation models and vice versa. As the building refurbishment involves data that are more related to thermal energy while solar PV models rather deal with electric energy, no interactions have been detected. Therefore no interaction-protocols were necessary to be modelled. (c) Integration of decisions of the different actors about the same locations in terms of their suitability for solar PV installation or building refurbishment. Since the LOD of the building refurbishment modeling was at a census (group of buildings) level, the solar PV planning data were also aggregated to the census level. Then, decisions about the integrated suitability in terms of solar PV or building refurbishment were modelled from different perspectives. E.g. from a building owner perspective, a census is more suitable for building refurbishment if the net present value (NPV) of this investment is greater than the NPV of a solar PV investment.

## 5. Conclusion

The developed ontology answers questions that different stakeholders raise to understand how their different interests are affected by the potential implementation of an energy strategy (i.e. stating which locations to use for solar PV or building refurbishment). The questions that the ontology provides answers for are listed in Table 1 and Table 2. The ontology is validated through its application within a district (about 1200 buildings) in the city of Vienna.

All answers are geo-referenced i.e. each location is related to a set of answers. Concerning building-integrated solar PV, the answers are available at each single buildings level, however for the case of building refurbishment, given the current data availability, answers are related to groups of buildings. Therefore, the integrated assessment of building refurbishment with solar PV was possible only at the group of buildings level.

The developed ontology fulfills the four conditions of urban energy planning support [13] that have been set as objectives for this work. (1) Different stakeholders are provided with specific answers to their particular concerns, as shown in Table 1 and Table 2. (2) The answers that are provided are then summarized at each location (building or group of buildings) level, as very good, good, or bad locations, from the perspectives of each actor, then again as very good, good, or bad locations from all the perspectives together. (3) As explained in the methodology section, components interactions are captured, and integrated in the ontology, allowing the possibility to check data consistency and the integration of different computation models and planning decisions. (4) The development methodology allows the flexibility in calculating each single answer in more than one level of detail, using different calculation models e.g. if more detailed data are available about a given share of the city, more detailed models can be used for these, while the rest is calculated using more general models that do not require detailed datasets. Mechanisms of integrating multiple levels of detail data are formalized and integrated within the ontology.

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# The 5 % Approach as Building Block of an Energy System dominated by Renewables

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## Abstract

We describe an approach for doubling distribution grid capacity for connecting renewable generators based on curtailing a maximum of 5 % of the yearly energy fed in to the grid on a per-generator basis. The paper contains information about the control unit needed for automatic minimum curtailment and the field test that has been set up to validate the approach. Furthermore, topics concerning the operationalization of the 5 % approach using both, operational technology and information technology are discussed.

## 1. Introduction

Following the current German legislation the distribution grid has to be laid out such that it can absorb the entire electricity generated from renewable energy sources. The usage of distribution grids for electricity in Germany is more and more determined by feed-in distributed energy resources (DER). This leads to situations in which allowable transformer loads or cable loads are exceeded or in which voltage thresholds are violated. Grid operators are only allowed to temporarily throttle renewable generators (grid curtailment) if there are no other options to prevent harm to the power grid infrastructure. Furthermore, they are forced to execute grid construction after grid curtailment actions have taken place, which additionally provides security for investments into renewables as subsidies are connected to the amount of feed in.

Assessment of load and system design both follow a worst case approach resulting in the system being dimensioned towards a maximum load. In the case of grids dominated by decentralised power feed-in, this maximum load is given by the cumulated installed generation capacity combined with minimal electricity consumption. Frequency and duration of such load situations is not taken into account in the worst case approach. This typically results in a low number of hours of full grid capacity utilisation, since utilisation is determined by the feed-in characteristics of connected generators. Figure 1 depicts the annual load duration curve of a photovoltaic generator. It is obvious that the generator only reaches its maximum output for a few hours per year. Accordingly, the fraction of electricity generated in the upper power region with respect to the annual energy quantity (area below the curve) is very small.

Thus, distribution grid dimensioning in Germany is currently adjusted to feed-in situations only occurring a couple of hours per year. As a consequence enormous investments in grid construction are required. Therefore, the following questions concerning system layout of today's distribution grid structures arise:

- Is it macroeconomically reasonable to plan distribution grids based on rare maximum loads?
- By which percentage can grid connection capacity be augmented when the distribution grid does not have to account for rare maximum loads?
- What is the overall macroeconomic balance when substituting grid expansion by grid capacity extension by means of fine-grained curtailment?

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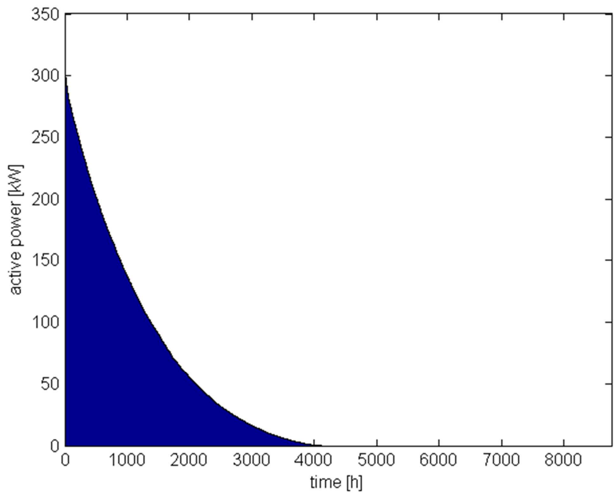


*Figure 1: Illustration of a simulated annual load duration curve of a photovoltaic generator*

## 2. The 5 % Approach

The main hypothesis of the 5 % approach is that load flow dependent throttling of a low percentage (i.e., less than 5 %) of yearly power feed-in carried out in maximum load situations leads to a drastic increase of grid connection capacity. The approach's key characteristic is the load flow dependent throttling of generators, since voltage stabilisation and equipment usage result from summed up load both from consumption and feed-in. This substantially discriminates the 5 % approach from an overall throttling of generators since both frequency and duration of throttling are minimised by load flow dependent control of generators.

In the sense of smart grids we look at an intelligent system for generation management consisting of the following main components:

- metrological coverage of all voltage- and load critical components of the distribution grid.
- possibility for continuous control of reactive power output of all generators based on ICT
- online load flow calculation based upon a grid state identification to continuously monitor all relevant system parameters
- continuous identification of sensitivity of monitored system variables towards generator feed-in in order to identify optimal target values (minimum throttling)
- temporary and well-dosed throttling of relevant generators in case of impending threshold violations of equipment currents or node voltages

### 2.1. Assessment of the Approach's Potential by Simulation

To assess the potential that can be achieved by the approach described above, simulation experiments were carried out on basis of a model corresponding to a rural type grid as controlled by the distribution system operator EWE NETZ. The model characteristics were as follows:

- Steady-state power flow calculation based on a yearly time series (15 minute resolution)
- Consumption loads modelled based on a load-model devised by RWTH Aachen [1]
- Definition of feed-in (e.g., photovoltaics, wind) based upon measured yearly time series

Based on the medium-voltage grid model, different simulation scenarios were evaluated, using a scenario with 100 % feed-in as reference. To determine 100 % feed-in, all generation capacities were iteratively increased until minimal allowed voltage stability and maximum allowed transformer utilization were reached. In the subsequent comparison scenarios, feed-in was further increased stepwise. Using an optimization algorithm feed-in in course of a simulation year was reduced whenever system parameters exceeded tolerance limits. Installed generation capacity was stepwise increased from 100 % to 325 %.

Figure 2 shows the results from simulating the different scenarios. The diagrams show grid connection capacity for feed-in depending on the percentage of curtailed generation. Each scenario was calculated both for a wind intensive year and for a year with low winds in order to take into account different wind years.

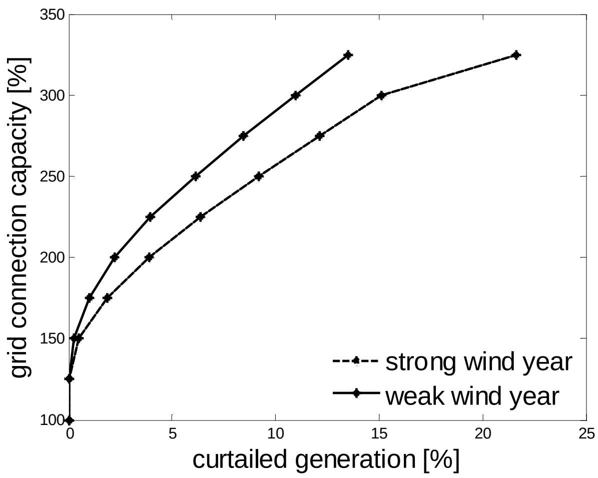


*Figure 2: Dependency between curtailed energy and grid connection capacity during one year*

The simulation results strongly support the hypothesis. Curtailing the yearly energy feed-in by 5 % would allow to double grid connection capacity in rural type distribution grids.

## 3. Validating the 5 % Approach

Before implementing the 5 % approach, the promising simulation results have to be validated under real conditions. To this end, a field test is carried out to validate the relationship between reduced feed-in and grid connection capacity. The field test is characterized by a power flow dependent scheduling of renewable generators.

In order to validate the 5 % approach for general distribution grids, a system study is carried out. Therein, critical parameters are identified by means of a sensitivity analysis and it is studied by which amount distribution grid connection capacity can be increased using intelligent management of power generation.

Note, that regulatory aspects of the 5 % approach are not part of the field test. However, in the German context, it is obvious that implementing the 5 % approach must not lead to financial disadvantages for plant operators. A possible preliminary approach would be paying the fed-in energy with factor 1.05 compared to the current price for electricity from renewables fixed in current laws. Whenever there is at least one control action for a given generator within an accounting period, all fed-in energy will be paid for. If there is no control action in the accounting period, only 95 % of the fed-in energy will be paid for (95 % * 1.05 = 100 %). Following this strategy, no difference in funding will be imposed by implementing the 5 % approach.

### 3.1. Field Test

Figure 3 depicts the selected field test area being representative for medium voltage grids operated by EWE NETZ. The selection occurred such that connected low voltage grids do not substantially contribute to the overall power feed-in. Thereby, it can be avoided to include feed-in from generators installed on the low-voltage level into the 5 % control.

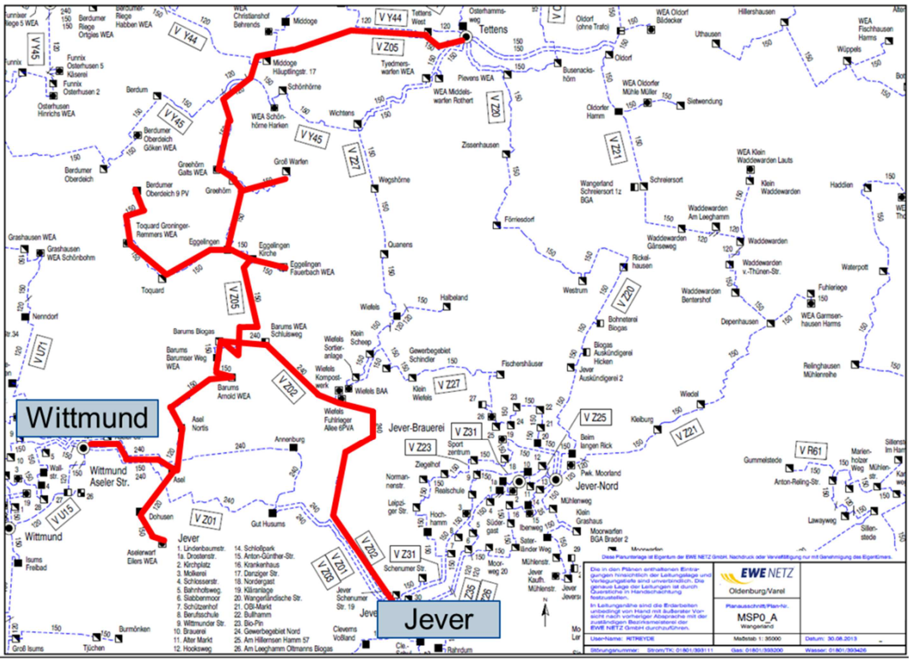


*Figure 3: Field test area*

In order to guarantee that equipment usage (electrical current) and voltage stability only depend upon measured and controllable feed-in, the switch from switching station Tettens has to be opened resulting in connection to the high voltage grid only via Jever substation.

The selected grid area contains 11 generators corresponding to a maximum feed-in of 10 MW. These generators are controlled during the field test. In order to avoid control activities external to the field test, generators are operated with a constant reactive power ratio. The following values are measured (once per minute) in order to provide information to a controller performing the task of regulating feed-in from power generators:

- Currents from lines, substation and switching station
- Voltages from substation, switching station and grid connection points of power generators.
- Power and primary voltage from all low-voltage-transformer substations
- Reactive power, active power and voltage of distributed generators

Furthermore, for purpose of validation, wind and radiation measurements are constantly taken.

Figure 4 shows the general system configuration for the field test.

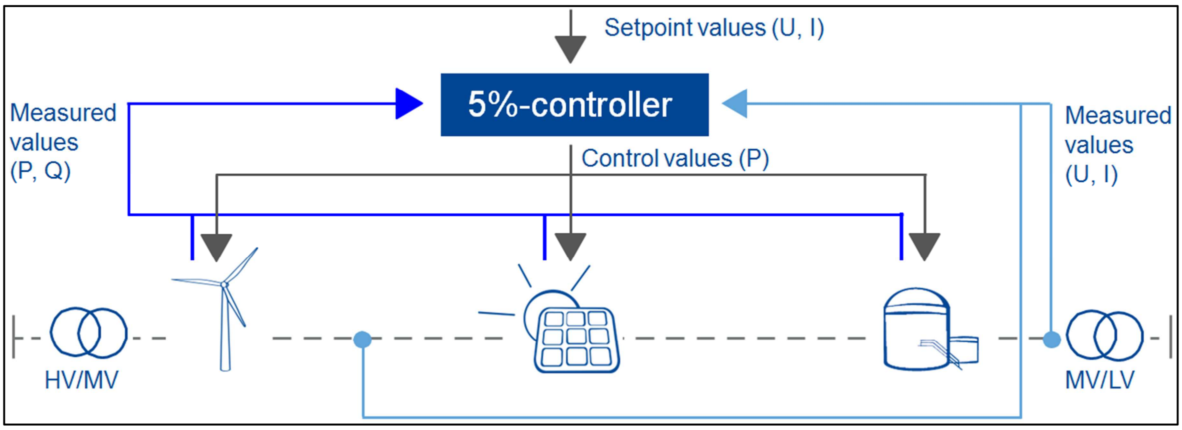


*Figure 4: System configuration of the 5 % controller in the field test*

The quantities relevant for assessing the increase of grid connection capacity are the admissible voltage ranges according to EN 50160 [2] and the allowable currents for grid equipment. Since doubling of power generation capacity is not possible during the field test, evaluation will be based on the following assumptions:

- Calculation of virtual operational thresholds (grid voltage thresholds and maximum allowable equipment currents) based upon 50% of the actually installed generation capacity
- Operation of the field test grid with 100% of the actually installed generation capacity and control of generators such that the virtual operational thresholds are observed

In order to validate the 5 % approach, the energy curtailed must not exceed 5 % of possible generation taking into account the weather conditions (wind, radiation). To gather statistically adequate evidence, the field test has to run for at least an entire calendar year. Only after this period the ratio between curtailed energy and available energy can be properly calculated.

### 3.2. Field test requirements towards an implementation of a 5 % control unit

Measurements take place separately and in a given frequency. Both, the necessary frequency and the timespan between threshold violation detection and the issuance of control values will be evaluated during the field test. Generator feed-in reduction shall occur in steps of 10% of generator capacity. As soon as the control unit determines that feed-in reduction can be (partially) taken back without thresholds being violated, feed-in reduction shall (partially) be taken back.

The control strategy shall take into account:

- safety margins for set point values after threshold violation
- Delayed approach of nominal values to real values in order to avoid short-time electrical overloading of grid equipment due to exorbitant inertia of the whole control
- Grading of nominal value in order to avoid oscillation

Since the quality of control has a significant influence on the successful implementation of the 5 % approach, a control quality (deviation from set point values in per cent) for voltages and for currents must be guaranteed. Quality of control will be evaluated throughout the field test.

## 4. Control Unit Design

The control unit supporting the 5 % approach is based upon a product called BTC | Grid Agent. It operates in a continuous loop consisting of three steps:

1) Read measurements and set points
2) Calculate control values for generators using power flow calculation and taking into account technical limitations
3) Send control values to generators

Thus the controller uses a model-based method, a grid model being used for power flow calculations. The main advantage of this method over PID controllers (see [3]) that are not model-based is the reduced number of control actions needed to correct threshold violations due to the higher possible accuracy. This results in faster control process alignment, especially in face of low quality communication links. Generally model-based-approaches enhance stability of control due to the higher amount of knowledge of the system under control.

During the field test, the controller has to evaluate measurements from about 20 measurement points and has to issue about 10 control values in each cycle. The frequency of control cycles necessary for ensuring the needed control quality will be evaluated during the field test. Having been evaluated in scenarios for controlling reactive power settings of heterogeneous wind farms, the control unit can perform multiple control cycles per second. However, this performance will most likely not be reached during the field test for validating the 5 % approach, because the increased size of grid models needed.

Note that, besides control values being sent to generators, event information is sent to distribution management systems or other supervising systems. Also, parameters e.g. for transforming set point values can be modified during run time. They are held in the parameter and curves storage.

Another property to be mentioned is that the grid agent takes into account whether generators react to the control values issued. If they do not react, they are incorporated into control for a period of time that can be specified.

The grid agent's architecture is depicted in Figure 5. The agent has three main types of modules that are executed in each control cycle: Set point modules calculate set point values from set point information (electrical quantities and precision information) and ongoing measurements. Control modules calculate control values from set points and measured values. There are several variants of control modules. One variant splits control values to power control values for single generators using power flow calculation. Another variant limits power change rates to acceptable values for generators depending on their operation conditions. Finally, monitoring modules serve the purpose of restricting set point values, e.g. stub currents, to the technical specifications of electrical equipment and generators.

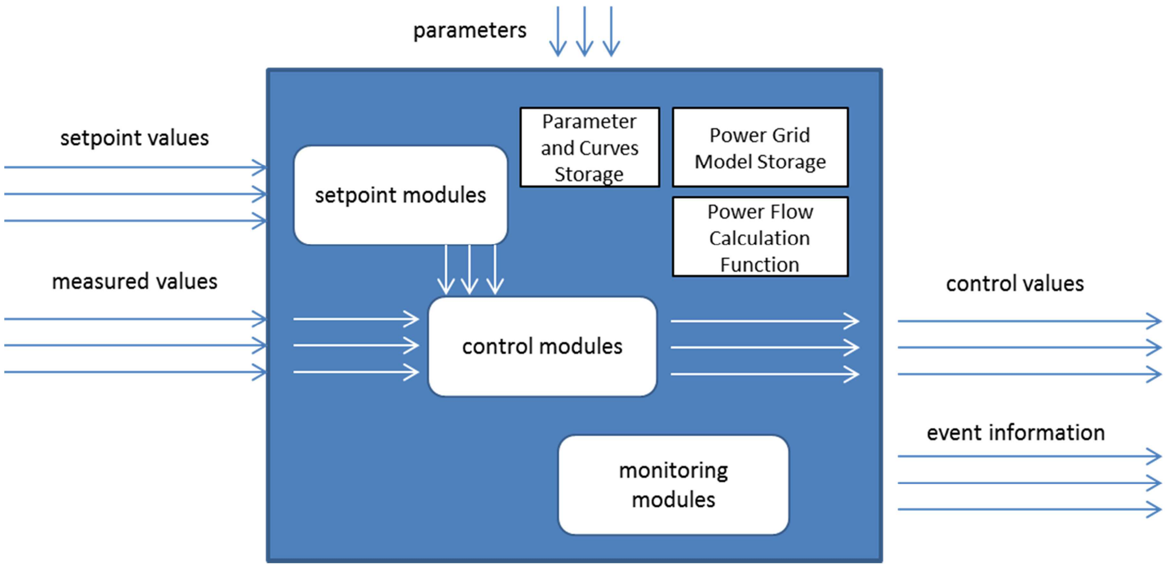


*Figure 5: Conceptual architecture of the Grid Agent*

The control unit software has been designed with universal extendable APIs so that it can be adapted to different execution environments (e.g. embedded PCs, matlab, SCADA systems, the simulation framework MOSAIK [4]) by adapters. A couple of those have already been developed.

The power flow calculation function is used by the control modules and relies upon the power grid model stored in the power grid model storage.

## 5. Convergence between IT and OT and the 5 % Approach

Systems in the energy sector can be distinguished into OT (operational technology) and IT (information technology) [5]. Operational technology is focused on monitoring, supervision, control, and automation; for instance SCADA systems, automatic control units and sensors are considered as OT-systems. Typical non-functional requirements of OT are high availability, 24/7 operation, and redundancy. IT systems provide functions for business, market, documentation, and management that are usually not directly connected to the physical energy system equipment. IT systems are mainly used during office times and typically require less availability than OT systems, and do not typically run on embedded systems. Examples for IT systems are billing systems, GIS (geographic information systems), asset management systems, customer care systems, or energy trading systems. A core element of smart grid architectures (see e.g. [6]) is to connect IT and OT systems, sometimes called IT/OT-Convergence. Most systems that are discussed in the following are systems of the grid operator.

The 5 % approach can be assigned to the OT-domain. We consider it an OT-component because it is a non-market mechanism to continuously operate the grid and to deal with exceptional feed-in situations. While the field test focus is on the electrical principles (i.e., pure OT), several scenarios for IT/OT integration relevant to business and regulatory integration can be identified:

- **Billing:** Billing systems and Meter Data Management Systems (MDMS), both systems of the IT-domain, are involved in the 5 % approach, to implement the financial compensation for the loss of feed-in subsidies. Advanced Metering Infrastructure (AMI) would be suitable to provide billable measurement data about the feed-in (measurements provided by the DER control might be not billable, as it is not measured.
- **Topology:** The 5 % approach requires an up-to-date model of the grid topology (i.e., the model fits to the physical reality in terms of connection and switch positions), as the control units implementing the 5 % approach need to know which and how DER relate to a bottleneck. Typically, a GIS (geographical information system) is the primary software system for static grid topology (graph of nodes such as transformers and edges for electrical connections). Dynamic topology additionally includes current switch positions and is typically held in a DMS (distribution management system). For any topology model based control, it has to be ensured that GIS and DMS are integrated to provide an up-to-date and high-quality dynamic data model. The technical integration of topology models should rely on standards (e.g., from the IEC CIM family [7]) in order to reduce medium- and long-term integration costs, and to avoid a vendor lock-in [8].
- **Providing information to DER operators:** Operators or owners of DER should be informed about current, future and past grid curtailment actions. This can be a regulatory requirement. The information allows them to schedule maintenance to times when the DER is not allowed to feed-in. The Customer Information Systems (CIS), Customer Relationship Management (CRM) and Customer Portals are (potential) systems of the IT-domain that need to be informed about actions that are made by the OT-component implementing the 5 % approach.
- **DER master data:** The non-topological master data of DER, such as address information, installed capacity, and communication parameters, are typically managed by Enterprise Resource Planning or Asset Management systems. As with the topology data model, it is an IT/OT-integration challenge that the data from the IT-systems is up-to-date and of sufficient quality.

A general challenge of these IT/OT integrations is the quality of data (topology data, DER master data) from the IT-systems. The quality level is not always that required for use in critical automatic control systems. Additionally, each connection used for IT/OT integration could be used for an attack against the critical control systems in the OT-domain. Completely separating OT (such as SCADA) from IT would provide security, but “no network connection between IT and OT” is not a realistic option for SCADA systems [9]. Therefore, sophisticated security architectures are required for IT/OT integration. Standardized communication (e.g., using the IEC CIM standard family [7]) can support the security of integration as the exchanged data could be decoded and scanned by a security system that supports the standard.

Besides the IT/OT integration challenges, IT/IT data exchange between owners of different market roles may have to be provided for completely implementing the 5% approach as well. For instance, the correct amount of the billed energy may have to be reported to transmission system operators and further reported to official authorities.

## 6. Conclusion and Further Work

It is the purpose of the described field test to validate the 5 % approach. The next step will be to align the regulatory framework and the 5 % approach and to create solutions allowing distribution grid operators to implement it efficiently, taking into account aspects of integrating OT and IT.

Reliability and maintainability are very important factors for distribution system operation. Their interdependency as well as their dependency upon the degree of centralisation of OT and IT and also their influence on costs are important topics that still have to be looked upon in the context of smart grids.

There are a number of other purposes for control in distribution grids. An interesting topic, still to be researched is the coexistence of control strategies with different aims and for different grid domains. The cooperation or coordination between control units can either be mediated by distribution management systems or take place directly between controllers.

A possible extension to the 5 % approach could be to combine it with approaches with near-future predictions, such as load predictions and feed-in predictions to enable curtailment actions coordinated with energy market action instead of reactive actions. However, it is a real challenge to predict the local feed-in and load for distribution grids, and it needs to be studied whether the potential benefit compensates the risks and costs for dealing with prediction errors.

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# Calculation of current land use for renewable energy in Germany

Nils Koldrack[1]


## Abstract

The energy revolution in Germany is a nationally and internationally highly acclaimed and debated topic. The phase-out of nuclear energy by the end of 2022 opens the door to enter the age of renewable energy. Energy system of the future should be eco-friendly and secure. Currently, Germany is a pioneer of this global development. The implementation of the energy revolution implicates increased space requirements for renewable energy. Thus, particular areas for wind turbine, biogas plants, open space photovoltaic units, hydroelectric power stations and the technical infrastructure are used. The dynamic expansion of renewable energies in all sectors and the rapid expansion and modernization of power grids will change the characteristic landscape of Germany conspicuously. For this reason in this paper the current land use of renewable energy is analysed. The observation of further development asks for appropriate indications and the necessary data bases. One more focus of this paper is to examine the effects of land use for renewable energy to protected resources and landscape features.

As a result the current land use of renewable energy systems is being visualized and analyzed. In concrete terms, a current land use of 180 km² was observed (up to 2012). Thereof open space photovoltaic units take up 60.2 % and thus the most of the area. If required cultivable acreage for renewable resources for biogas plants are included, the current total land requirement is about 28,000 km². This represents about 7.8 % of the area of the Federal Republic of Germany. During investigation it became clear, that there are still significant gaps in the data. Therefore the results may underestimate the real situation.


## 1. Introduction

As part of a Master Thesis [5] which was developed on the Leibniz Institut für ökologische Raumentwicklung (IÖR) in Dresden, the occupied area by the renewable energies in Germany was analyzed. In particular, wind turbines, open space photovoltaic units, biomass plants and pumped storage power plants were investigated.

Installations of geothermal and hydroelectric power plants were also considered, but is not signify because of the small number of plants and land use overall. Solar panels on house roofs were not included, because they are already installed on a sealed surface. Objectives were:

- to ascertain and evaluate the current land use,
- to examine what data bases are available for a current survey,
- to find and close data gaps,
- identify ways of the repetition (monitoring).

## 2. Geospatial localization of land use

For regular monitoring of land use by plants which produce renewable energy a data base is necessary, which is collected as regularly as possible and with a great attention to detail. For this Germany's available spatial data source of the Basis-DLM (ATKIS) of the national survey

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administrations may be one of the best sources. Therefore, the main focus of the investigation lies on ATKIS data. In addition, there are a variety of other data sources that provide such information. It should be emphasized to use only those that are spatially located, or have reference surface and are regularly updated.

It quickly became apparent that from the Erneuerbare-Energien-Gesetz (EEG)-data a good overview of the distribution of the individual plants can be obtained. However, these data are georeferenced by the postal code and some sections (e.g. biogas plants) are also incomplete.

The other data bases are mostly for singular studies or they are only sectorally created or not available for the entire country. In addition the underlying spatial data are often inaccessible.

So far only ATKIS has a good data base for **wind turbines** on mainland. 21,137 plants were performed as point-like objects under the property "AX_BauwerkeOderAnlageFuerIndustrieUndGewerbe" with the value "1220" in the data from the year 2012. With the rapid establishment of turbines throughout Germany, it is almost impossible to achieve an exact number of wind turbines. The Fraunhofer Institute for Wind Energy & Energy System Technology (IWES) stated on 12/1/2012 that in the Federal Republic 23,043 systems have been installed [4]. The Deutsche WindGuard estimated the number at 22,664 on the 7/15/2012 [3]. In the AAA-Model of ATKIS for 40 % of wind turbines under the identification "HHO" (average height of 103.4 meters) the height is given. The federal state of Saxony is the only state that has assigned a height for each facility. Thuringia in turn is the only state, which indicates an area to wind turbines. Approximately for 87 % of the facilities in Thuringia a "primary energy surface" are assigned. The average size amounts to 1,044 m². The Bundesamt für Bauwesen und Raumordnung estimates the land use for each plant similar. It indicates that for a wind power plant an area of 0.1 ha is required. Based on this information an area-based extrapolation could be done.

The Bundesamt für Seeschifffahrt und Hydrographie collects and provides data for offshore wind turbines in the North- and Baltic Sea. In contrast to the data of the onshore data the offshore installations are digitalized as surface geometry. In the German Baltic Sea 7 km² are currently used through offshore wind turbines and only 3.9 km² in the North Sea [1].

The **open space photovoltaic units** are recorded in the ATKIS feature class catalogue in the property "AX_IndustrieUndGewerbefläche" under the identification "PEG 3000" but they have been documented only partially by the federal states so far. 713 open space photovoltaic units are collected in the ATKIS-data in 2012. The data of the EEG of 6/4/2013 implies that 3,288 open space photovoltaic units are distributed in Germany. Since the operators are required to report data like location, capacity and date of commissioning according to §§ 45 and 46 EEG, it can be considered a very good actuality of the EEG-data. Because the information of the EEG-data are not geo-referenced, but include the specific postal code, location and sometimes roads, other data sources (e.g. Geoportal Baden-Württemberg and Brandenburg, Raumplanungsinformationssystem Sachsen) was needed. Furthermore a large part of plants were captured manually with digital orthophotos (DOP) of the Bundesamt für Kartographie und Geodäsie (BKG). Due to the lack of timeliness of aerial images newer photovoltaic units could not be documented. The internet portal "Energy Atlas Bayern 2.0" by the Bavarian State Ministry of Environment and Consumer Protection includes geo-referenced open space photovoltaic units for Bavaria and makes the data available for download. A total of 1,984 plants are maintained [6]. Because the constructions were geo-referenced only as points and not as surface data, the plants were just captured manually as in the EEG-data. Overall 1,470 open space photovoltaic units were collected on this way.

The **hydropower, geothermal and biomass plants** are indeed just as clearly defined in the ATKIS feature catalogue in the property "AX_IndustrieUndGewerbefläche", but also out patchy, as the open space photovoltaic units. The ATKIS-data of 2012 recorded 1,319 hydropower plants with an average area of 3,452.2 m²/plant. However the EEG-data shows that there are 7,449 plants for electricity generation from hydropower in Germany. Seven geothermal plants for electricity production are documented in the EEG-data, while on the other hand ATKIS collects 15 plants which are used for electricity and heat production (Ø 8,286.1 m²). According to the EEG-data in July 2013 14,348 biomass plants are distributed on the area of the Federal Republic of Germany. On the other hand ATKIS lists only 1,397 plants (Ø 1,325.6 m² land use). As in the EEG-data for all plants, the rated power is specified, a method for the approximate calculation of the land use of the required biomass surface was developed as part of the investigation. To answer the question how much land is required to produce 1 MWh/a, the substrate consumption of biomass plants had to be determined. For this purpose, information was used of the operator surveys of the DBFZ from 2012 [2]. On the basis of the average parameters (example: to generate 1 MWh/a with energy crops, an area of 125 m² is required) the land use was calculated. Summarized for all substrates an average of 726.7 m² are required to produce 1 MWh/a. With a current power production of biomass from 36,427,461 MWh/a, area of about 2.6 million ha is needed. This approximate estimate has to take into account, that substrates are also imported from neighbouring states of the Federal Republic of Germany.

## 3. Evaluations for selected types of renewable energy

In the following sections, selected results from Koldrack [5] are presented.

### 3.1. Wind turbines

Nearly a quarter of 21,137 wind turbines have been installed in Lower Saxony (including Bremen 5,129), followed by North Rhine Westphalia (2,809). In the period from 2006 to 2012 Lower Saxony had an increment of 38.8 %, which is immense in view of the already high number of wind turbines in 2006 (3,695). The state of Brandenburg (including Berlin) owns with 79.6 % the second highest rate of growth. Only Saarland has a higher rate (188.5 %). The distribution of the wind turbines per km² (Fig. 1) shows, that North Germany over a wide range has significantly higher values than southern Germany. Along the North Sea and Baltic Sea, there are many counties with a value exceeding 0.11 plant/km². The two counties Emden and Dithmarschen on the North Sea coast of Lower Saxony have the highest values (0.68 and 0.51 plant/km²). In contrast most counties of Baden-Württemberg and Bavaria have mostly a value below 0.025 plant/km².

Extrapolating the average land use of wind turbines of 1,044 m² on the number which depends on the data source (Fraunhofer Institute for Wind Energy & Energy System Technology or ATKIS) a land use between 22.1 km² to 24.1 km² results.

Another method was used to assess the claim of space from a planning point of view. Around each wind turbine, a buffer of 155 m (average height of wind turbines in 2012) was created. The claimed area arises from the common distance space of wind turbines. Because these covered areas deprives other structural measures. With this method, wind turbines cover an area of 794.9 km² in Germany. An analysis of local conditions of all wind turbines in Saxony showed, that 94 % of all plants are installed on vegetation areas (81 % farmland, 16 % grassland, 4 % forest and wooded area, 1 % heaths and 1 % woodland). 4 % are installed on formerly urbanized surface and 2 % on recreational areas.

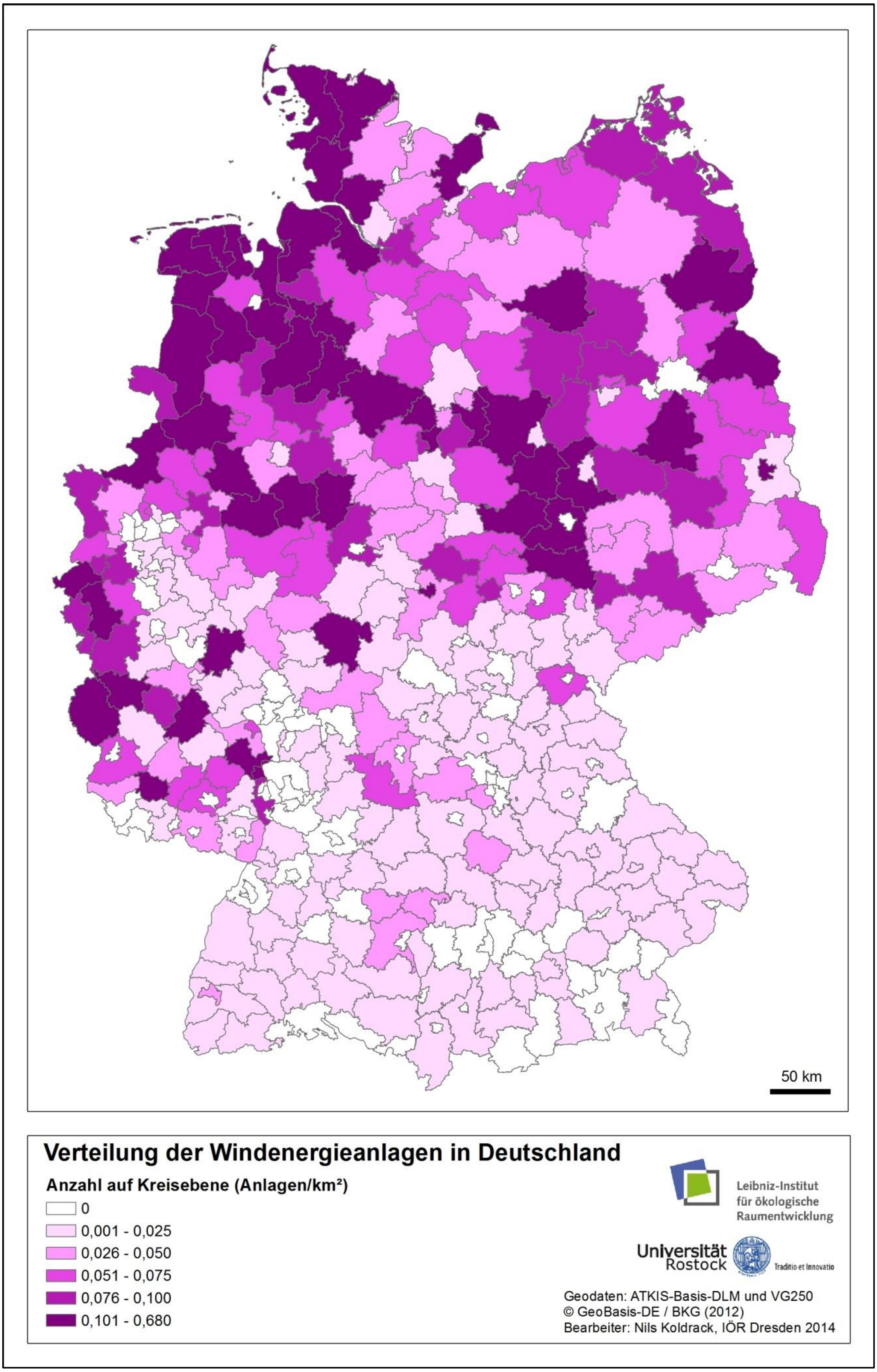


*Figure 1: Distribution of wind turbines in Germany on administrative districts*

### 3.2. Open space photovoltaic units

In distribution of photovoltaic open space units on administrative districts it is conspicuous that most of the 1,470 systems were mainly installed in south and east of Germany. Bavaria protruded with 873 systems, well ahead of Saxony with 145 plants. In the district of Passau on the border to Austria the most systems are installed (59), followed by the district Straubing-Bogen with 33 (Fig 2).

A reason for many abutting districts in Lower Saxony, North Rhine-Westphalia and Schleswig-Holstein, where no open space photovoltaic units were installed, may be the low solar potential in the regions, but also the patchy data base can be a reason for that.

Nationwide, 1,470 plants were recorded, which occupy a total area of 112.8 km². In correlation to the large number of plants in Bavaria the largest surface of photovoltaic units was built (45.9 km²), followed by Brandenburg (18.2 km²). This is remarkable, because in Brandenburg in comparison to other provinces, relatively few systems have been installed (30). In the district of Potsdam-Mittelmark open space systems were installed on an area of 5.5 km². It is the district with largest land use of open space systems, followed by Elbe-Elster district around 4.4 km².

A local analysis at the example of Saxony showed that 26.8 % of newly installed ground-mounted systems were installed on forest and wooded area, followed by grassland (25.2 %) and farmland (18.5 %). Random samples showed that forest and wooded areas are mostly former landfills and mining areas, former barracks or military training areas.

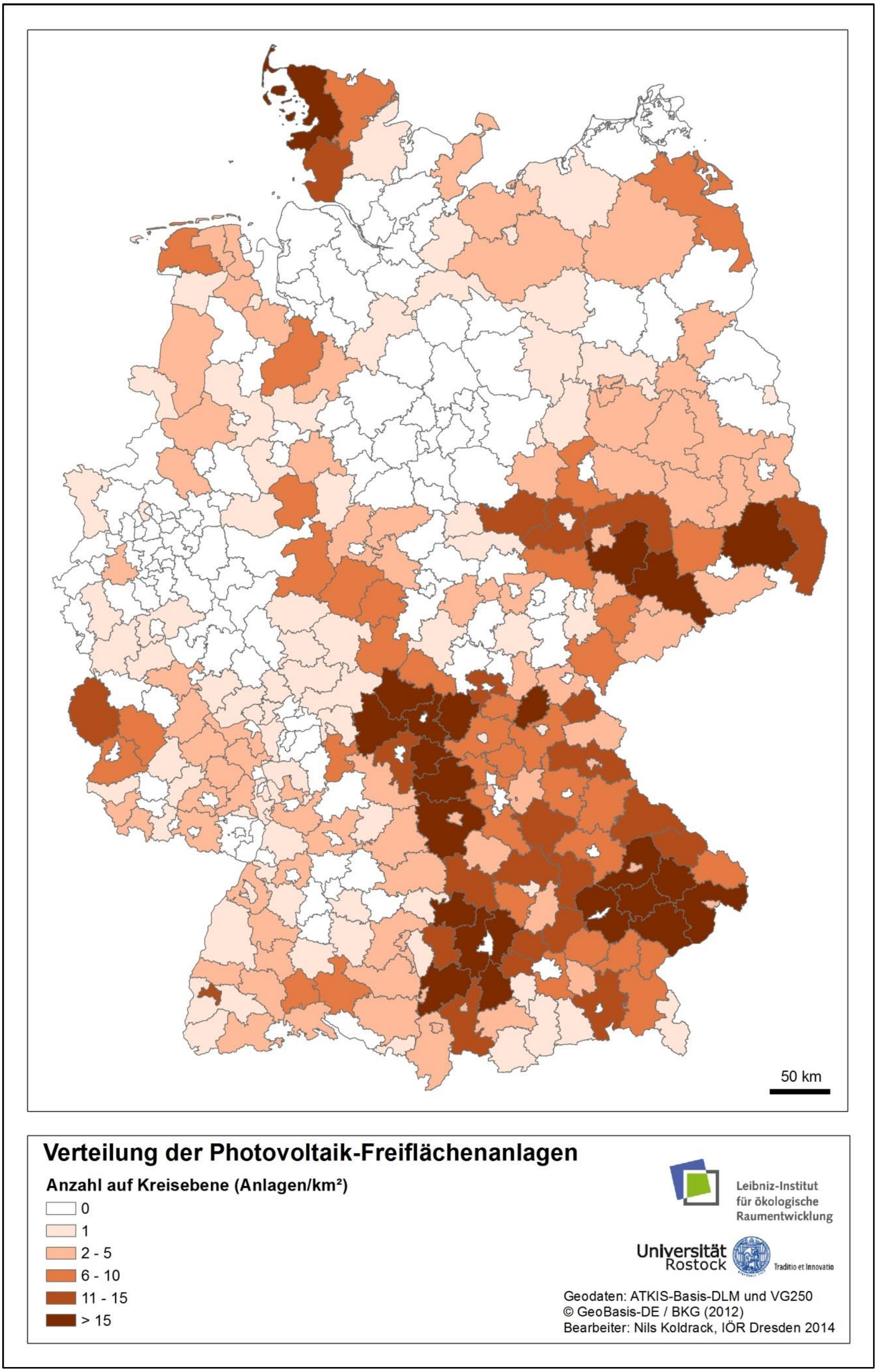


*Figure 2: Distribution of the open space photovoltaic units on administrative districts*

## 4. Results and conclusions

Overall, information for almost 43,000 plants was collected [5]. In the analysis of direct land use through renewable energy installations a total area of 179.2 km² was determined. In the used spatial data, the surface data were mostly documented inadequate or incomplete. Therefore average values for area calculation for wind energy, biomass, hydropower and geothermal plants were used. Therefore a certain span of land use must be considered. By using a confidence interval of 95 % a span of direct land use of 175.8 km² to 188.1 km² results.

In the distribution of direct land use of the facilities for the renewable energy, open space photovoltaic units make up the largest part, followed by the hydropower plants (Fig. 3). If the acreage of biomass is included, this would take 99.3 % of the land to generate renewable energy.

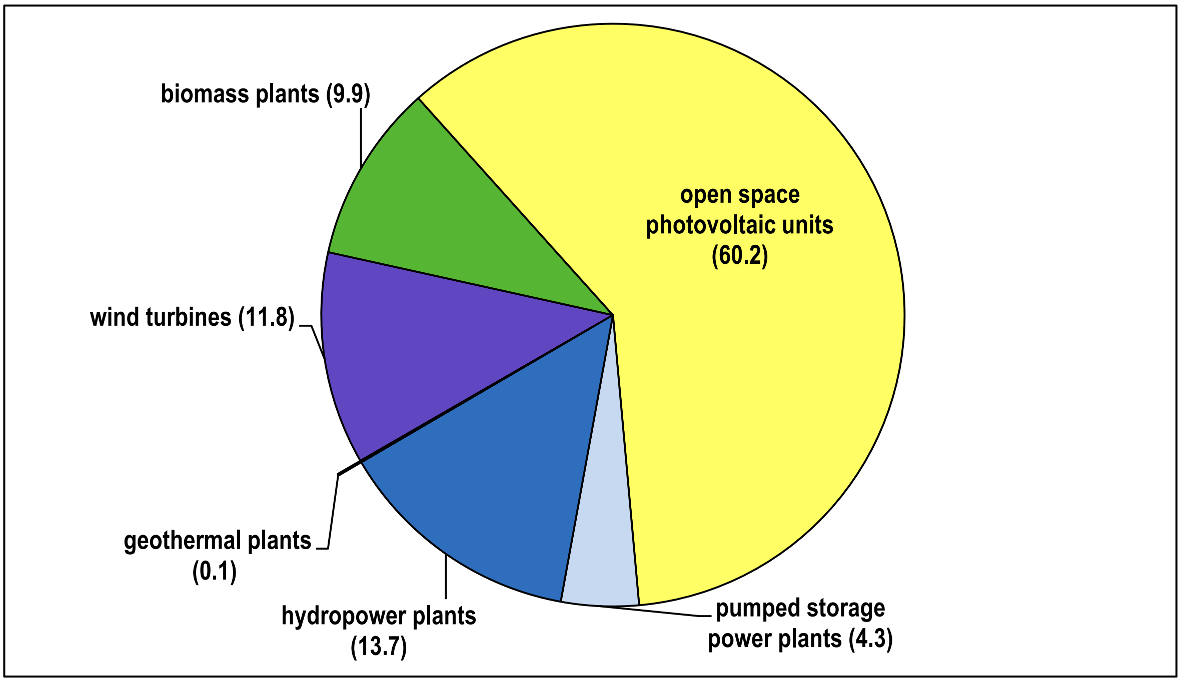


*Figure 3: Percentage distribution of the areas of renewable energy plants in the respective divisions, own evaluation based on data bases: ATKIS basic DLM © Geobasis-DE / BKG (2012), DGS (2013), RAPIS (2013) AROK (2013), GDI-BE/BB (2013)*

For the topicality it can be stated that the renewable energy installations are recognized only incomplete in the current ATKIS data. Wind turbines constitute an exception. The essentials for acquiring the turbines are given in the ATKIS object catalogue of the basic DLM, but they are not sufficiently used by the federal states yet. The cadastre of the regional planning of the individual federal states have not fully adapted to the digital capture of the buildings for renewable energy sources. It would be desirable that countries provide geospatial information for current use or planned construction of such facilities at all levels, as for example in the Raumplanungsinformationssystem Sachsen (RAPIS). An opportunity to ensure a nationwide basic timeliness of plants in the institutions can be, that the offices include the EEG-data. Through the compulsory registration of operators for renewable electricity generation, a nationwide basic timeliness of plants could be depicted. An area calculation with average values could be avoided and an accurate calculation of land use of renewable energy systems will be performed. In view of the importance of the energy transition a current official data source should contain the systems and their area consumption. In this regard, ATKIS is to be well on the way and a continuous monitoring would be possible.

The evaluations demonstrate the significant area requirements for the generation of renewable energy. In particular, biomass cultivation is by far the largest area. Wind turbines and solar fields have only fraction of the land use, but they mark the landscape through their technical character. Information about sites and use of land can be used for further studies, for example, for analysis on the effects on environment and nature. In view of the climate change, a better management for the conversion of energy sources on renewable, sustainable energy, with a suitable data base should be used to minimize the impact on nature and environment.

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# The quality of weather information for forecasting of intermittent renewable generation

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## Abstract

The weather forecasts are affecting different aspects of our everyday life. Nowadays, thanks to many tools and methods we are able to predict meteorological phenomena. It is possible, with a level of uncertainty, to take control over the unpredictability of the future weather conditions. Unfortunately, the predictions of the future meteorological variables are far from perfection, and it is confirmed not only by scientific research but also by every-day experience. Hence, the quality of the weather predictions has to be evaluated. Especially, as this information is critical for numerous sectors, amongst which the renewable energy sector may be distinguished. Nowadays, an accurate prediction of the power output of intermittent renewable energy sources (RES) is highly dependent on weather and climate conditions. Thus, the energy decision- makers have to depend on the quality of the obtained weather information. However, there are no commonly accepted standards that would allow for the evaluation of the quality of information gained from different sources. The aim of this paper is to provide a critical overview of the currently used assessment methods of the quality of weather forecasts. The main focus is put on the methods and criteria for evaluation of weather information that is used for predicting power output from intermittent RES.

## 1. Introduction

Weather forecasting is based on predicting the state of the atmosphere in the future. Nowadays, thanks to many tools and methods we are able to predict meteorological phenomena. Thus, it is possible, with a level of uncertainty, to take control over the unpredictability of the forthcoming weather conditions. Moreover, progress in measuring techniques, computing and information technology had a huge impact on the quality and the usefulness of weather forecasts [17].

The various energy production units, different consumption patterns and the energy system in general have different technical, legal and even behavioural constraints [14]. To plan ahead for the future energy production and consumption, energy specialists, like any other analysts, rely on a system of equations [30]. According to [58], the choice of the appropriate forecasting model relies on four characteristics: the forecast horizon, the availability of historical observation data, the level of data aggregation and finally on the amount and quality of the external information, amongst which the weather and climate information plays a significant role [36]. Unfortunately, as confirmed by both the research and the everyday life experience, the predictions of the future meteorological variables are far from perfection. Often, even the seemingly best weather forecast may prove to be inaccurate when conditions change unexpectedly [28, 32]. Hence, the quality of the weather predictions has to be impartially evaluated. Especially, as this information is critical for numerous sectors, amongst which the renewable energy sector may be distinguished.

An accurate prediction of the power output of intermittent renewable energy sources - RES (especially wind and solar power) is highly dependent on weather and climate conditions. Consequently, the currently used forecasting methods of energy generation are relying on weather forecasts. Thus, the energy operators have to depend on the quality of the obtained weather information. However, the problem of assessing the quality of weather forecasts for the use

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of energy forecasting is very complex. In the context of RES, a number of questions arises: (1)What is the real usefulness of the weather forecasts provided? (2)What is the most appropriate forecasting horizon? (3)How far in advance should the weather forecast for a particular day be published in order to be useful and reliable for forecasting RES output? (4)What are the sector relevant measures of the quality of the weather forecasts?

The paper is structured as follows. Section 2 presents the general weather information quality terms. Additionally it provides a critical overview of the currently used types of forecasts and methods of their quality assessment. Section 3 focuses on the topic of how significant is the weather information in renewable energy sector. Moreover, it addresses the forecasting horizons and their operational usability in the context of weather and climate variables that influence the RES performance. Section 4 discusses the information attributes relevant to the quality assessment of weather forecast and the needs of the renewable energy sector. The main findings are summarized in the concluding Section.

## 2. The weather information and its quality

### 2.1. The quality of information

ISO 8402 standard defines the quality term as all features and characteristics of a product or service used to satisfy identified or anticipated needs [44]. In this sense, the quality of the information should be understood as the satisfaction degree of the user requirements. Therefore, quality should be estimated from the perspective of the needs of the entity, which relies on it. Thus, it is necessary to specify the information recipient [1]. The latter is the one that imposes his requirements, and determines the manner in which information can be evaluated. This involves determining the quality of information by using the evaluation of attributes (features) connected to the information. In the literature, one can find many attempts to define the attributes of information [23, 43, 62]. However, these publications do not differ significantly from one another. The differences arise mainly from the fact that there are various configurations in the set of features or different names for information attributes are used, but in fact they are understood similarly. It is worth to emphasize that even the information itself, due to the widespread use in various fields of science and life, does not have a common definition. It is also assessed differently depending on the context of its application.

In general, the quality of information may consist of many elements, such as its reliability, timeliness, security, usefulness etc. Nevertheless, there are no commonly accepted standards that would allow for the evaluation of the information quality [23]. Section 2.2 provides a critical overview of the currently used types of forecasts and methods of their quality assessment.

### 2.2. Forecast types and verification methods

According to [51] data used in forecasting may occur in various types (nominal, ordinal, interval and ratio). Moreover there are different forecasting methods that can be applied to generate the prognosis. These forecasting approaches can be divided by their nature, space-time domain or specificity. Table 1 presents a classification scheme, proposed by [32], of verification methods assigned to a particular forecast type and grouped by three aforementioned categories.

| Category | Forecast type | Appropriate verification methods |
|---|---|---|
| nature of forecast | deterministic | visual, dichotomous, multi-category, continuous, spatial |
| | probabilistic | visual, probabilistic, ensemble |
| | qualitative | visual, dichotomous, multi-category |

| | | |
|---|---|---|
| space-time domain | time series | visual, dichotomous, multi-category, continuous, probabilistic |
| | spatial distribution | visual, dichotomous, multi-category, continuous, probabilistic, spatial, ensemble |
| | pooled space and time | dichotomous, multi-category, continuous, probabilistic, ensemble |
| specificity of forecast | dichotomous | visual, dichotomous, probabilistic, spatial, ensemble |
| | multi-category | visual, multi-category, probabilistic, spatial, ensemble |
| | continuous | visual, continuous, probabilistic, spatial, ensemble |
| | object- or event-oriented | visual, dichotomous, multi-category, continuous, probabilistic, spatial |

*Table 1: A classification scheme for forecast verification methods.*

According to Table 1 there are seven categories of verification methods: visual, dichotomous, multi-category, continuous, spatial, probabilistic and ensemble. Apart from their applicability to the specific forecast type, it worth to examine both pros and cons of these approaches. Visual or "eyeball" verification methods are one of the simplest. Among others, time series plots, maps, histograms, box plots, scatter plots, reliability diagrams can be distinguished. These methods are based on a human judgment during graphical comparison of presented forecast and observations. Main advantage of this group is that they provide the simplest way to quickly verify the model accuracy. However, this approach is not quantitative and thus there is a room for individual interpretations and subjectivity. As such, these are the biggest disadvantages of the visual verification methods.

The next groups - dichotomous and multi-category verifications can be described together since both are using contingency tables and dichotomous contingency tables. As the latter is a special case of a multi-category verification table. The contingency table method is based on a table where the frequency of forecasts and observations are placed in the appropriate cells [39]. Each row and column represents one of the category (in dichotomous contingency table case categories are "yes" and "no") [38]. In general it is easy to diagnose the nature of forecast errors, but it is difficult to summarize the error by using "one number method". Luckily, there are many statistics that can be used to evaluate error in the contingency table, such as: accuracy, Heidke skill score, Hanssen and Kuipers discriminant, Gerrity score, bias score, probability of detection (hit rate), false alarm ratio and many others [6, 50].

The most commonly utilized verification methods belong to the continuous variable verification category. These approaches are: mean error, multiplicative bias, mean absolute error (MAE), root mean square error (RMSE), mean squared error (MSE), absolute mean percentage error, linear error in probability space, stable equitable error in probability space, correlation coefficient or anomaly correlation [50]. During the error interpretation it is widespread to use just two methods - MAE or RMSE, rather than MSE. The former two are measured in the same data units as the observational data. Thus, it is easier to interpret their scores unlike to the MAE approach. Also, the RMSE is better than MAE if we want to put an emphasis on the forecast outliers, but in few studies this method is criticized due to this feature [3, 65]. Two atypical verification methods: correlation coefficient and anomaly correlation are usually used to check the linear association and phase difference between observations and forecasts. These methods are sensitive to outliers, but say nothing about forecast bias [21, 64].

Another category is based on a probabilistic verification methods. The probabilistic forecast is in fact a value between 0% and 100%. The usefulness of this method can be observed only when there is a significant amount of probabilistic forecast generated [50]. From the probabilistic category we can distinguish brier score, brier skill score [37], relative operating characteristic [34], ranked probability score, ranked probability skill score and relative value [45].

The spatial and ensemble verification methods form the last category. Among many others, such approaches may be distinguished: intensity-scale verification [9], discrete cosine transformation [12], fraction skill score [46], spatial multi-event contingency table [4], neighbourhood verification method [15], CRA verification [16], method for object-based diagnostic evaluation [7], cluster analysis [33], displacement and amplitude score [24], correspondence ratio [52], likelihood skill measure, Nash-Sutcliffe efficiency coefficient [41], alpha index [25], quantile-based categorical statistics and many others [50]. In the following sections the focus is put on the significance of the weather information in a particular energy sector – renewable energy. Moreover, the attributes of weather forecasts quality are identified and the appropriate verification methods proposed.

## 3. The significance of weather information in renewable energy sector

The irregular production of electricity in RES and their constantly increasing integration with the power grid is currently being one of the major challenges for the energy system operators. It is a known fact that the process of generating energy from this sources is random and problematic in the face of maintaining the security of the network.

The crucial requirements towards RES power forecasting are defined by the forecast horizons that determine the operational, practical usage of the forecasts and are demanded by the electricity value chain participants. Table 3 presents the most commonly industry-requested forecasts.

| Forecast horizon | Granularity | Operational usability |
|---|---|---|
| Intra–Hour: 15 minutes to 2 hours | 30s to 5 min | Management of variability and ramping events |
| Hour Ahead: One to max 9 hours | Hourly | Transactions on intraday energy markets, load following forecasting, congestion management |
| Day Ahead: One to 3 days | Hourly | Operational planning, switching sources, short-term power purchases, reserve planning, system balancing, programming backup, ancillary services |
| Medium-term: 7 days to max 2 months | Daily | Plant optimization, risk assessment, congestion management |
| Long-term: One to more years | Monthly and annual | Targeting return on investments |

*Table 2: Forecasting horizons in renewable energy sector (general approach) and their operational usability [26, 28, 32]*

Undoubtedly, the most important forecasting horizons for managing the RES output are the hour and day ahead time spans. It might be said, with a great deal of confidence, we may say that the most valuable weather forecasts are in situ and remote observations. Apart from the time horizon, an accurate prediction of the power output of intermittent RES is highly dependent on weather conditions (wind speed, wind direction, radiation, cloudiness, storms etc.). Consequently, the currently used forecasting methods of energy generation are relying on weather forecasts and climate predictions. It is worth to mention that weather attributes are highly dependent on the geographical localization. Table 3 summarizes the dependencies between RES technology and main meteorological variables that have an effect on the amount of generated power.

| Renewable energy source | Weather / climate variable |
|---|---|
| Solar power | Radiation affected by latitude and clouds, air temperature |
| Wind power | Wind speed, wind direction, wind gust, icing, storms |
| Hydropower | Precipitation (rain, snow), evaporation, surface slope, air temp. |
| Biomass power | Temperature, precipitation, insolation |
| Wave and tidal power | Wind |

*Table 3:Weather and climate variables influencing the RES performance.*

The energy forecasting of the specific time scales, presented in Table 2, and the relevant weather variables distinguished in Table 3, imposes various requirements to the applicable data sources, weather forecasting models, forecasting techniques that can convert available data into high quality RES power forecasts [26, 28]. In general, the weather forecast can be derived using such techniques like Numerical Weather Prediction (NWP), statistical models, satellite-based forecasting or total sky imager–based cloud cover (Sky Image Processing in general), discussed in detail in [17, 28, 58].

## 4. The characteristics of the weather forecasts' quality and its value for the renewable energy sector

The issue of quality assessment of weather information was widely discussed in meteorology. Throughout the years, a variety of evaluation techniques has been developed and applied [19, 21, 32, 56, 57]. Due to the number of forecast quality measures, in order to avoid confusion, their use must be obvious, easy to calculate and their statistical significance should be testable [56]. In the book [21] one can find a detailed list of common assessment metrics with full discussion of their advantages and limitations. Mailer et al. [32] pointed out that the literature on assessment of forecast quality is largely written to meet the needs of forecasting models developers. However, the evaluation of the quality of weather forecasts in the case of various sectors and users is still to be performed.

Referring to the forecast verification methods presented in Section 2.2., it can be said that renewable energy sector has to use such methods to determine the forecast quality. For example, in the case of wind speed forecasting the most commonly used verification methods are root mean squared error [48, 49, 59, 63] and mean absolute error [5, 20, 40, 47]. In many studies both methods are used and compared, because of the RMSE advantage and disadvantage at the same time – outliers sensitiveness. Equally often the mean absolute percentage error (MAPE) is used in different studies [27, 29, 59, 63]. This method has the such advantage that it abstracts from data units and it is easy to compare different research results. In some studies another verification methods are used like brier score [2], but less frequently than other methods. The situation looks very similar in the case of solar radiation forecasting, scientist mainly use mean absolute percentage error [11, 42, 53, 54] and RMSE verification methods [11, 18, 42]. In noticeably smaller number of studies was used mean square error or mean absolute error [53, 60]. Some researchers use the less popular methods such as ranked probability score or contingency table, but always with support of more popular verification methods [55, 60]. What is interesting, almost no one is using more advanced verification methods for spatial forecasts, generally in that case MSE or RMSE are used with support of the visual methods.

Having in mind the applicability of different forecasts' verification methods commonly used in the renewable energy output forecasting, we can know characterize the main attributes of a weather information. Out of the set of information attributes, mentioned in Section 2.1, we have distinguished these relating directly to the characteristics of weather forecast and the needs of decision-makers from the renewable energy sector. Table 4 presents the relevant attributes of information and their short description.

| Information attributes | Description |
|---|---|
| Completeness | Information is complete if it is reliable and useful. Completeness of information does not mean that all needed information is given in a specific situation. In other words, the scope of the information should be relevant to the problem [1]. |
| Accuracy | Information accuracy decides whether the information is accurate and convergent enough with reality. The consumer must find the data accurate. For example, the data should be correct, objective and come from reputable sources [62]. |
| Correctness | It is strongly linked to accuracy of information. Correct information should be free from errors, mistakes and distortions. It should not be biased. |
| Timeliness | Timeliness is connected with the information subject which is up-to-date if it describes the present (or last possible to identify) state of some reality. Timeliness may refer to the time when information is received by the recipient or the state of reality when it was created [1]. Information should not be outdated or obsolete. |
| Relevancy | Relevancy is the information validity assigned to it by the user. Thus, information relevance depends on the user. Therefore, it is a subjective quantity. It can be considered on four dimensions: temporal, personal, geographical and economical [1]. |
| Utility | Information is useful if it meets the needs of the recipient. Utility is connected with the recipient, not the sender. Therefore, the same information may be useful for some recipients, and for others – useless. Moreover, the same information may be useful for some recipient in certain circumstances but in others not [1]. |

*Table 4: Attributes of information relevant to quality assessment of weather forecast and the needs of renewable energy sector*

Attributes listed in Table 3 allow for measuring and estimating the information quality. According to [21] these measures must be defined, so they can be quantified. It should be remembered that the overall quality is affected above all by the quality of the data, which is used to forecast the weather, local dependencies and ground limitations.

It is worth to empathize that no single verification measure provides complete information about the product quality [56]. Moreover, the literature shows that not always good quality of weather forecast reflects in a simple manner on its value to the users [31]. There are also different studies showing how various information attributes can affect the forecast value for the user [26, 31, 35]. According to Milligan et al. [35] the most accurate forecast gives the highest benefit from the power resource, but improving accuracy to 100% declines marginal benefits. On the other hand, the forecast accuracy strongly depends on the local conditions at the forecast site [26] and surprisingly the biased forecasts could be more valuable to the power generator than unbiased ones [31] depending on a type and time of day on power markets. Therefore, the importance of “fitness for use” concept that is also widely adopted in the quality literature [10, 13, 22, 62] should be emphasized. Having that in mind, we have decided to take the consumer “fitness for use” in the conceptualization of the underlying aspects of weather information quality.

## 5. Conclusions

Even though the energy sector is one of the major users of weather information there are still changes that should be made to better meet the consumer needs and to achieve the highest possible quality of the weather predictions.

In this paper we focused on the quality of the weather information and its impact on the RES forecasting. The findings from the critical literature review have led us to a place where we can undoubtedly say that despite many attempts no standardized approach towards assessing the real quality of the weather forecasts has been yet introduced. There are actually three mainly used methods to validate the quality- RMSE, MAPE and MSE. However, the accuracy of prediction which may help evaluate the offers of the forecast service companies is actually a matter of subjectivity. Therefore, apart from different attributes that can describe the quality of the weather information, there is one particularly important – utility. As such we can define “quality of weather information” as the fit for use by information users, in our case: the decision-makers from the renewable energy sector.

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# The Impact on Human Health and the Environment of Different Types of German and Polish Power Plants: A First Scoring Approach in Germany

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## Abstract

This paper gives a short overview about the types of power stations in Germany and Poland. The energy production in Germany in 2012 was 629,7 TWh. Every type of power plant poses a risk to humans and the environment but in a different way and to a different extent. A discrete mathematical method, named Hasse diagram technique is applied. The software package used is the PyHasse software. A first ranking approach is presented taking the 8 most used types of power plants in Germany into account and ranking those applying 5 different evaluation criteria, including 3 environmental health attributes. In this first approach not only nuclear power stations but also coal-driven power stations come worst in this ranking method. Renewable energies come best in our approach. Unfortunately their percentage of the overall energy production is still too low (about 22,1 % in Germany and 10,4 % in Poland). This underlines the necessity for urgently supporting the development of renewable energy power plants. Furthermore, we plan to extend our scoring approach to other European countries, starting with the neighboring country Poland.

## 1. Introduction: Energy Use

Energy use is central to human society and provides many health benefits. But each source of energy entails some environmental and health risks. In a review article, entitled Energy and Human Health [1] it is stated that the largest acute health impacts of today's energy systems come from the extraction and combustion of solid fuels. Nuclear energy has a small direct impact but moreover a serious genetic impact concerning the waste and fatal impact concerning possible accidents [2]. Coal is the major energy source worldwide (25 %). Nuclear energy supplied around 11 % of the global energy production in 2011. Human-engendered climate change, which is largely but not entirely caused by energy use, is already imposing health impacts. Environment and health impacts from renewable energy sources are likely to be much smaller than those from classical energy sources.

### 1.1. Energy Mixture in Germany

The mixture of energy in Germany for the years 1990 and 2012 is given by the Umweltbundesamt in Dessau [3]. Both the gross power generation as well as the power consumption has been increasing since 1990 in a continuous way (exception 2009). The amount of renewable energies has been continuously rising since 1993 with one exception in 2009. Since 2003 the gross power consumption has been constantly lower than the gross power generation. The surplus is exported. Germany is still heavily depending on coal (soft coal and hard coal), and nuclear energy. Renewable energies comprised 22 % in 2012.

We distinguish among: Classical energy sources: Soft coal (lignite, brown coal), hard coal (stone coal), natural gas, nuclear energy, mineral oil product, Renewable energy sources: Photovoltaic energy, wind energy, biomass, water energy (running-water power station), municipal waste, and

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others. The Arbeitsgemeinschaft Energiebilanzen [4] lists on its Website the latest energy production data which are given in Table 1. We specify the energy sources together with the given acronym used in in our data evaluation approach later. We take the 2012 data into account as the 2013 data were not final ones at the date of our evaluation.

*Table 1: Energy Sources Germany: Gross Power Generation 2012: 629,7 TWh*

| **Energy Sources** | **Abbreviation** | **Portion of TWh 2012** | **% 2012** |
|---|---|---|---|
| Biomass | BIO | 39,7 | 6,3 |
| Mineral oil products (fuel oil) | FOI | 7,6 | 1,2 |
| Natural gas | GAS | 76,4 | 12,1 |
| Hard coal (stone coal) | HCO | 116,4 | 18,5 |
| Municipal waste | MWA | 5,0 | 0,7 |
| Nuclear energy | NUE | 99,5 | 15,8 |
| Others | OTH | 25,5 | 4,1 |
| Photovoltaic energy | PHO | 26,4 | 4,2 |
| Soft coal (lignite) | SBC | 160,7 | 25,5 |
| Water energy | WAE | 21,8 | 3,5 |
| Wind energy | WIE | 50,7 | 8,1 |
| **Sum** | | **629,7** | **100 %** |

## 1.2. Energy Mixture in Poland

The main prime energy source in Poland is hard coal and lignite (soft coal), which cover 56% of the demand. Crude oil also has a significant share of 25%. Even to maintain current levels of energy generation, Poland needs to invest huge amounts into energy generation capacity (between 41 billion and 98,5 billion € by 2020 and factually upgrade or redesign its entire energy system as almost 85% of electricity is produced from coal and furthermore, two thirds of the installed coal capacity is older than 30 years and almost 20% (7 gigawatt) of the current generation capacity have to be phased out by 2015. Poland plans to have nuclear power from bout 2025 as part of an energy portfolio, moving away from heavy dependence on coal and imported gas [5]. However, a positive trend in the growth of the renewable energy sector in Poland can also be observed. The most important source is wind energy. According to Energy Regulatory Office (URE), in 2012, there existed 663 wind plants in Poland of a total capacity of 2341 MW. Most wind farms are located in north-western Poland, not far from Baltics sea. The current share of wind energy in total renewable electricity of origin is 57.6%. It ranked first among renewable energy sources already in 2009. Currently about 40 % of the Polish electricity from renewable source is produced from biomass while a third comes from co-incinerating biomass in coal-fired power plants. Increasing support for the alternative technologies will lead to new opportunities to develop projects at industrial locations that produce large amounts of biomass. The large share results in Poland’s significant biomass potential and its large share of coal power plants that generate about 90 % of Poland’s electricity. By using this existing infrastructure, Poland was able to significantly increase its share of renewable energies in just a few years. Today, 30 of the 39 Polish coal power plants are co-incinerating biomass. Biomass energy power plants were analyzed for the years 2001-2010 by Budzianowski [6].

The development of renewable energy is strongly encouraged in Poland via support through a system of green certificates. Unfortunately, the amount of green certificates issued per unit of produced renewable electricity is not associated with the type of renewable energy technology. Therefore, the existing energy policy system inhibits the development of some renewable technologies, even if they have attractive potentials for sustainable electricity production in the near future [7]. The Polish Ministry of Economy plans to change the system of green certificates. The most supported power technologies in Poland will be bioenergy and wind energy. The number of issued green certificates is to decrease with increasing output power of a plant thus the modified system will stimulate the development of distributed renewable power systems. In Table 2 the current situation of the Polish energy mix is given in electricity production (http://www.rynek-energii-elektrycznej.cire.pl/st,33,207,tr,75,0,0,0,0,0,podstawowe-dane.html).

*Table 2: Energy Sources Poland: Electric Power Generation 2012: 161,7 TWh*

| **Energy Sources** | **Abbreviation** | **Portion of TWh 2012** | **% 2012** |
|---|---|---|---|
| Biomass | BIO | 10,09 | 6,2 |
| Mineral oil products (fuel oil) | FOI | 3,9 | 2,4 |
| Natural gas | GAS | 6,3 | 3,9 |
| Hard coal (stone coal) | HCO | 80,6 | 49,7 |
| Nuclear energy | NUE | - | - |
| Photovoltaic energy | PHO | - | - |
| Soft coal (lignite) | SBC | 54,1 | 33,3 |
| Water energy | WAE | 2,0 | 1,3 |
| Wind energy | WIE | 4,7 | 2,9 |
| **Sum** | | **161,7** | **100 %** |

## 2. Urgent Need for Comparative Energy Sources Evaluation

We are of the strong opinion that a scientific approach, e.g. ranking the types of different power stations with criteria of general importance, like the availability of the energy source in Germany, the everyday availability, as well as environment and health criteria: $CO_2$ emissions, impact of accidents in the power station on human health and the environment, and waste disposal is of great interest. Usually only one criterion is considered in the political and scientific discussion.

### 2.1. Types of Energy Sources in Germany

The current energy resources in Germany are taken into account as objects to be ranked by the above-mentioned criteria. The basis for our evaluation is generated by the official statistical data for the gross energy production in Germany for 1990 till 2013 [4], (see Table 1). Every energy source poses a risk for human health and the environment. A comprehensive listing of the risks would surpass the scope of this paper. That is the reason why we only quote a few examples. Further reading is recommended, e.g. in Smith et al. [1]. While access to electricity affects health positively, combustion of coal in power plants causes well-documented adverse health effects. A review study of respiratory, cardiovascular, reproductive, and neurologic health outcomes associated with exposure to coal-fired power plant emissions is presented by Buchanan et al. [8]. An article published 2007 in the medical journal, *The Lancet,* summarizes the burden of the health effects of generating electricity from coal and lignite (a type of coal). The authors estimate that for every TWh (Terrawatt-hour) of electricity produced from coal in Europe, there are 24.5 deaths, 225 serious illnesses including hospital admissions, congestive heart failure and chronic bronchitis, and 13,288 minor illnesses. When lignite, the softest and most polluting form of coal, is used, each TWh of electricity produced results in 32.6 deaths, 298 serious illnesses, and 17,676 minor illnesses [9]. Comparison of different forms of commercial power generation by use of the fuel cycle methods developed in European studies shows the health burdens to be greatest for power stations that most pollute outdoor air (those based on lignite, coal, and oil). The topic of mercury emissions from coal-fired power plants in Poland was investigated by Glodek and Pacyna [10]. The direct health burdens are appreciably smaller for generation from natural gas, and lower still for nuclear power. This same valuation also applies in terms of greenhouse-gas emissions and thus, potentially, to long-term health, social, and economic effects arising from climate change. The negative effects on health of electricity generation from renewable sources have not been assessed as fully as those from conventional sources, but for solar, wind, and wave power, such effects seem to be small; those of biofuels depend on the type of fuel and the mode of combustion. Wagner et al. [11] compared the $CO_2$ emissions from different kinds of energy production sources. The impact of nuclear power plants on the environment and human health has been studied extensively. Short-term and long-term health risks of nuclear-power-plant accidents are commonly known and well-documented in numerous papers. A review article is recommended for further information [12]. Scherb / Voigt [2] could demonstrate the impact of running power plants on the environment and human health by evaluation the change in the sex ratio near nuclear power plants in Germany and Switzerland. Not only the conventional energy sources but also the renewable energy sources have an impact on the environment and human health. For biomass power plants a recently published paper named the health problems for nearby residents [13]. Also wind turbines pose a health risk being a new noise source. A review on the health effects of wind turbines has been published [14].

Concerning the disposal of waste from different sources of energy production only the waste disposal of radioactive waste poses a major problem which has not been solved to a satisfactory extend for the world’s population. Birkholzer et al. [15] provide an overview of current waste disposal approaches, scientific issues, and safety assessments related to mined geologic repositories for high-level radioactive waste.

## 2.2. Chosen Evaluation Criteria for Energy Sources

Apart from the environmental and human health criteria concerning the air, water, soil pollution of power plants with not only $CO_2$ emissions but also with particular matter emissions and other dangerous chemicals and the extremely important criterion of the waste disposal, especially for radioactive waste, impact of accidents in the power stations, other criteria of general importance, like the availability of the energy source in a country, the everyday availability play an important role. All criteria are to be looked upon at the same time in this first scoring approach (see Table 3).

*Table 3: Ranking/Evaluation Criteria for Energy Sources Germany*

| Criterion | Abbreviation |
|---|---|
| Availability every day: yes/no | AAT |
| Availability in Germany: yes/no | AVG |
| $CO_2$ emission (high/medium) | COE |
| Impact of Accidents | IOA |
| Waste disposal | WAD |

### 2.3. Ranking Method and Software: PyHasse

Concerning the data evaluation of energy sources, we apply an appropriate ordinal data analysis method to find out conformities and differences in data sets. This is a discrete mathematical method named Hasse diagram technique and is explained in detail in Bruggemann/Patil [16]. The software package used is the PyHasse software. This software is written in the programming language

Python by Dr. Rainer Bruggemann (brg_home@web.de) and is under constant development. PyHasse comprises several modules which are of great support also in the ranking of energy sources by general as well as environmental and health aspects.

## 3. Ranking of Different Types of German Energy Sources

For our comparative evaluation we take 8 of the 11 sources listed in Table 1, leaving out other sources, mineral oil products, and municipal waste incineration. We use two general evaluation criteria AAT (Availability every day: yes/no) and AVG (Availability in Germany) and three environmental and human health criteria COE ($CO_2$ emission), IOA (Impact of accidents) and WAD (Waste disposal), listed in Table 3. In this first approach we determined the following scores: 2= negative, 1= medium. The Score 0=no effect on the environment and humans is not provided, as to our knowledge there does not exist a single energy source with no impact. It is evident that this 1, 2 scoring approach is rather broad and does by no means fully take into consideration the vast scope of impacts of energy sources. The scores are listed in Table 4 and their graphical evaluation is displayed in Figure 1.

*Table 4: Given Scores for Energy Sources Germany*

| **Energy Sources** | **AAT** | **AVG** | **COE** | **IOA** | **WAD** |
|---|---|---|---|---|---|
| BIO | 1 | 1 | 1 | 1 | 1 |
| GAS | 1 | 2 | 1 | 1 | 1 |
| HCO | 1 | 2 | 2 | 1 | 1 |
| NUE | 1 | 2 | 1 | 2 | 2 |
| PHO | 2 | 1 | 1 | 1 | 1 |
| SBC | 1 | 1 | 2 | 1 | 1 |
| WAE | 1 | 1 | 1 | 1 | 1 |
| WIE | 2 | 1 | 1 | 1 | 1 |

The corresponding Hasse diagram is given in Figure 1.

A Hasse diagram visualizes so-called partially ordered sets (posets). As demonstrated in Figure 2 a partial order is given and not a linear order. HDT is appropriate for comparative evaluation of objects, in this case different types of power plants when a multi-criteria assessment is envisaged; here several criteria are of importance. All objects which are connected by a line are comparable, e.g. NUE, GAS, BIO=WAT, whereas for example NUE and PHO are incomparable. The comparabilities and incomparabilities are given by the PyHasse program along with the number of equivalence classes (equivalent objects). BIO and WAE are equivalent objects. In this diagram we have maximal objects, HCO, NUE, PHO=WIE. These are the worst types of energy sources in our approach.

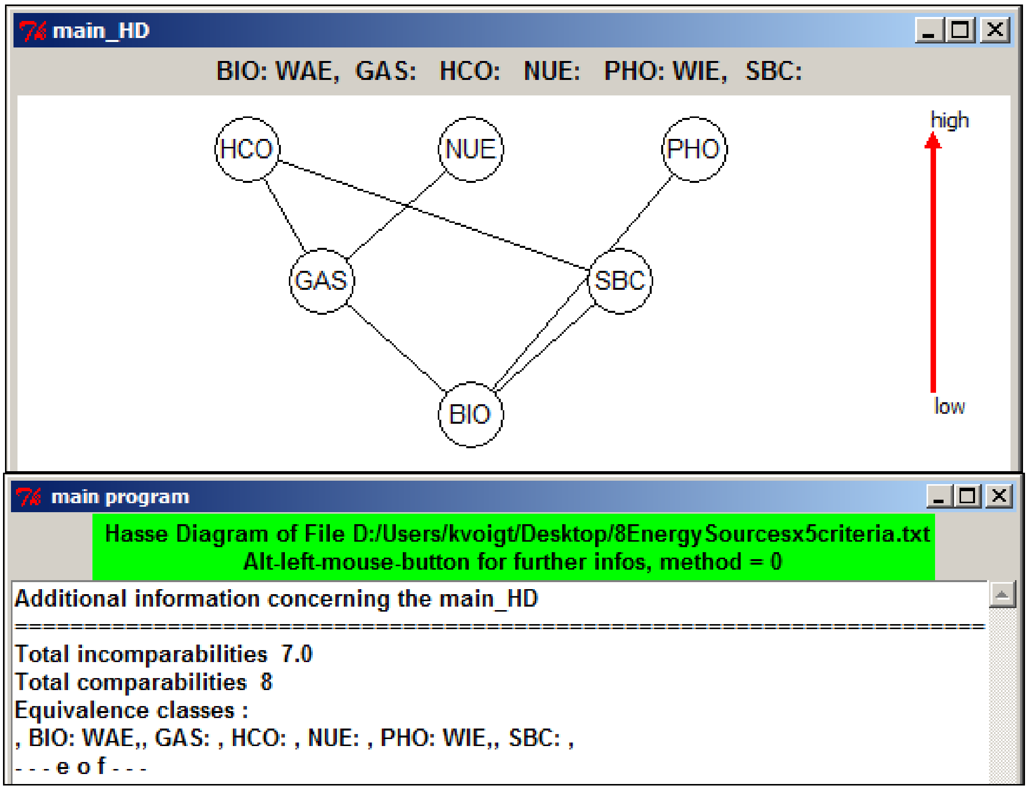


*Figure 1: Hasse diagram for 8 types of power plants in Germany evaluated by 5 criteria*

The best or rather the better sources are the minimal objects, namely BIO=WAE. The renewable energy sources biomass and water energy have the best results. Unfortunately these two energy sources only have a percentage of 10 % of the German power plants. Why do solar and wind energy are maximal objects? They receive a high 2 score in the criterion availability every day. Soft coal (brown coal) has a middle position in this Hasse diagram. It is better than hard coal and worse than BIO=WAE. While Germany imports high amounts of hard coal, the country mainly uses the own soft coal resources [17].

All criteria receive the same importance in this approach. It is now possible to perform the Hasse data analysis taking only the environmental criteria COE, IOA, WAD into account or calculating the Hasse diagram for only the general criteria, namely AAT and AVG. Figure 2 shows the results. On the left hand side the Hasse diagram for the environmental criteria is displayed and on the right side the one for the two general criteria.

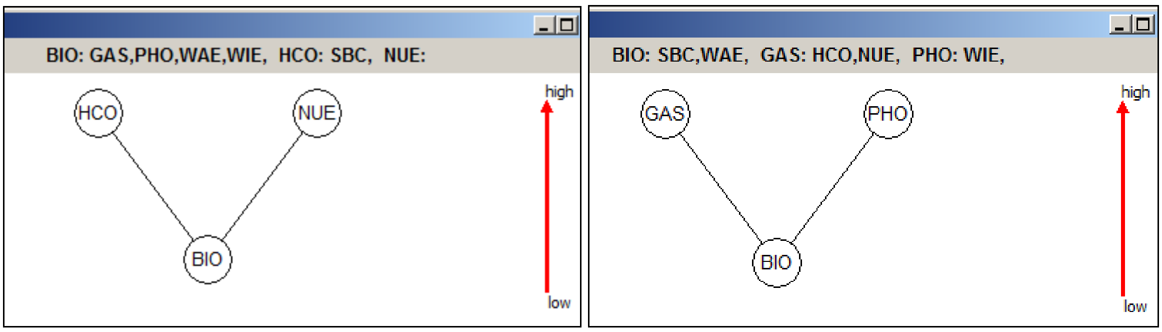


*Figure 2: HDs for 8 types evaluated by 3 environmental (lhs) and 2 general criteria (rhs)*

Taking a closer look at the Hasse diagram showing the environmental criteria, we see that HCO is equivalent with SBC, that is to say both coal types are maximal objects, which have a high impact on the environment and human health. NUE is a maximal object and comparable to BIO=GAS, PHO WAE, WIE. These are minimal objects.

The Hasse diagram for the two general criteria shows a different situation. BIO and WAE are again the best types of energy sources, but also the SBC, say the soft coal, as its availability is solely looked upon. GAS, HCO, NUE are all worse than BIO, WAE, SBC. The reason why GAS=HCO, NUE on the one hand and PHO=WIE on the other hand lies in the different types of availability. Whereas photovoltaic and wind energy sources are available in Germany their power is not continuously generated. Gas, hard coal and nuclear energy sources are available every day but have to be imported. In Figure 2 several discrepancies between environmental/health criteria on one side and general data on the other side are revealed.

## 4. Conclusion and Outlook

It can be demonstrated that Germany is with the current energy mix still in a rather unsatisfactory situation, especially concerning the impact of the mix on the environment and on human health. The two renewable resources which are shown to be best in the ranking procedure applying the Hasse diagram technique, the PyHasse software, biomass and wind energy do only count for 14,4 % of the energy sources in Germany (see Table 1). Adding photovoltaic (4,2 %) and water energy (3,5 %) which are maximal objects in the environmental health approach (see Figure 3 lhs) this sums up to 26,7 % of the energy mix. Hard coal (18,5 %), soft coal /lignite (25,5 %) and nuclear energy (15,8 %) which showed a bad result, especially in considering the environmental health criteria sum up to 59,8 %. In comparison to these numbers, Poland is currently running on 83 % of coal power plants and 10,4 % renewable energy (see Table 2).

A better strategy for the energy production and consumption must be implemented in the very near future in order to protect the citizens from serious problems. The environmental as well as the public health implications of the impact of the current power generation could be severe, and could be a heavy loading of national economies. A great effort would be necessary to reduce the external and internal exposure to dangerous chemicals, not only $CO_2$, but also particulate matter (PM), sulfur dioxide ($SO_2$), nitrogen oxide ($NO_2$), mercury (Hg) and not to neglect radionuclides, just to name a couple, to decrease the social burden of such impacts. An accelerated switch to renewable sources has the potential to deliver appreciable health benefits, though a major switch will pose challenges particularly in relation to the intermittency of renewable production, land use requirements, and cost [9]. Energy storage, energy efficiency, energy saving must be addressed in a more conscientious and more efficient way. An overview of the advanced energy storage systems to store the electrical energy generated by renewable energy sources is presented by Rahman et al. [18].

We plan to extend our scoring approach to other European countries, starting with the neighboring country Poland in order to support the improvements in the future Polish energy strategy. Furthermore, we intend to enlarge our set of environmental health evaluation criteria with the topic of "extraction of energy source".

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# Nuclear Energy: Danger Only in Case of Accidents?

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## Abstract

The environmental impacts of nuclear energy are highly underestimated. Nuclear weapons, atomic bomb tests, and nuclear accidents are considered a danger for the environment and a human cancer risk. However, childhood leukemia is consistently elevated near nuclear power plants and the Chernobyl accident entailed elevated human birth sex ratios across Europe. We studied the annual sex ratio near nuclear facilities in Germany, France, and Switzerland at the municipality level. We will demonstrate that low doses of ionizing radiation cause effects in human beings. This is shown by strongly consistent spatial-temporal shifts in the human sex ratio trends in the vicinity of nuclear facilities. In the chosen countries complete official data on over 70 million gender specific annual births at the municipality level are available. By Lambert-93 coordinates (France) and GK3 coordinates (Germany, Switzerland) we determined the minimum distances of municipalities from major nuclear facilities. Spatial-temporal trend analyses of the annual sex ratio depending on municipalities' minimum distances from nuclear facilities were carried out. Applying ordinary linear logistic regression (jump or broken-stick functions) and non-linear logistic regression (Rayleigh functions) we demonstrate that the sex ratio at birth shows the influence of mutagenic ionizing radiation on human health. As important environmental chemical contaminants are also mutagenic, the usefulness of the sex ratio at birth as a genetic health indicator can be inferred by analogy.

## 1. Introduction

Nuclear energy supplied 11% of global electricity production in 2011. Three countries draw more than half their electricity from nuclear plants (France leads at 78%, followed by Slovakia and Belgium at 54% each), and ten additional countries, all but one in Europe, draw more than 25% from this source [1]. For example, the running 58 French nuclear reactor blocks generate 78 percent of the entire country's electricity, and France is also the largest exporter of nuclear electricity in the European Union. France is second in the world (behind the United States) in terms of total nuclear power production, contributing 16 percent of the world's nuclear electricity. The risks of a catastrophic impact on the environment and human health by nuclear power plant accidents are evident and well documented. The modelling results by Lelieveld et al. [2] indicate that previously the occurrence of INES 7 major accidents and the risks of global radioactive contamination have been underestimated. Hence high human exposure risks occur around reactors in densely populated regions, notably in West Europe and South Asia, where a major reactor accident can subject around 30 million people to radioactive contamination. The recent decision by Germany to phase out its nuclear reactors will reduce the national risk, though a large risk will still remain from the reactors in neighboring countries. Furthermore, many nuclear facilities are 30-45 years old.

The health consequences among populations living near nuclear facilities have been feared and in some countries extensive and expensive studies have been performed concerning e.g. childhood cancer and childhood leukemia. A meta-analysis of standardized incidence and mortality rates of childhood leukemia in proximity to nuclear facilities has been carried out [3]. It was stated that the majority of those ecological studies found elevated rates of childhood leukemia, although usually

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not statistically significant. Case-control studies on cancer and leukemia in young children were performed in Germany [4, 5], in Switzerland [6], in Great Britain [7], and in France [8]. Although the authors remained vague in general (weak evidence, possible confounding, no causal relation), in most studies concern was raised over an increased general human health risk in the vicinity of running nuclear facilities. Our previous work [9, 10] provides considerable evidence that not only after serious nuclear accidents but also near normally running nuclear power plants and especially near nuclear processing and storage sites, the human sex ratio at birth is distorted and in some places to a rather large extent.

## 2. Sex Odds as an Indicator of Genetic Health

According to Neel and Schull [11], the sex ratio, or in technical/mathematical terms sex odds, is unique among the genetic indicators. Its uniqueness arises from the fact that maternal exposure is expected to produce sex odds different from sex odds after paternal exposure. Therefore, the odds of male to female offspring at birth may be a simple and non-invasive way to study and monitor the reproductive status or reproductive health of a population. According to Scholte and Sobels [12], one of the few methods available for studying the genetic effects of ionizing radiation in man is the observation of changes in the sex odds among offspring from irradiated parents. Lethal factors of varying degree of dominance on the X chromosome, depending on whether an impaired X chromosome is derived from the mother or the father, impact the formation and the survival probability of the female zygote, entailing more or less girls at birth. According to theory, Cox found a reduced offspring sex ratio in irradiated women, and James, on the other hand, states, “ionizing radiation is the only reproductive hazard, which causes” (irradiated) “men to sire an excess of sons” [13-15]. In addition to lethal factors on the X chromosome, Scholte and Sobels [12] allude to nondisjunction resulting in X0 genotypes, which are non-viable in man and, thus, may also distort the birth sex odds. Except in societies where selective abortion skews the sex odds, approximately 104 to 106 boys are born for every 100 girls. In humans, on the one hand, the sex odds at birth is constant at the secular population level [16], but on the other hand, considerable variability may be observed under a variety of specific circumstances. A lot of hypothetical sex odds determinants, among them race and season, and methodological challenges assessing those determinants have been discussed in the literature [17]. Steiner [18] points out that proposed determinants often showed associations in small samples that could not be replicated in larger populations. This, of course, may be due to insufficient statistical power due to small effects and/or small study-populations.

Anthropogenic chemicals and ionizing radiation are determinants of the human secondary sex odds at birth. From animal experiments it has been known for long that exposure to mutagenic chemicals or ionizing radiation can alter the natural sex odds of living beings [19-21]. Stevenson and Bobrow [22] provide a detailed account of methodological issues relevant for the assessment of determinants of the sex odds in man with special emphasis on the impact of male fetal mortality dynamics on the sex odds. Terrell et al. [23] reviewed approximately 100 publications on possible environmental and occupational determinants of the sex ratio. They concluded: “Limitations in study design and methodological issues make it difficult to draw firm conclusions from the existing sex ratio literature”. This highlights the difficulties in generating firm knowledge on sex odds determinants in man. Since recently, we put research emphasis on the effect of chemicals on the human secondary sex odds. In our first evaluation approach around chemical plants, we considered the influence of chemical accidents on the sex odds. We took a closer look at the live birth sex odds in the vicinity of Hoechst-Griesheim, where an accident occurred in 1993 spreading tons of nitroarenes into the environment [24]. Here, we detected a remarkable decrease in the sex odds after the chemical accident [25]. Sociological influences, like e.g. stress, have also been reported.

We just name the sex odds studies after earthquakes in Chile [26] and Italy [27]. In accordance with the Trivers-Willard hypothesis [28], the results of these studies suggest decreases of the human sex ratio at birth under adverse living conditions. However, the most dramatic influence on the sex ratio is man-made, namely sex selective abortion, which poses a problem for example in China and in India [29, 30].

## 3. Data and Statistical Methods

Complete annual gender specific birth data at the municipality level from 1968 (minimum) till 2013 (maximum) were provided by French, German, and Swiss national statistical authorities. Data were processed with SAS and stored in a data base composed of several SAS data sets. The characteristics and geographical positions of the investigated running and closed nuclear power plants was obtained from the comprehensive documentation by the IAEA "International Atomic Energy Agency" nuclear power plant information system (http://www.iaea.org/pris/home.aspx). For geo-coding municipalities and nuclear facilities in the German and Swiss evaluation studies geographic coordinates given in the Gauss–Krüger coordinate reference system (CRS) are used. For France, we used Lambert-93. Lambert-93 is a projected CRS that is suitable for use in France - onshore and offshore, mainland and Corsica. Lambert-93 is a CRS for large and medium scale topographic mapping and engineering survey. It was defined by information from IGN – Paris, "Institut national de l'information géographique et forestière" (http://www.ign.fr/). Lambert-93 is well suited for our purpose of determining the distances of municipalities from nuclear facilities in France. To assess time trends in the occurrence of boys among all live births, and to investigate whether there have been changes in the trend functions after distinct events, we applied ordinary linear logistic regression. This involves considering the male proportion among all male (m) and female (f) births: $p_m = m/(m+f)$. Important and useful parameters in this context are the sex odds: $SO = p_m/(1- p_m) = m/f$, and the sex odds ratio (SOR), which is the ratio of two interesting sex odds if those two sex odds have to be compared, e.g. in exposed versus non-exposed populations. We used dummy coding for single points in time and for time periods as well. For example, the dummy variable for the time window from 2001 on is defined as $d_{2001}(t) = 0$ for $t < 2001$ and $d_{2001}(t) = 1$ for $t \geq 2001$. The simple and parsimonious logistic model for a trend and a jump in 2001 has the following form (LB = live births):

$Boys_t \sim Binomial(LB_t, \pi_t)$:

$$\text{log odds}(\pi_t) = \text{intercept} + \alpha * t + \beta * d_{2001}(t)$$

The data in this study were processed with Microsoft Excel 2003. For statistical analyses, we used R 2.11.1, MATHEMATICA 8.0, and mostly SAS 9.3 (SAS Institute Inc: SAS/STAT User's Guide, Version 9.3. Cary NC: SAS Institute Inc; 2012).

## 4. Results

As a typical example, we consider the nuclear power plant Philippsburg, Germany. This power plant also operates an interim storage for highly active waste (HAW) from the year 2001 onwards (http://www.bfs.de/de/transport/zwischenlager/dezentrale_zwischenlager/standorte/kkp.html). As we have shown that within 40 km from the HAW storage site in Gorleben the sex odds at birth is distorted [31], it is interesting to look for a similar effect in the more highly populated area around the nuclear power plant at Philippsburg. Figure 1 shows that indeed from 2001 onward the human sex odds at birth trend is subject to a significant jump with a sex odds ratio of 1.026, 95%-CL=[1.009, 1.043], p-value=0.0023. This striking result confirms our corresponding observation at Gorleben [31].

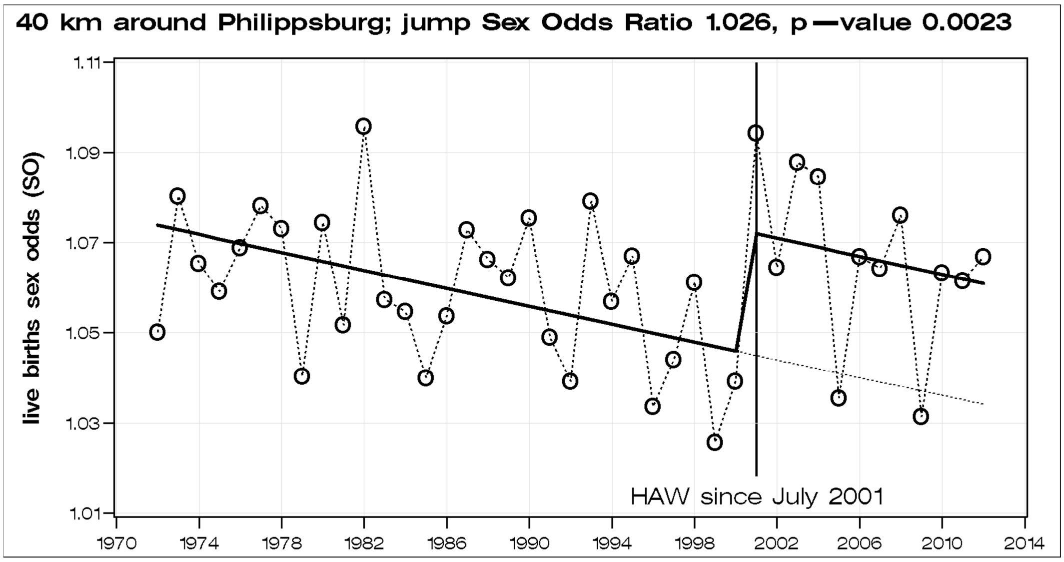


*Figure 1: Trend of the human sex odds at birth within 40 km from the HAW storage Philippsburg, Germany*

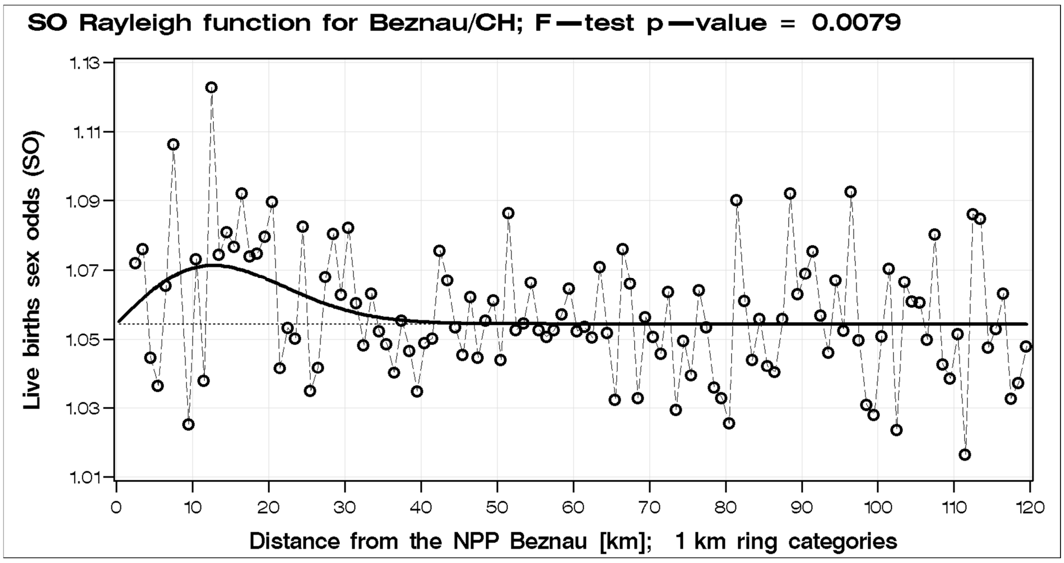


*Figure 2: Spatial trend of the sex odds (1969 - 2012) within 1 km distance rings around Beznau in Switzerland (CH)*

Figure 2 displays the optimum Rayleigh function for the spatial distance law of the sex odds in Swiss municipalities depending on the proximity to the Swiss nuclear power plant Beznau. The estimated base line sex ratio is 1.0544. The estimated sex odds peaks at 12.7 km (95% CI: 7.8, 17.6) with a $SOR_{peak}$ 1.0161 (95% CI: 1.0043, 1.0281).

As a significantly elevated human sex odds at birth has been found in the vicinity (< 35 km) of nuclear facilities in Germany and Switzerland [9], we tested whether this was also the case in France. In fact, within 35 km from the selected 28 French nuclear facilities listed in Table 1 we also found significantly elevated sex odds. The sex odds ratio SOR for the jump at 35 km distance is 1.0028 (95% CI: 1.0007, 1.0049), F-Test p-value 0.0096, see Figure 3 (l.h.s).

*Table 1. French nuclear power plants (n=23) and 5 major nuclear facilities*

| | Nuclear power plants | Location | Exposure since |
|---|---|---|---|
| 1 | BELLEVILLE | LENE | 1986 |
| 2 | BLAYAIS | BRAUD ST.LOUIS | 1980 |
| 3 | BUGEY | ST. VULBAS | 1971 |
| 4 | CATTENOM | CATTENOM | 1985 |
| 5 | CHINON | AVOINE | 1962 |
| 6 | CHOOZ | CHARLEVILLE | 1966 |
| 7 | CIVAUX | CIVAUX | 1996 |
| 8 | CRUAS | CRUAS | 1982 |
| 9 | DAMPIERRE | DAMPIERRE-EN-BURLY | 1979 |
| 10 | EL4 | BRENNILIS | 1966 |
| 11 | FESSENHEIM | FESSENHEIM | 1976 |
| 12 | FLAMANVILLE | FLAMANVILLE | 1984 |
| 13 | G2/PHENIX | MARCOULE | 1958 |
| 14 | GOLFECH | AGEN | 1989 |
| 15 | GRAVELINES | GRAVELINES | 1979 |
| 16 | NOGENT | NOGENT-SUR-SEINE | 1986 |
| 17 | PALUEL | PALUEL | 1983 |
| 18 | PENLY | PENLY | 1989 |
| 19 | RAPSODIE | CADARACHE | 1966 |
| 20 | ST.ALBAN | SAINT-MAURICE-L'EXIL | 1984 |
| 21 | ST.LAURENT | ST. LAURENT DES EAUX | 1968 |
| 22 | S/PHENIX | CREYS-MALVILLE | 1985 |
| 23 | TRICASTIN | PIERRELATTE | 1979 |
| | **Nuclear facilites** | | |
| 24 | RESEARCH CENTER | GRENOBLE | 1971 |
| 25 | RESEARCH CENTER | CAEN | 1983 |
| 26 | STORAGE SITE | LUXEUIL | 1966 |
| 27 | URANIUM MINING | KRUTH | 1953 |
| 28 | WASTE DISPOSAL | SOULAINES-DHUYS/CSA | 1992 |

An impartial Rayleigh function, which is based on 3 parameters instead of only 2 parameters for the jump function, and which does not require an arbitrary predefined distance category like 35 km, yields an even more precise result. The overall F-test p-value for the Rayleigh function is 0.0018. The estimated base line sex ratio is 1.0506 (95% CI: 1.0499, 1.0514). The estimated sex odds peaks at 9.1 km (95% CI: 5.8, 12.4) with a $SOR_{peak}$ 1.0084 (95% CI: 1.0036, 1.0132), see Figure 3 (r.h.s). The jump and Rayleigh function analyses are based on all 33,114,626 births in France from 1968 to 2011. These findings essentially mean that within 35 km from the investigated 28 nuclear facilities in France combined, the sex odds is 1.0535 whereas outside of these combined areas, i.e. in the rest of France, the sex odds is 1.0506. If this increase in the sex odds by the factor 1.0028 (sex odds ratio) in the vicinity of nuclear facilities were exclusively due to a deficit in girls, it would correspond theoretically to 5730 (95% CI: 1499, 9982) missing girls in the combined 35 km vicinities of those 28 nuclear facilities. We emphasize that this is most probably a rather conservative estimation of the “real effect” as there are many more nuclear facilities in France not yet investigated, and the effect is probably further ranging than 35 km. The latter can be anticipated from close inspection of Figure 3 (l.h.s): the 50 km range is also significant (data and results not shown). Moreover, we must assume considerable non-differential misclassification biasing our results towards null. There is a great variety of eligible ionizing materials, differing exposure pathways, as well as exposure conditions of susceptible people. Also, as long as we have not identified all relevant nuclear facilities, our control region, i.e. the “rest of France”, is contaminated so to speak. This inevitably entails only a partial reflection of the presumable “real effect”.

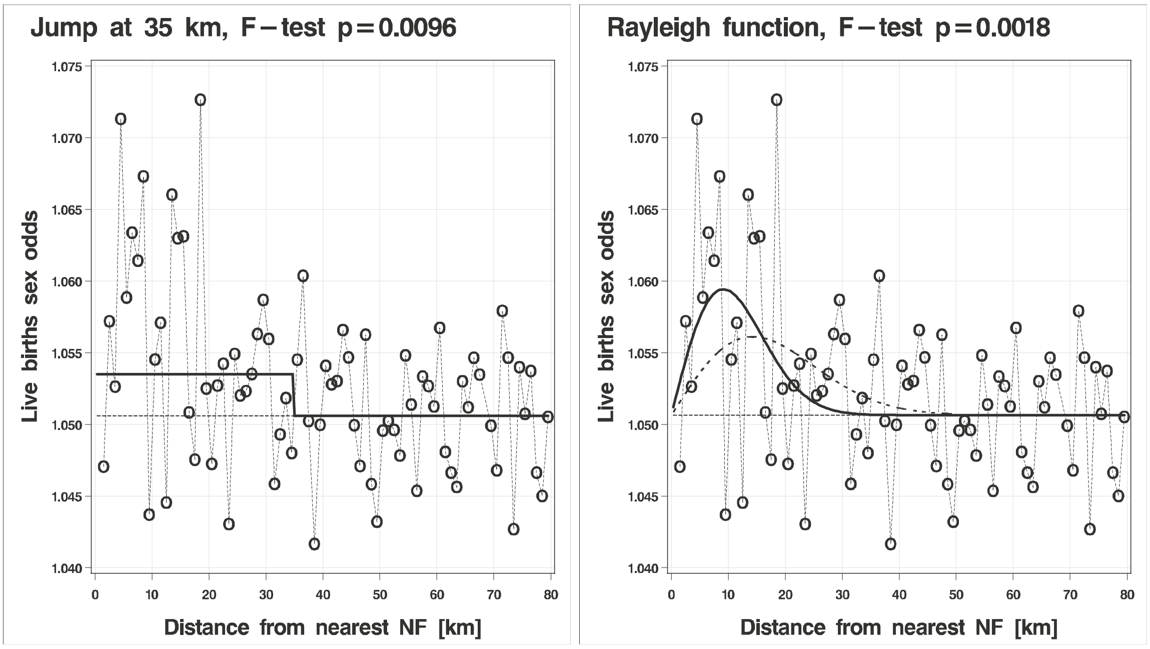


*Figure 3: Jump function (35 km, l.h.s.) and Rayleigh function (r.h.s.) for the live births sex odds (male:female) depending on distance form nuclear facilities (NF) in France (Table 1). The broken Rayleigh function (r.h.s.) is the base line adjusted Rayleigh function in Figure 4 by Scherb and Voigt (2011) for Germany and Switzerland combined*

## 5. Discussion

There is little doubt that mutagenic physical and chemical environmental hazards can alter the human sex ratio at birth. We found consistently elevated sex ratios after Chernobyl across Europe, and even in Cuba contaminated foodstuffs from the former Soviet Union presumably caused increases in the sex ratio [10, 32-34]. Recently, based on our findings, Grech [35] has shown that the sex ratio increased in parts of Scandinavia and especially so in the most exposed Norway in the 10-years period following the October 1957 Windscale/Sellafield accident in the United Kingdom. Since childhood cancer and leukemia are elevated near nuclear power plants and increased cancer and increased sex ratio after Chernobyl originate in genetic effects at the molecular and cellular levels, it was a self-evident enterprise to investigate the sex odds in the vicinity of nuclear reactors and more generally near nuclear facilities of all kinds. In fact, based on 20 million annual births in Germany and Switzerland at the municipality level from 1969 to 2009, we found increased sex odds near nuclear power plants and other nuclear facilities [9, 10].

Our temporal and spatial analyses on French nuclear facilities corroborate our previous findings in Germany and Switzerland. There is a small increase of a few per mill in the sex odds around nuclear facilities including nuclear power plants in France. The strength of our approach is the fact that we analyze total national data and no random samples from data. Therefore, sampling error and sampling confounding is not an issue for our studies. A clear weakness of our approach is of course the highly aggregated nature of our data at an annual municipality basis ignoring alternative sex ratio determinants. However, this obvious drawback is perhaps more than outweighed by the sheer amount of individual births data in the tens of millions, the corresponding full registration over decades within all municipalities at a national basis. The last author has investigated the possibility of thermal neutron activation near casks containing highly radioactive waste [36]. According to this analysis, the activation product 41-Argon may play an underestimated role. Another possibility is that fast neutrons (≈1 MeV) at the surface of highly active nuclear waste casks are underestimated with respect to range and biological effectiveness [31]. The possibility of incomplete knowledge in the radiation sciences has recently been stressed in the nuclear accident context: “There may be ‘unknown’ exposure pathways or unsuspected radionuclides, among other factors” [37]. This applies also to normally running nuclear facilities in as much as they emit radiation or radioactive elements insufficiently investigated. Moreover, the authors of the so called French GeoCap study who found increased childhood leukemia near French nuclear power plants stressed the possibility of an unidentified causal radiation factor as there was no obvious association of increased childhood leukemia with measured radiation dose categories (dose-based geographic zoning): “Overall, the results suggest a potential excess risk over 2002–2007 that may be due to unknown factors related to the proximity of NPPs” [8]. In conclusion, we obtained evidence in favor of the existence of an unexpected effect of ionizing radiation on the human secondary sex ratio after nuclear accidents as well as within tens of kilometers from seemingly normally running nuclear facilities of all kinds including nuclear power plants. Further research in this field is urgently needed. We are of the strong opinion that nuclear facilities pose a genetic risk to humans and creature and that more research should be initiated in this respect. Action must be taken to phase out of nuclear power and not to construct new nuclear power plants.

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# Informatics to Support International Food Safety

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**Abstract**

Diseases and pathogens in the food supply cause large numbers of illnesses annually. One example was the enterohemorrhagic *Escherichia coli* (EHEC) outbreak in Germany which resulted in approximately 4,000 people infected and nearly 50 deaths in 2011. The estimated economic impact of foodborne illnesses is significant. Governments and the private sector seek to minimize food safety risks. Informatics plays an increasing role in dealing with the big data generated, which must be analyzed to support risk assessment, prevention, and mitigation programs to optimize food safety outcomes. However, economic and organizational issues require attention. Public and private sector collaborations are necessary to identify food safety outbreaks as a starting point, and to then trace the potential causes to their sources. The GLOBALG.A.P. initiative is an international public-private sector collaboration, headquartered in Germany, to assure product safety throughout the food supply chain to the retail level. Another preventive approach to food safety is the United States implementation of the 2011 FDA Food Safety Modernization Act. Informatics plays a key role in providing the analytic framework and procedures at the multiple levels needed to successfully assess and control the risks involved as food is tracked through the supply chain. This paper provides additional examples of individual company and international collaborations to harness big data, provide the analytics, and implement improved food safety protocols. One issue which must be resolved between producers and companies selling the digital information systems incorporated into farm machinery working the fields is who owns and controls the data generated.

## 1. Introduction

Every year, there are large numbers of illnesses and deaths caused by diseases and pathogens in the food supply. This is true in developed countries as well as in developing countries. For example, in the United States alone there were an estimated 48 million cases of foodborne illnesses (about 1 in 6 citizens), 128,000 hospitalizations, and 3,000 deaths in 2011 [1]. Fresh produce, meat and poultry, dairy and eggs, and fish and shellfish are primary sources of these illnesses. More than half the hospitalizations and deaths are caused by unspecified agents, and these agents also account for four times as many illnesses as known agents. The latter group includes noroviruses – which sicken the greatest number of people, and are thus also among the small set of pathogens estimated to cause the most fatalities; *Salmonella* and *Listeria* are also in this group.

The estimated economic cost of foodborne illness is an important factor in guiding food safety policy. These cost estimates also help focus strategies for preventing and mitigating such illnesses and for establishing programs to monitor the effectiveness of risk-reduction measures, including broad information-sharing initiatives. In 2012, two studies found that five U.S. foodborne pathogens were the most costly in terms of medical care, lost work time and premature deaths in the United States. Of the 14 major pathogens responsible for over 95% of foodborne illnesses, hospitalizations and deaths in the United States these five account for 85% of the cost [2].Economic impacts of food safety incidents are significant, and government as well as private sector programs seek to minimize food safety risks. Informatics plays a crucial role in addressing

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food safety issues, with large amounts of data being collected and analysed to support an extensive suite of risk assessment, prevention, and mitigation programs.

Recent advances in information and communication technology have redefined what comprises food safety data and how these data are captured, shared, and managed. The volume, velocity and variety of big data create challenges for its efficient use in decision making by both the private and public sectors. Informatics approaches and tools are being developed and applied to identify, combine, and manage data from multiple sources to create information that is directly useful to decision-makers, and advanced analytic models will facilitate predictions that can optimize food safety outcomes [3].

One example of a severe food safety outbreak occurred in Germany, where the deadliest outbreak of enterohemorrhagic *Escherichia coli* (EHEC) resulted in approximately 4,000 people infected and nearly 50 deaths in 2011. Researchers immediately started working with the big data gathered during that outbreak to prevent a repeat and improve chances of survival for future patients. They were concerned about finding the bacterium's reservoir, how far the pathogen may have spread, how likely it was to persist, and what made this particular EHEC so dangerous. More than 100 German patients received Eculizumab, an antibody that targets a protein involved in regulating the human immune system. By pooling data of patients treated with Eculizumab in clinics in four different cities, researchers set out to determine its efficacy. This is a daunting task because of the need to consider numerous confounding factors such as other treatments received, lab tests, and prior illnesses of the patients that might have influenced the EHEC-patient outcome. The challenge is to determine how to evaluate novel treatments in a disciplined, ethical and useful manner when such rare catastrophic emergencies occur [4].

But food safety incidents are an ongoing and not infrequent concern, in spite of scientific progress in understanding the causes of foodborne illnesses and programs in the public and private sectors to mitigate them. Examples of efforts to quickly identify and squelch food borne illness outbreaks in the United States include two web based tools created by the US Centers for Disease Control and Prevention (CDC)—FoodNet and PulseNet. FoodNet brings together a number of sites maintained by professionals across the United States to track the ebb and flow of food safety incidences. CDC can then examine in depth the big data coming from those sites to better understand foodborne diseases. PulseNet relies on DNA fingerprinting to track illness-causing bacterial strains that researchers have examined and scan this big data for patterns. The researchers can then track epidemiology, which has allowed them to detect many multistate outbreaks beyond what might have been detected without the PulseNet tool. As CDC continues to improve its use of the tools, they are better able to respond to a potential outbreak as well as promote better understanding of how to manage and prevent outbreaks of foodborne illnesses [5]. By linking these information systems, CDC is able to identify patterns in the big data sets that would not be apparent to researchers working in isolation within their own institutions or collaborating with one or a few others.

Of course, the metrics applied to big data generally involve correlation, which is not causation. This means that patterns detected can serve as an early warning system of developing problems. Still further investigation by scientists understanding various aspects of potential foodborne illnesses is required before decisions can be reached about likely sources of contamination involved in an outbreak. Certainly the availability of the data sets and the creation of informatics-driven data discovery environments make it possible to quickly sort out the important features of the data set without a lot of preparation [6]. The rapidity of developing preliminary results increases the chance of heading off more severe outbreaks through continued exposure and therefore reduces the impact on consumers.

## 2. Global food safety context

While technological capacity to aggregate and analyze the big data related to foodborne illnesses is available, economic and organizational issues may present some challenges. Sharing the cost of the specialized skills to develop analytics needed to take advantage of big data will likely be problematic within the agricultural and food arena, just as in other industry segments. Thus, while between-firm collaboration may be limited, the desire for spreading the costs may lead to consolidation within the supply chain to bring together the resources needed. For example, Monsanto acquired US-based Climate Corp. to obtain access to localized weather forecasts based on historical weather data which were generated in the course of developing insurance offerings to protect farmers against weather related production problems [7]. Monsanto's ownership of Climate Corp. enables it to offer prescriptive farming solutions to increase yields through better timing of fertilizer applications, insecticide and pesticide treatments, and other field activities which are weather dependent for successful outcomes.

Previously, US land-grant universities and the US Department of Agriculture would likely undertake with public funding the research and development to take advantage of big data possibilities. In today's economic climate, private firms in the agricultural and technology sectors collaborating with public institutions will need to do that research and development. Sonka believes that success will be driven by organizational and managerial strategies as much as by technological capacity [3].

Public and private sector collaborations are necessary to identify food safety outbreaks as a starting point, and to then trace the potential causes to their sources which can be eliminated or at least mitigated. Unfortunately, under current conditions, by the time the source of an outbreak has been identified, many implicated food products are usually already in the hands of consumers, and it is often too late for any recall to be effective, especially if the food is perishable (such as lettuce or cantaloupe). For this reason, preventive measures are greatly preferred to dealing with outbreaks after they occur. One example of such a proactive program is GLOBALG.A.P., an international public-private sector collaboration headquartered in Germany, that is working to establish preventive measures through standardized best practices in agricultural production to assure product safety throughout the food supply chain to the retail level. GLOBALG.A.P. was established in 1997 by food retailers as EUREPGAP to address consumer's growing concerns about product safety, environmental impact, and safety of agricultural workers and animals. Retailers set out to harmonize their own standards and procedures and develop an independent certification system for Good Agricultural Practices (G.A.P.). The standards help producers meet Europe-wide accepted criteria for food safety and other desired outcomes including sustainable production methods, and worker and animal welfare. The harmonized standards provide savings to producers as they no longer need to undergo multiple annual audits against different criteria. The system spread throughout Europe and beyond in the face of food system globalization. EUREPGAP became GLOBALG.A.P. in 2007 and is now the world's leading farm assurance program to translate consumer requirements for food safety and other characteristics into Good Agricultural Practice in more than 100 countries. An extensive network of more than 140 GLOBALG.A.P.-certification bodies around the world ensures that standards are adapted and applied consistently on every GLOBALG.A.P.-certified farm. The GLOBALG.A.P. Secretariat function to support the system is provided by FoodPLUS GmbH, a nonprofit company based in Cologne, Germany, creating a single management platform for GLOBALG.A.P. It provides agricultural producers access to three separate sets of 16 standards—for crops, livestock, and aquaculture. Buyers can obtain source-certified products that meet the baseline requirements for food safety and hygiene, thereby reducing exposure to product safety risk for food retailers.

GLOBALG.A.P.'s traceability system allows buyers to monitor producers and validate their certificates through a database of unique 13 digit numbers which identify each certified producer, as well as review producers' certification audits. Consumer demands for safe and sustainable food production drive improvement and development efforts for the GLOBALG.A.P. standards [8]. This unique system involves retailers and producers working together to create the standards to which all producers adhere. It recognizes that food safety must begin at the point of production and continue throughout the supply chain so that retailers may deliver the level of food safety consumers expect.

There are also sanitary and phytosanitary (SPS) provisions in most international trade agreements, designed to prevent trade of contaminated products which may lead to food safety issues. Individual country trade agreements may provide for inspection by the importing country representatives of processors and handlers of food exports in the country of origin. In most cases, the point of entry to the importing country is where the inspections to identify contaminated food products which must be removed from the food supply chain are carried out. The challenge in that case is to have enough resources devoted to inspection to head off the riskiest food products.

Nonetheless, the prevalence of personal devices, shipment tracking practices, and consumer purchase trails from the retail sector generate big data which makes possible improved traceability from producer through to consumers. This may allow for rapid and accessible recalls of foods suspected in safety outbreaks which will continue to occur. By establishing analytics to digest information, companies will be able to develop shortcuts to decisions and follow-up actions that reach purchasers of the foods [6].

One important element of the US preventive approach to food safety is the implementation of the 2011 FDA Food Safety Modernization Act, specifically implementation of Proposed Rules on Sanitary Transportation of Human and Animal Food. The goal is to prevent practices likely to create food safety risks, including "failure to properly refrigerate food, inadequate cleaning of vehicles between loads, and failure to properly protect food during transportation". Requirements would establish measures such as maintaining adequate temperature controls, procedures to exchange information about temperature control between shipper carrier and receiver, and maintaining the procedures and records related to temperature control as well as other factors which could contaminate food during transportation. Importers will be required to ensure that imported food is as safe as that produced in the United States. Further, a program would be established to accredit third-party auditors or certification bodies to audit food safety practices of foreign facilities' exporting human and animal food to the United States [9]. In response, food producers and transporters are adopting sensor-based technologies and analytics which will incorporate big data to monitor their supply chains, providing potential to trace any contaminated shipment to the farm source [10].

## 3. Data Challenges

Risk assessments are important for identifying vulnerabilities or weak links in the food supply chain beginning at the farm level and continuing through to retail food stores and restaurants, and even in the home. Informatics plays a key role in providing the analytic framework and procedures at the multiple levels needed to successfully assess and control the risks involved as food is tracked through the supply chain. For example, temperatures are now being monitored in real time as perishable foods move throughout the supply chain, including during cross-country transportation. Considered across a substantial number of products and locations, this type of tracking produces large quantities of data requiring timely analyses in order to make intelligent decisions about determining critical points in the supply chain which should be monitored most closely and for which to develop preventive practices.

With huge amounts of monitoring data being generated from the farm level and food supply chain, informatics has emerged as a key player in agricultural food safety programs. Gary Nowacki, CEO of TraceGains, Inc. argues that big data provides a framework for companies to better organize critical information—often scattered across numerous documents related to product quality and safety—into a reportable, searchable, and actionable central data base. This enables companies to report, search and use food safety and quality data to enhance proactive as well as reactive strategies. Food companies can then risk profile their suppliers to proactively identify the riskiest points in their supply chain; and for reactive needs, the company can receive instant notification if an incoming raw material fails to meet its specifications for quality and safety [11]. This example illustrates the kinds of efforts underway in the US food system to harness big data that is already being generated by creating usable formats for analysis to better protect quality and safety of food products. Given the importance of maintaining product integrity to a company's reputation and survival, demand for these types of database development and analytic algorithms to support decision making throughout the food supply chain will continue to increase at a rapid pace.

Further, extensive sharing of big data that affects food safety in international as well as domestic contexts is expected to increase. At this time, data are generally insufficient to effectively assess risk at each level in the supply chain. In Asia, a number of governments are looking to liberalize open data policy to allow more data to be publicly available for use in development of analytics to create more efficiencies in various sectors, according to Bob Chua, CEO of Pulse Group plc, Asia's leading big data and marketing analytics agency [12]. Certainly food safety is a prime candidate for such open sharing of data to facilitate domestic food safety as well as to be a trusted partner in the global food supply chains.

For example, one concern in handling grain is to keep deadly aflatoxins out of the food supply. This may become an increasingly important control issue as climate change results in more frequent hot and dry growing conditions for grains. Extensive testing can prevent contaminated grains, especially maize, from entering the food supply, but rapid testing at delivery of the crop is necessary to pinpoint dangerous levels of aflatoxins. High-risk periods due to extreme heat are expected to highlight the importance of environmental informatics approaches and systems to developing effective control measures based on well-coordinated data gathering, recording, and tracking efforts [13].

Even better is the potential to identify dangerous levels of aflatoxins in the farm field. That possibility is now feasible with the digital information systems being used by farmers in their agronomic practices. The data gathered can include identification of areas within a field which are subject to aflatoxin contamination because of particular crop conditions. Further, the use of drones to scan fields provides an additional opportunity to identify aflatoxin-affected areas within a field. However, more research is required to make that a reality in the near future. Combining data generated by the farmer during the course of conducting agronomic practices with that gathered by drones offers a potentially powerful tool to keep aflatoxin-infested grain from even reaching the first point-of-sale for food use. Such fields may be harvested for industrial uses not affecting aflatoxin's effects on human food as well as animal feed. This is just one example of how earlier intervention may increase the safety of the food supply starting at the farm level. Other pathogens likely to occur in crops could also be kept out of the food supply chain starting at the farm level.

Seed, fertilizer, and equipment companies have worked with farmers to monitor and collect data at the farm level. When properly analyzed and correctly interpreted, the information can be valuable to both the farmer and the company. The company analyzing the data generally charges the farmer for the analysis, even though it is using the farmer's data. The company gains by strengthening its predictive analytic capabilities, improving its strategic benchmarking prowess, and building its marketing advantages. The farmer who is already using precision technologies may gain productivity from providing the data and then buying the company's analytic report, but there is no guarantee of an overall farm output increase. So the farmer must evaluate whether the benefits of providing the data outweigh the possibility that the data would be released or misused by others. At least that is a major concern among a number of US farmers currently [14].

At the other end of the food supply chain, retailers including grocery stores and restaurants are extremely concerned about food safety issues to protect their customers from foodborne illnesses. Their reputation, and even survival as a viable business, demands that they pay close attention to this issue in an increasingly global context. The possibilities for foodborne illness outbreaks are multiplied by international travel and the potential for invasive pathogens, as well as from endemic pathogens already prevalent in the US food supply chain. Big data and the associated analytics provide the opportunity for retail establishments to implement stronger food safety protocols to protect their customers and their brand. For example, The Cheesecake Factory is a US-based restaurant chain which is using IBM big data analytics to quickly alert their restaurants to remove ingredients that do not meet safety standards. Like many restaurant chains, The Cheesecake Factory generates a variety of data from its complex global food supply chain. Large volumes of data provide information about everything from transportation of food at the appropriate temperature to shelf life of food items and withdrawals of products by manufacturers. The magnitude of this data makes it difficult for large restaurant chains to get a quick insight and then manage appropriately. This is where IBM's advanced analytics, in conjunction with IBM's business partner N2N, provide solutions which allow The Cheesecake Factory to quickly withdraw any ingredient failing to meet its standards for quality and consistency [15]. Other restaurant chains will undoubtedly demand such services to assure that they are as equally protected from food safety risks.

An example of an international collaboration to improve food safety is found in ComBase, which is a combined database for predictive microbiology. It is managed by a consortium of the Institute of Food Research in the United Kingdom, the Agricultural Research Service of the United States Department of Agriculture, and the University of Tasmania Food Safety Center in Australia. ComBase is the most recognized free, web-based resource for quantitative and predictive food microbiology. It provides a systematically formatted database of quantified microbial responses to the food environment, with more than 50,000 records. The database contains thousands of microbial growth and survival curves collated in research establishments and from publications. It further provides predictive models which are a collection of software tools utilizing the ComBase data, designed to predict the growth or inactivation of microorganisms in food. Together the database and predictive models allow researchers worldwide to predict and improve microbiological safety and quality of food; allow companies to develop new food products and technologies, and store foods economically; and facilitate assessing microbiological risk in foods and setting up the government regulatory or industry voluntary guidelines, as appropriate. A user of the ComBase Internet interface defines relevant criteria for their query, including: the type or species of organism, the type or class of food, temperature, and specific food conditions, as well as more technical conditions [16]. The ComBase consortium provides training in the use of its product by hosting workshops throughout the world.

## 4. Looking ahead

Who owns and controls the data generated by the technology at the farm field level is an issue which must be resolved between producers and companies selling the digital information systems incorporated into farm machinery. This digital technology allows site specific decisions about fertilizer and pesticide applications, crop irrigation needs, and other agronomic practices; as well as provides information about yield variation within fields, disease problems and product quality characteristics. The data generated is transmitted back to the system vendors, as well as being available to the farmer. The big data generated at the farm level makes it a challenge for farmers to fully utilize the results. Recent developments aggregating data from various sources to create huge data files, which have value at the farm level but also when aggregated across farms, provides data vendors an opportunity to repackage the data and sell it for substantial sums, perhaps totaling in the billions of dollars. This has raised privacy concerns, as well as a desire by farmers to have access to more of the value added by these technologies. Currently there is a mix of arrangements between the technology providers and the producers using it, but these agreements are rapidly evolving. Prior to big data becoming such an important component of decision-making, the contracts between the technology providers and farmers using it were relatively straightforward. After raising serious concerns, US farmers appear to have obtained some control over details about their crop and growing conditions on their own land. However, most data sellers who are the providers of the digital information systems retain the ultimate say over how they can use the information. For example, Deere & Company and Monsanto’s Climate Corp. continue to claim an absolute right to the data collected by the combines, tractors and other equipment working the fields [17].

One strategy being tried by farmers is to form cooperatives to collect the data and develop analytics to create value from it, which they would then retain among the cooperative members. The American Farm Bureau Federation, the largest US farm organization, is giving serious consideration to establishing a data warehouse and analytics system for its members who contribute data to it. It is likely that these actions are in part responsible for the gains farmers have achieved thus far. Whether private sector actions such as this, collaboration between farmers and digital information systems purveyors, or public policy created through government action will resolve the issues involved remains to be seen. Clearly some of the data gathered at the farm level and aggregated across farms holds potential value for food safety throughout the supply chain. How the privacy and access to data issues get resolved will therefore impact food safety.

ISOBlue is an innovative approach organized by engineers at Purdue University and cosponsored by FarmLogs—a Michigan-based company backed by Silicon Valley money which sells software and data analytics that lets farmers fully control the information collected—to provide an alternative to farmers. ISOBlue teaches farmers how to capture and store their own data rather than needing to rely on the analytics from the equipment providers. Many pieces of modern farming equipment “share a standardized communications bus, known as ISO11783 bus, or ISOBUS. It is a standard CAN communications bus operating at 250 kbps. The ISO11783 protocol specifies application layer-packet structures which are sent via the CAN link and Physical layers.” Due to the proprietary data collection systems from tractor manufacturers, most farmers, researchers and interpreters cannot easily access massive amounts of mineable data generated by tractors and related sensors. The goal of ISOBlue is to free the data by forwarding it directly from the bus wirelessly over Bluetooth to devices capable of doing things with it. By getting precision agriculture data into the cloud, this project provides access to those trying to leverage advanced information technologies to produce more food efficiently and safely [18].

Demand for public access to monitoring data for foodborne illnesses will likely increase as people become increasingly aware of safety concerns surrounding food production domestically as well as from ever more prevalent imported supplies. The latter is of particular concern as global trade agreements have increased the flow of many food products, including processed foods that may come from countries with less stringent food safety processes in place than those to which developed countries are accustomed. Private sector approaches to providing access to information about foodborne illnesses and safety risks are likely to increase to satisfy this demand. Public-private collaboration to establish and maintain open access to information resources will undoubtedly play an important role in addressing this demand. Certification of inspection results for food safety conditions, as generally provided by third parties who have been certified by government agencies, will likely continue to be important to the selection and integration of key data that drive private sector management decisions and public policy.

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# Considering Environmental Health Risks of Energy Options: Hydraulic Fracturing and Nuclear Power

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## 1. Introduction

Increased public concerns about the global impacts of climate change have heightened interest in reliable energy sources that reduce greenhouse gas (GHG) emissions. Greater awareness of the impact of these emissions on climate change has led to coal-fired power plants being phased out in many areas of the world, including in the United States. At the same time, new plants are being developed in other areas (including China), as are plans for more nuclear power plants [1]. Recent projections for the U.S. suggest that natural gas will surpass coal as the largest component of electricity generation over the next twenty years, accounting for more than a third of the total by 2035. The share of electricity generated by nuclear power plants is anticipated to increase by 5% by 2040. In comparison, renewable energy sources other than hydropower are projected to comprise 28% of the overall growth in electricity generation during this same period [2].

With conventional fossil fuel sources identified as dominant contributors to the GHG problem, the push for alternatives including renewable energy systems has been strong. Recent technology developments such as advanced optical materials and feathered turbine blades that accommodate a wider range of wind speeds have improved lifecycle estimates for variable renewables like solar and wind energy, respectively. Nevertheless, traditional sources such as nuclear fuel and oil and natural gas continue to be regarded as primary anchors while alternative energy sources are developed, or as transition or bridge sources toward ultimately establishing a sustainable set of energy options. With a focus on environmental health issues, two options that engender substantial public concern are: (1) nuclear power plants, and (2) unconventional oil and gas development and production, notably hydraulic fracturing. Opportunities for information and communication technologies (ICT) to promote targeted information sharing and facilitate citizen science initiatives are increasing, toward improving the understanding of specific environmental implications of energy options. A key goal is to more broadly inform the development of sustainable energy programs.

## 2. Environmental releases and health risk concerns

Different environmental pollutants are associated with nuclear power plant operations and hydraulic fracturing activities. Illustrative issues that have been raised for each are highlighted below.

For nuclear power plants, radioactive releases are a primary concern. Liquid effluents are routinely discharged as part of normal operations, with the amount of radioactivity depending on the type of reactor. For example, pressurized water reactors typically release more tritium than boiling water reactors, by a factor of 20 or higher [3]. In the event of an accident at a nuclear power plant, airborne releases are the key concern, with potential for widespread dispersion and deposition. The scale of contamination is well illustrated by the recent Fukushima disaster. Cancer morbidity and mortality represent primary health concerns for exposure to ionizing radiation; potential noncancer endpoints such as cardiovascular effects have also gained attention more recently [4]. Potential

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effects associated with atmospheric releases and proximity to nuclear facilities has been reported by Scherb and Voigt [5, 6] using sex odds at birth as a proxy in the absence of actual exposure data (which would be important to determining such a link; see related note from McKenzie et al. [7] below regarding the need for exposure data to explore associations indicated by a proxy).

For hydraulic fracturing, chemical pollutants are a primary concern; naturally occurring radioactive material (NORM) and technologically-enhanced NORM (TENORM) also represent public concerns. In some cases, unconventional gas development is occurring in regions where uranium has been mined and milled, with a history of exposure and risk concerns regarding natural radionuclides such as radium (as highlighted in a recent review by [8]. Such natural radioactivity is also of concern for wastewaters from hydraulic fracturing.

Considering impacts to water quality, five different sources of contaminant releases have been identified: (1) spills during transportation of fracking fluid and produced water; (2) leaks from casings of production wells; (3) leaks through fractured rock in the affected zone; (4) discharges from the drilling site; and (5) wastewater disposal [9]. The latter has been identified as the driving concern for water contamination, posing a threat estimated to be thousands of times higher than from the other pathways [10].

In a recent review, Vengosh et al. [11] report evidence of effects in areas of intensive shale gas development that include stray gas contamination and surface water impacts. Various waste management approaches are being evaluated to reduce levels of dissolved pollutants released to water, such as a recent study that blends flowback fluid with acid mine drainage effluent to precipitate solids for subsequent removal [12].

One of the reasons for heightened public concern about impacts to water – notably drinking water sources – stems from the lack of public information about all the chemicals involved in the fracking process, including proprietary proppants. A recent study reports that natural gas drilling operations increased the activity of estrogen-disrupting chemicals in local surface water and groundwater [13].

In considering the potential for chemicals released by natural gas development activities to include teratogens, McKenzie et al. [7] conducted a retrospective cohort study of birth outcomes in rural Colorado using distance to maternal residence as an estimator of possible exposure. The authors reported a negative association with preterm birth, a positive association with fetal growth (the magnitude of association was small), and no association with oral clefts. From this initial evaluation, the authors observed an association between density and proximity of natural gas wells within a 10-mile (16-kilometer) radius and prevalence of congenital heart defects and possibly neural tube defects. The authors importantly qualify these observations with the statement that specific exposure estimates are needed to further explore the associations.

Although some chemical data are available via a clearinghouse website (see the discussion of FracFocus in Section 4), a substantial amount of data are not. Beyond the chemical content, associated contaminants of proppants and other materials that are being imported for use in well development and production are also concerns. It is difficult for agencies and citizens to assess the need for exposure controls to limit health risks when the nature of those potential exposures is unknown.

Airborne releases associated with hydraulic fracturing are also a substantial concern, with particulate matter and methane being among the pollutants of interest. The type of fracking affects the extent of releases, with the volume of water needed having a marked influence. For example, to support recent evaluations by the U.S. Environmental Protection Agency [15], the transport of water needed for coal-bed methane extraction was estimated at 16 to 115 trucks per well fracture event, compared to about 1,660 trucks needed for shale gas extraction [14]. Thus, diesel particulate matter (DPM) emissions are substantially higher for shale gas extraction, and these highly respirable particulates have been identified as a key public health concern, with effects ranging from lung cancer and asthma to heart disease [16].

Another health concern related to air quality effects involves frac sand, due to substantial releases associated with mining, transport, and staging for use in fracking operations. In response, some states are pushing to develop air quality standards for these crystalline silica particulates to help assure health protection, including the State of Minnesota. Key health concerns include respiratory and cardiovascular diseases [17].

Fugitive methane also poses a substantial air quality concern, although it is not typically a health risk issue. These significant threat posed by these fugitive emissions is to climate change; methane is a highly potent GHG, readily transforming to ozone in the atmosphere. The scale of these releases is illustrated in the following example for a U.S. shale gas development area of Texas. During a July period, it was estimated that more than more than 270 tonnes (300 tons) of fugitive methane was released each day by hydraulic fracturing activities in the Dallas-Fort Worth area, mostly from the condensate and oil tanks at the well sites. This amount generated by oil and gas extraction activities was estimated to account for more tropospheric ozone in that area than the entire fleet of cars, trucks, and other mobile sources combined [18].

## 3. Citizen science: monitoring initiatives

Environmental monitoring programs are commonly constrained by competing demands for limited resources. ICT advances have made it possible for citizen scientists to help fill in some of the resulting gaps in environmental characterization, as community-based initiatives are providing alternate means for collecting and combining data from the local to the regional scale and beyond.

For example, following the Fukushima disaster, it was difficult for Japanese citizens to find information about environmental radiation levels, not only in the immediate area of the failed nuclear reactors but also for areas in which many lived and to which others had moved, beyond the evacuation zone. In response to delays in obtaining data from government officials, the Japanese citizens and nongovernmental organizations responded with grassroots efforts to collect the data themselves, with assistance from a number of organizations including sensor developers [19, 20].

Similar community-based initiatives are under way to collect and share environmental quality data related to hydraulic fracturing activities. One example is the Marcellus Citizen Stewardship Project, designed to provide local Pennsylvania citizens with tools and knowledge to monitor activities in the Marcellus shale and help protect community health. A key tool developed for this project is FracTracker, an interactive data platform that can be used to track drilling activity; it includes a map feature that shows where the fracking wells are located, as well as wastewater treatment plants [21]. (Note that these treatment plants play an important role in the region because produced water from that shale formation is not being disposed of via deep-well injection. Thus, these plants treat millions of gallons of that wastewater and release the effluents containing residual contaminants into local surface waters.)

A related initiative involves the partnership of a community-based alliance with a local college to develop citizen-focused training materials for monitoring water quality in streams and other surface waters affected by releases from hydraulic fracturing activities in the Marcellus shale [22].

## 4. Web-based information resources

In addition to the citizen monitoring initiatives noted above, a number of organizations have developed websites to share environmental information, and some of these have become go-to resources for the general public. In some cases, regulatory agencies also rely on these websites as part of their open and transparent communication efforts.

For nuclear power plants, government agencies have traditionally served as the primary source of environmental data related to releases. That has changed more recently, including in response to the Fukushima disaster and broad public desire for information about resultant radioactive contamination worldwide. To illustrate, the Woods Hole Oceanographic Institute is pursuing partnerships and community support for collection and sharing of data on radioactivity levels in the ocean, as part of assess potential impacts of the Fukushima releases [23]. Additional resources are available via non-governmental organizations, such as the Institute for Energy and Environmental Research (IEER) [24, 25] and Citizens for Nuclear Technology Awareness (CNTA) [26], which provide information about nuclear energy and ionizing radiation, including medical applications, that provide a public perspective beyond basic scientific data available via national and international agency websites. Selected online resources that emphasize citizen context are highlighted in Table 1.

For hydraulic fracturing, FracFocus [27] has emerged as among the most popular website for citizens, industries, and agencies alike. The online chemical disclosure registry available via this website provides information about wells fractured since early 2011. The current registry contains data for more than 68,000 groundwater wells, and it can be searched by location (e.g., state and county), with chemical selected from an extensive set of "ingredients" ranging from acrylamide/ammonium acrylate copolymer to zirconium compounds. Some states require oil and natural gas industries operating in their states to use this FracFocus registry to disclose information about their wells, and a number of industry personnel operating in other states without this requirement also voluntarily provide information via this website.

Considering the extensive and increasing amount of information available in this database, to facilitate efficient searches, the number of chemicals that can be included in a search was limited to 20, and the total number of disclosures returned from a single search was limited to 2,000. Recognizing that well development is projected to continue at an increased pace, registries such as FracFocus and other online databases are anticipated to benefit from ongoing ICT advances toward the goal of sharing information in real time among the broad and varied audience interested in environmental implications of hydraulic fracturing.

The Secretary of the U.S. Department of Energy (DOE) recently called on an advisory board to prepare a status report on FracFocus website. The Board's findings [28] included a call for increased transparency about what chemicals are used in fracturing fluids, asking industry to report a complete list of their chemicals and quantities added at each well, using Chemical Abstract Service (CAS) numbers, and reporting a complete list of products (the Board indicates that by not linking the products to the chemicals used, proprietary information will be protected, so this approach would reduce the number of "trade secret" claims being made by industries to avoid reporting).

The Board also encouraged upgrading the website to achieve a more usable interactive database, including the following recommendations: (1) allow searching by any field (including additive purpose and trade name); (2) eliminating the 2,0000-record display limit or adding a "next" function; and (3) including tools for searching and aggregating data by chemical, well, company, and geography, with one way of doing this being to release the full contents in raw, machine-readable form on the website. Note that data are submitted through XML files, an improvement over the earlier data submittal process using Excel sheets.

| **Organization** | **Energy Category** | **Topic** | **Uniform Resource Locator (URL)** |
|---|---|---|---|
| Alliance for Aquatic Resource Monitoring (ALLARM) | Fracking | Volunteer monitoring of local water quality | http://www.dickinson.edu/downloads/20173/alliance_for_aquatic_resource_monitoring_allarm |
| Catskill Citizens for Safe Energy | Fracking | Grassroots information, including about towns with fracking bans | http://catskillcitizens.org |
| Citizens for Nuclear Technology Awareness (CNTA) | Nuclear | Grassroots educational information, ranging from energy sources to medical radiation applications | https://www.facebook.com/pages/Citizens-for-Nuclear-Technology-Awareness-CNTA/124045627631778 |
| Energy Information Administration (EIA) | Nuclear, fracking | Production status and energy forecasts | http://www.eia.gov |
| FracFocus 2.0 | Fracking | Chemical disclosure registry, well locations, data and maps | http://fracfocus.org |
| FracTracker Alliance | Fracking | Environmental impacts of global oil and gas industry, data and maps | http://www.fractracker.org |
| Institute for Energy and Environmental Research (IEER) | Nuclear | Data and analyses geared for the public, including regarding Fukushima | http://ieer.org |
| Woods Hole Oceanographic Institution (WHOI) | Nuclear | Ocean impacts of Fukushima radiation | http://www.whoi.edu/main/topic/fukushima-radiation |

*Table 1: Selected Web-Based Resources with Information Related to Nuclear Energy and Fracking*

Another community-based organization, FracTracker Alliance, also shares maps, data, and analyses online to communicate impacts of oil and gas development; this organization’s website covers information beyond the United States, including a link titled “worldwide resistance to hydraulic fracturing” that indicates locations of national movements, moratoria, and bans [29]. The website includes a mapping tool, FracTracker, which contains an index of pre-made maps that provides information such as locations of wells drilled, those in violation of current requirements, watersheds, and storage facilities, based on available data. The organization's earlier data/mapping platform (Data.FracTracker.org) is being phased out, as it has been replaced by the new FracTracker tool that runs on the Esri-based platform, ArcGIS Online. More features are being developed for the new FracMapper, anticipated to be available in fall 2014, including the ability to store and share the data behind the maps.

## 5. Summary

Growing public concerns about climate change and environmental health impacts related to energy production have led to increased consideration of alternate sources. Nuclear power and unconventional oil and shale gas development are among the options least favored by the public, with pollutant releases resulting from routine operations as well as accidents being among the key concerns. Advances in ICT approaches and the increasingly widespread accessibility of information resources and tools have facilitated community-based initiatives and broader data sharing that can directly contribute to more informed evaluations of energy options, toward more sustainable programs from the local to the global scale.

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# Modelling Rebound Effects in System Dynamics

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## Abstract

The induction of demand by increasing the efficiency of a production or consumption process is known as the rebound effect. Feedback loops in System Dynamics can be used to conceptualize the structure of this complex phenomenon and also for communicating model-based insights. In passenger transport, the rebound effect can be induced through increased cost efficiency (direct economic rebound) and/or increase in speed (time rebound). In this paper we review and compare two models on environmental effects of passenger transport—including a model on the role of information and communication technology. We highlight the feedback mechanisms used to deal with the rebound effect (price, efficiency, and time rebound).

## 1. Introduction

Energy efficiency helps devices provide the same services using less energy, and thus can be a solution for reducing greenhouse gas emissions. However, it can also induce more demand if the energy saved leads to a lower price of a service. The induction of demand by increasing efficiency is known as the rebound effect. To better understand the complexity of rebound effects of investments in efficiency, dynamic models have to be used. System Dynamics provides an approach to conceptualizing the structure of such complex phenomena and communicating model-based insights [13, 23, 25]. We will use the domain of passenger transport as an example.

In passenger transport, the rebound can be induced through increases in fuel efficiency or other improvements reducing the variable cost per person-kilometre (direct economic rebound) and/or increase in speed of modes (time rebound). In this paper we review and compare two models on environmental effects of passenger transport, including a model on the impact of information and communication technology (ICT) on transport. We highlight the feedback mechanisms used in both models to deal with the different types of rebound effect (direct economic and time rebound).

Brief definitions of the concepts of rebound effects, elasticity of demand, System Dynamics, causal loop diagrams are presented first.

Rebound effects can be categorized as follows [14, 24] (See [12] for a very brief history of rebound analysis):

- Direct economic rebound effects: When cheaper energy (or energy efficiency improvement in using energy-intensive goods) induces price reductions that trigger an increase in the demand for the cheaper good.
- Indirect economic rebound effects (income rebound): If the consumer saves money on one good (because it is used more efficiently and its price goes down) her disposable income is higher than the income she can spend—because she didn't use the money for the purpose, she can use it for something else.

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- Economy-wide rebound effects, which appear when declining energy prices induce a reduction in the prices of intermediate and final goods throughout the economy, and cause structural changes in production patterns and consumption habits.
- Time rebound effects, which is based on time efficiency in consumption: If a consumer can consume a product or service in less time, she tends to demand more of it.

In this paper we only address the direct economic rebound and time rebound. If the efficiency increase is enabled by ICT, both direct and indirect rebound effects are subsumed under the so-called third-order effects of ICT [10].

The size of the economic rebound effect depends on demand elasticity. Economic elasticity of demand with regard to price, or price elasticity of demand (PED) is defined as the percentage change in demand divided by the percentage change in price. Elasticity of demand is one way of modelling rebound effects (See [16] for an overview of price elasticities of transport demand).

Use efficiency can be expressed via price as an input for calculating price elasticity of demand. If for example a vehicle is used more efficiently by transporting more persons at a time, the cost per person kilometer is lower, which can lead to an increase in demand.

System Dynamics is a computer-aided systems modeling approach based on cause-and-effect analysis and feedback loop structures, used for to theory building, policy analysis and strategic decision support [13, 23, 25]. A feedback loop is a closed path of causal influences and information, forming a circular-causal loop of information and action. If the tendency in the loop is to reinforce the initial action, the loop is called a positive or reinforcing feedback loop; if the tendency is to oppose the initial action, the loop is called a negative, counteracting, or balancing feedback loop [23].

Feedback loops in System Dynamics are represented using causal loop diagram (CLD). In a CLD, relationships between variables, as shown in Fig. 1, are depicted using arrows with a positive (+) or negative (-) sign placed besides the arrowhead to indicate link polarity. A positive link polarity implies that "if a cause increases, the effect increases above what it would otherwise have been" and vice versa [25]. Similarly, a negative link polarity "means that if the cause increases, the effect decreases below what it would otherwise have been" and vice versa [25]. A CLD (as a qualitative technique) can be translated into stocks (accumulations or levels) in the system and their inflows and outflows (rates) [25, ch. 6]. Mathematically, a system of difference equations (similar to differential equations but with a fixed time step) formulates relationships between stocks and flows and supports quantitative modeling in System Dynamics [23, 25].

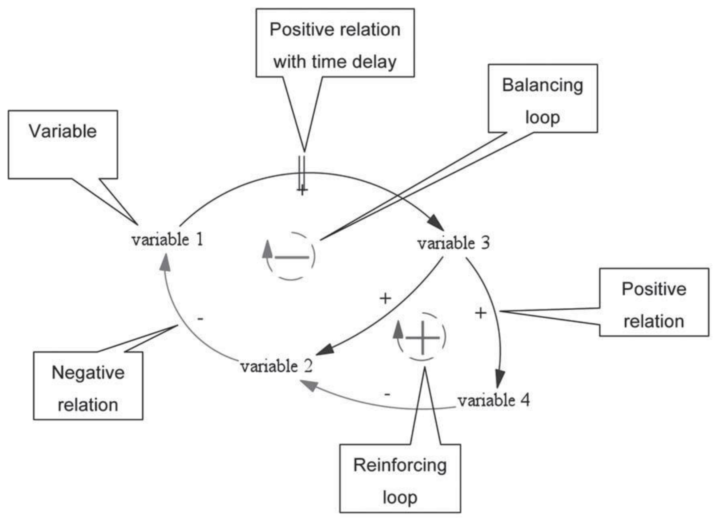



Fig. 1: Elements of causal loop diagrams (taken from [22])

## 2. Selected models

Two models from literature have been chosen to illustrate how rebound effect is modelled using System Dynamics feedback loops. The first model (Model 1) models the dynamics of how information and communication technology (ICT) positively or negatively affects the passenger transport demand and modal split. The second model (Model 2) models the dynamics of how pollution-saving technologies positively or negatively affect the tourist transport demand and greenhouse gas emissions.

Feedback loops related to Model 1 and Model 2 (as shown in Fig. 2 and Fig. 3 respectively), which are used to the rebound effects, are presented and discussed in the following sections.

## 3. Model 1: Future Impacts of ICT on Environmental Sustainability—Submodel of Passenger Transport (IPTS Study)

In 2002, the European Commission's Institute for Prospective Technological Studies (IPTS) commissioned a study to explore the current and future environmental effects of ICT to a consortium led by the Institute for Futures Studies and Technology Assessment (IZT), Berlin, Germany. The aim of the study was to estimate positive and negative effects of the ICT on environmental indicators with a time horizon of 20 years. The method applied was to develop future scenarios, build a model based on the System Dynamics approach, validate the model and use it to run quantitative simulations of the scenarios. The results were published in 2003 and 2004 in five interim reports [1-5] (the 4th interim report [4] describes the model and data used), one final report [6] and several articles [7-10].

In the passenger transport submodel of the IPTS study (called Model 1 here), the goal was to calculate the volume of passenger transport demand (in passenger-kilometres, pkm, for different transport modes) changing over time due to the causal mechanisms and dynamics modelled in terms of stocks and flows. Fig. 2a shows a high-level conceptual model for the passenger transport submodel in the IPTS study [4, 9]. Fig. 2b presents the three main feedback loops in this model: cost efficiency loop, resource scarcity loop, and mode shift loop.

Each loop exists twice (symmetrically) because of the two modes chosen here for illustration, i.e., mode A and B.

Fig. 2b is not a pure CLD, since it includes parts of the stock-and-flow diagram to better describe the central mechanism of shifting transport demand between traffic modes. This mechanism is illustrated here for only two modes of transport, Mode A and Mode B (which can be thought of, e.g., private car and public bus). In the IPTS model, this mechanism was generalized to n modes based on multimodal passenger transport models developed by Hilty [17, 18]. Five traffic modes were differentiated in the IPTS model: Private car (PCar), bus and coach (BusC), tram and metro (TraM), train, and air. In addition, three modes of "virtual mobility" including home-based telework, virtual meetings, and teleshopping were represented, which was a new feature developed for this project.

Two types of rebound effect were modelled in Model 1 with regard to passenger transport [9]: (1) Direct economic rebound effects, and (2) Time rebound effects (based on travel time budget).

The following subsections present how these two categories of rebound effects were addressed in Model 1.

### 3.1. Direct economic rebound effects in Model 1

The direct economic rebound effects in Model 1 are represented via demand elasticities for passenger transport. The IPTS study considered the rebound induced by the price level of each passenger transport mode: besides changes of market prices (e.g., the oil price), which are external to the mode, higher efficiency (e.g., fuel efficiency of vehicles) can lead to lower prices per pkm (direct rebound effect), which will create more demand according to empirical elasticity parameters. Table 1 presents the elasticity parameters for five traffic modes and for three virtual mobility modes that were used as input to the model. As shown in Fig. 2b the elasticity parameter of each mode together with per-pkm price of the mode are controlling the inflow rate of transport volume associated with the mode.

Elasticity is defined as a %-change in demand divided by a %-change in price. It will not be realized immediately, i.e., if the price changes, in that moment no change occurs in demand, but gradually over the years. Empirical studies of elasticity of demand therefore usually distinguish between "short term" and "long term" elasticity. The IPTS model expresses the temporal aspect of elasticity by adding a time constant to each elasticity value: The time values mentioned in Table 1—for example "5 a"— indicates that it takes five years until the adaptation to the price change is realized. Note that all adaptations in the IPTS model including the elasticity-based adaptation of demand (also the shift between modes based on relative speed and time deficit, which will be discussed later) are not immediate in Model 1, but controlled by time constants.

| **Description** | **Elasticity Parameters** |
|---|---|
| Economic elasticity of PCar traffic demand with regard to fuel prices | -0.3 (5 a) |
| Economic elasticity of BusC traffic demand with regard to BusC charges | -0.3 (5 a) |
| Economic elasticity of TraM traffic demand with regard to TraM charges | -0.3 (5 a) |
| Economic elasticity of train traffic demand with regard to train charges | -0.3 (5 a) |
| Economic elasticity of air traffic demand with regard to air fares | -1.5 (5 a) |
| Economic elasticity of home-based telework with regard to the cost of buying and running the equipment needed | -0.1 (2 a) |
| Economic elasticity of virtual meetings with regard to the cost of buying and running the equipment needed | -0.3 (2 a) |
| Economic elasticity of teleshopping with regard to the cost of buying and running the equipment needed | -0.01 (2 a) |

*Table 1. Elasticity parameters in the IPTS study, passenger transport [4]. Note: An elasticity value of -0.5 means that demand will decrease by 10% if prices increase by 20% (or that the demand will increase by 10% if prices are 20% lower).*

Direct economic rebound effects in Model 1 are represented via the following feedback loops (see Fig. 2): cost efficiency loop and resource scarcity loop.

*a) Cost efficiency loop:*

Traffic volume (pkm) for each mode—modeled as a stock—is controlled by an inflow rate depending of the elasticity parameter and the per-pkm fuel price associated with the mode. (For simplicity, fuel is used here a pars pro toto for the sum of all resources needed to produce a pkm which cause variable cost; these resources may vary depending of the mode of transport.)

The elasticity parameter represents "classical" elasticity of demand with regard to price (in the IPTS model: the "PED" submodel included for each mode). Because the fuel price per pkm does not only depend on the fuel price per liter but also on the efficiency with which the fuel is used ("Efficiency of A with regard to fuel"), the price of 1 pkm is affected by efficiency and will, depending on the elasticity, influence the demand (traffic volume). The efficiency can increase by technical measures (e.g., more efficient vehicles) or by better utilization of vehicles (more people in the vehicle means more pkm per vehicle-km). It is possible that more volume increases efficiency for several reasons (the "(+)"). However, for each concrete transport mode, one has to account for the specific causal link between volume and fuel efficiency and how fuel efficiency affects the price the user finally has to pay.

*b) Resource scarcity loop:*

Fuel (or any other resource needed to produce a pkm) may change in price if the total demand for this resource changes, depending on how supply reacts to demand in the market. Besides fuels, we may think of road pricing, which reflects the resource "infrastructure capacity" that is used to produce transport. Increasing use of any limited resource will at some point lead to an increase in price, which is reflected in this feedback loop. Again, it depends on the mode how this causal relationship is modeled in detail.

### 3.2. Time rebound effect in Model 1

In addition to direct economic rebound, the IPTS study (Model 1) included time rebound, another type of rebound effect based on time efficiency in consumption. Especially in passenger transport, time is a scarce resource and may affect behavior more than money. Model 1 (like Model 2) belongs to a class of models which abstain from converting time to money (which would be a straightforward approach in economic modeling) and keep financial budgets and time budgets of users separate. The time rebound effect was considered crucial in the IPTS study, because a core characteristic of ICT is the potential to accelerate processes.

Time rebound effects in Model 1 are modeled via the following mechanisms, as shown Fig. 2:

- Travel time budget mechanism
- Mode shift loop

These mechanisms work with time (not money as it is the case for cost efficiency loop and resource scarcity loop); a central variable is the speed of transport of each mode.

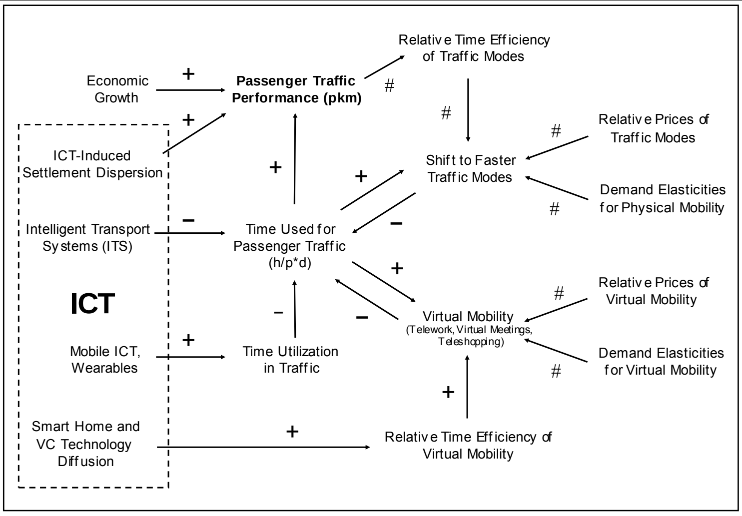
*a) Travel time budget mechanism:*

For the transport submodel the time rebound was considered via the so-called constant travel time hypothesis, assuming that the average daily time spent in transport over the whole population is more or less stable [26] (a critique of this hypothesis will be addressed later in this paper). At any point in time, the given travel volumes of all modes and their current speed levels make it possible to compare actual travel time with this time budget. If there is a deficit, this will cause a shift of the modal split from slower to faster modes. If Mode A is currently slower than Mode B, then traffic volume will shift to mode B, with some time constants similar to the ones mentioned for economic elasticity, and also with some limitations of the substitution potential. In the full IPTS model with five modes, this can for example mean that people having to commute over a higher distance will then maybe use a private car instead of the public bus, or that car drivers faced with increasing congestion will switch to the train or metro.

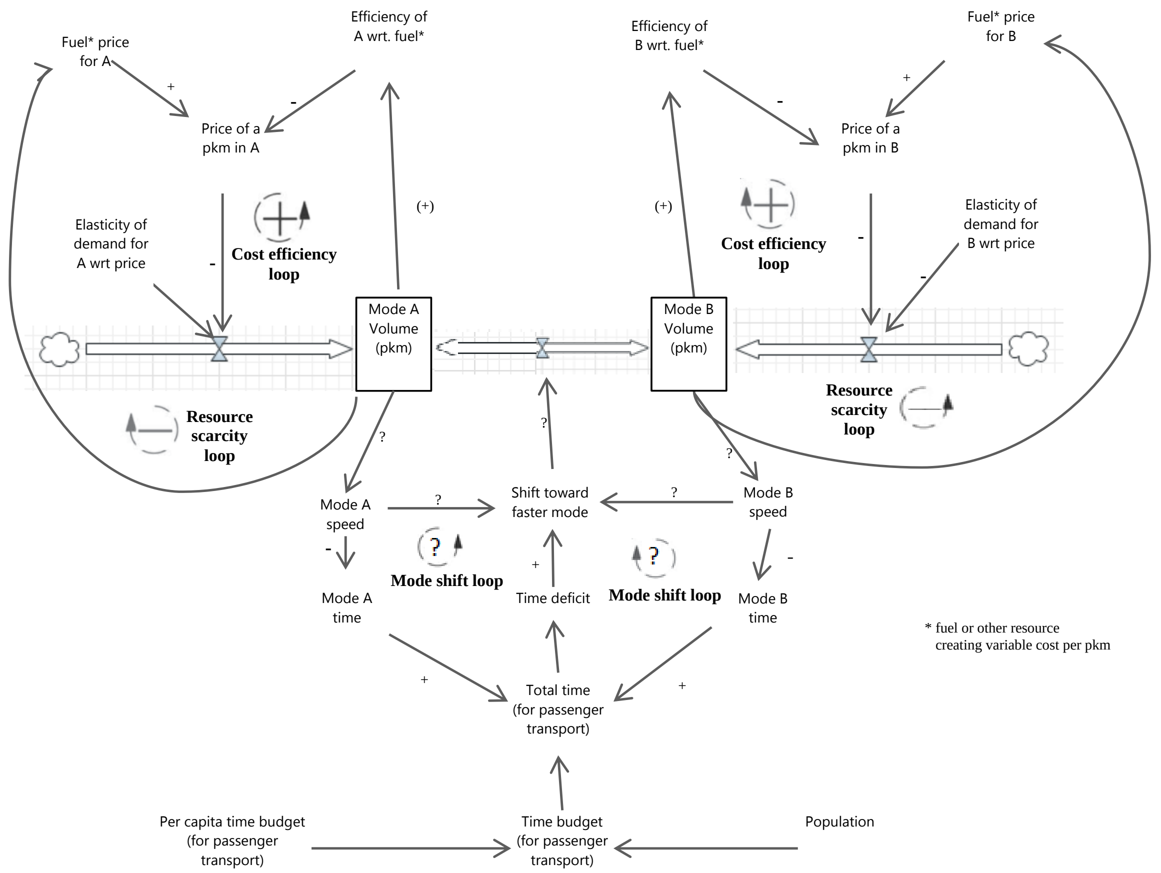
*b) Mode shift loop:*

As shown in Fig. 2, the mode-shift loop includes a causal link between the volume of each mode and the speed of this mode. This reflects the fact that utilization of each mode has an effect on time. It is important to see that this relationship can be different for each mode. For example, in public transport higher volume can lead to a better service (increased density in time and space) such as a higher frequency and more bus lines, which increases door-to-door speed for the passenger. Whereas in the private car mode, increased volume usually means that speed goes down, especially when congestion occurs. Model 1 makes this difference between "self-accelerating" and "self-limiting" transport modes and can therefore account for complex changes in demand, in particular when also the virtual modes and other effects of ICT come into play.

One of these effects is called the "time utilization effect" in the IPTS study (not represented in Fig 2b, but shown in Fig 2a): Because of mobile work that is possible to some limited, but increasing degree due to ICT, the time spent in traffic is not fully counted as transport time, i.e., a part of it is not charged from the travel time budget. Of course, the degree of time utilization is different from mode to mode (higher in public modes than in the private car mode) and changes over time with progress in mobile ICT devices and infrastructures. This is a core feature of the IPTS study. Time utilization effects can create more transport demand and influence the modal split towards public transport.




(a)




(b)

*Fig. 2: Causal loop diagram for Model 1: (a) more abstract diagram for the development of passenger transport performance, taken from the IPTS interim report [4]: "ICT has second-order effects when applied passenger traffic (all applications subsumed under Intelligent Transport Systems) and third-order effects in the long term via settlement dispersion, time use in traffic, smart home and videoconferencing technology. The "#" sign is used where the multidimensional variables are involved, leading to complex causal relationships." (b) less abstract diagram focused on main feedback loops*

Two features of Model 1 could not be shown in Fig. 2. First, different modes of transport can share infrastructure, which means that their speeds are coupled to a certain degree (e.g., public buses may be slowed down by congestion caused by private car traffic). This can be expressed in Model 1 by so-called coupling factors for each pair of transport modes. Second, there is an overall reinforcing feedback loop of passenger transport demand which works via settlement dispersion: more traffic volume slowly increases the level of dispersion. It is the level of dispersion which decides how a time deficit is corrected; the correction is in fact a mix between the two possibilities of shifting to a faster mode or reducing the distance covered.

## 4. Model 2: Tourism Transport, Efficiency, and GHG Emissions

The second model (Model 2) is taken from a study by Peeters [22] on modeling tourism transport demand considering rebound effects of technological efficiency improvement. In a similar way to Model 1, Model 2 has also addressed two types of rebound effects with regard to tourism transport [22]: Direct economic rebound effects and time rebound effects (based on travel time budget).

The following subsections present how these two categories of rebound effects were addressed in Model 2.

### 4.1. Direct economic rebound effect in Model 2

As shown in Fig. 3a, the direct economic rebound effects are represented via two reinforcing feedback loops in Model 2: Efficiency enhancing loop and emissions loop.

*a) Efficiency enhancing loop:*

This is the main reinforcing loop, which starts with investment in efficiency enhancing technology. The efficiency reduces energy consumption per seat-kilometer (skm), and thus it reduces cost per skm, which in turn can induce increases in transport volume (pkm) depending on the price elasticity of transport demand (although the economic elasticity is not clearly presented in [22]). More transport generates funds that can be used as more investment in technology improvement, creating a reinforcing loop that improves efficiency.

*b) Emissions loop:*

The reinforcing loop of efficiency improvement transport volume does not necessarily reduce total emissions due to the increase in transport volume in the reinforcing loop. Which of the two loops of efficiency and emissions has the most impact depends on the specifics of the transport system described by the model [22].

*c) Attitude loop:*

A third relevant loop in this system is the attitude loop, a balancing loop because an increase in environmental pressure will tend to increase the willingness to invest in pollution-saving technology, which also improves efficiency [22].

### 4.2. Time rebound effects in Model 2

Model 2, as shown in Fig. 3b, contains three reinforcing feedback loops—travel time loop, cost loop, and mode shift loop—and one balancing loop, i.e., max speed loop. The causal loop diagram in Fig. 3b is based on three basic assumptions drawn from literature (Peeters 2010):

- Tendency to travel longer distances (a significant part of a population has the aspiration to increase their range),
- Travel time budget (on a population level the total amount of time spent for actually traveling from home to destinations and back is more or less constant)

- Constant share of income (the average amount of money spent on transport per year on a population level is a constant share of income).

*a) Travel time loop:*

Assuming a constant travel time budget, if people have more money they will be able to travel more kilometers within the constant time budget (This is valid for the whole population, but not for the individual as they can temporarily change the amount of time and money spent on travel.) From ‘‘average distance’’ a reinforcing loop boosts the distances traveled [22].

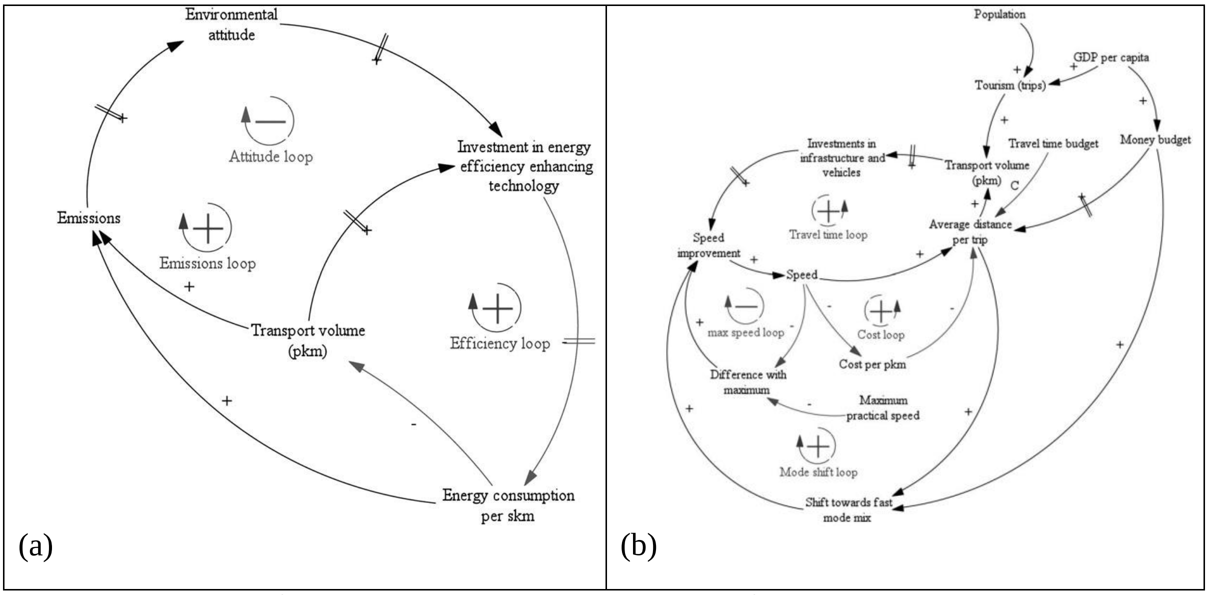



*Fig. 3: Causal loop diagram for Model 2 [22]: (a) Pollution-saving loops (b) Basic forces in transport systems (Time delay is indicated by the double strikethrough lines in the arrows.)*

*b) Mode shift loop:*

As shown in Fig. 3b, an increase in money budget and in average travel distance will increase the share of faster modes. Faster transport modes are used over longer distances [22].

*c) Cost loop:*

This reinforcing loop runs through cost of transport. With an increase in speed, operational costs generally reduce because productivity is increased faster than per hour operational costs, allowing for a higher number of kilometres to be sold [22].

## 5. Discussion and Future Research

Both Model 1 and Model 2 have employed System Dynamics feedback loops to explore the dynamics of transport volume (in passenger-kilometres, or pkm). A better understanding and calculation of the demand for transport volume is important because energy demand and greenhouse gas emissions are associated with transport volume. Both models showed that efficiency cannot necessarily reduce total emissions if the transport volume increases because of reinforcing feedback loops described above (both time rebound and direct economic rebound).

Both models included similar external variables such as population and the economic growth as drivers of transport demand. (See the upper right part in Fig. 3b and upper left part in Fig 2a)

The efficiency loop modelled in Model 2 (Fig. 3a) includes investment in efficiency enhancing technology. However, investments are not explicitly represented in Model 1.

Both models have employed the concept of economic elasticity of demand with regard to price. However, Model 1 addressed this in a more explicit way in terms of presenting elasticity parameters for different transport modes.

Both Model 1 and Model 2 in a similar way have used the constant travel time budget assumption to show the dynamics of speed versus demand; higher speed implies using the constant time budget to cover more distance.

*Critique of the travel time budget approach:*

Both Model 1 and Model 2 have assumed that on a population level the total amount of time spent for actually traveling from home to destinations and back is more or less constant (travel time budget). The idea of a travel time budget—which has been developed since 70s in the field of transport research (e.g., see [15])—has encountered critiques. For instance, Höjer and Mattsson [21] point out weaknesses of this idea and found it "hardly reasonable to presuppose that travel time is constant when planning for future transport systems and urban structures." It would be useful to further investigate the advantages and weaknesses of employing the hypothesis of constant travel time compared to other alternatives. Two points regarding the critique can be considered.

First, the travel time budget approach helps model the scarcity of the resource time. Without a travel time budget, a model could possibly predict that someone who can afford it would travel for more than 24 hours per day.

Second, Model 1 already showed a way how to relax the constant travel time hypothesis without loosing its advantages: the concept of (travel) time utilization, or dual use of time, mitigates some of the problems of this approach. As shown in Fig. 2a, the IPTS study modelled the variable of time utilization in traffic (This variable is not presented in Fig. 2b to make the diagram as simple as possible for the purpose of this paper), which means that if passengers can do something else while traveling, this "something else" makes travel less "time consuming." The IPTS study included certain factors regarding time utilization. For example, an hour on the train while reading is not a full travel time hour. As shown in Fig. 2a, time utilization can create more transport demand and it can influence the modal split via the mechanisms already explained, it has roughly the same effect as an increase in speed.

An alternative approach is to convert time into money, leading to the question of the subjective economic value of time spent on travel. The economic value of travel time has been investigated in empirical studies since the 1970s. As an example, if drivers have the choice to pay a fee to cross a bridge or to accept detour for crossing a bridge without paying a fee, these choices can be related to their income. It is known from such studies that the value people assign to the time spent while driving a car is between 1/3 and 1/2 of their net hourly income [18]. So it is not the same as working, but it is related to income. The advantage of this approach is that time cost could be added to fuel cost and other variable cost, yielding one price for each pkm. It would then be easier to apply demand elasticity data to determine the size of the rebound effect. There would be no specific time rebound, just the economic rebound effects. However, one problem with monetizing time is that the marginal value may increase dramatically; the second hour per day spent in traffic might be much more expensive than the first one, considering this makes the approach less different from the constant travel time budget approach than it may look like.

*Quantification of rebound effects*

Previous studies on rebound effects have presented the calculation of the magnitude of rebound effects. For example, Borenstein [12], in his microeconomic framework or evaluating energy efficiency rebound, provided illustrative calculations for improved auto fuel economy and lighting efficiency and showed that rebound likely reduced the net savings by roughly 10% to 40% from these energy efficiency improvements.

How could such a quantitative analysis be conducted using the models discussed in this paper? Each of the models would have to be run in two versions (so-called competitive models, [19]), an original version and a version with those feedback loops cut which are responsible for rebound effects. The model outputs, such as total energy consumption of passenger transport or total passenger transport volume, could then be compared quantitatively among the two versions. Such a simulation experiment could also be refined to a larger number of model versions by disabling only one type of rebound effect at a time.

To our knowledge, none of the two models discussed in this paper has been used in this way. This is due to the fact that the aim of designing these models has not been to quantify rebound effects, but rather to make predictions in the passenger traffic sector while considering the rebound effects.

## 6. Conclusions

The two models we discussed both represent the same types of rebound effects in passenger transport. Both are multi-modal transport models, considering the dynamic change of modal split as well. Feedback loops (closed causal chains) are an obvious concept to model rebound effects at a macro-economic level as it is done in System Dynamics (as opposed to use behaviour rules at the micro-economic level in agent-based simulation).

Despite the similarities, the comparison of the two models showed that there can be much variety in the details of modelling rebound effects in passenger transport. Model 1 puts greater emphasis on the different characteristics of transport modes and how they interact, on time utilization and virtual modes, whereas Model 2 explicitly considers investment in technology and environmental attitude as variables in the main feedback loops.

Future research should clarify how these elements can be consistently combined in a model of passenger transport that accounts for the dynamics of rebound effects while considering the various impacts of ICT on transport.

## Acknowledgements

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# Groen Gas - Sustainable Supply Chain Manager

## New combinations in the transition towards a sustainable energy production

Frans Debets[1] und Manuel Osmers[2]

## Abstract

Although the production of sustainable energy has grown rapidly, the experience of the last 10 years has proved that the road towards sustainability is a bumpy one. If we want to reach our goals we have to have broad consensus on three basis questions: *Why* do we want this, *What* can we do to reach our goals; *How* can we do this.

An analyses of the sustainable energy production shows that the largest part of the production is based on biomass. The fermentation of biomass into biogas in digesters is one of the methods. The development of biogas has been successful but now stagnation is looming. Despite this stagnation, new opportunities present themselves. A case in Coevorden is described as an example of developing new combinations. To facilitate new developments a software tool called the *Sustainable Supply Chain Manager* has been developed as a "deliverable" of the Interreg NSR IVA project Groen Gas/ Grünes Gas D-NL by the Carl von Ossietzky Universität of Oldenburg. Three cases were used to validate the tool: the case *Gemeinde Dornum* (D), the case *Gemeinde Westerstede* (D) and the case *Energy-Transition-Park in Coevorden* (NL).

In this paper we briefly look at the developments in the field of sustainable energy production, in both Germany and the Netherlands. The case Coevorden is presented as an example of *Neue Kombinationen*. The SSCM tool can be used to find the best option for new developments.

## 1. Introduction

The members of the European Union follow the Renewable Energy Directive of April 2009. The overall goal is to cover 20% of the energy use with energy from sustainable production. Part of this ambition is to reach a level of a 10% sustainable share in the transport fuels.

Each member of the EU will contribute to this goal according to its respective capabilities and ambitions. For instance Sweden has the possibility to use its vast hydroelectric potential and wood production, their renewable energy goal is 50%. The Netherlands has limited possibilities to generate renewable energy, their 2020 goal is 14%. Germany has set its goal on 18%.

In 2009 the overall EU status quo was about 8%. Some countries were already very near their 2020 goal, e.g. Sweden. Others still had a long way to go; Germany had reached 10% , the Netherlands reached 4%. [1], [2]. In 2013 the Netherlands had reached 4,5%, Germany has reached 12%.

These percentages are linked with the *gross energetic end use*. The definition of "*end use"* is different from the *primary energy use* that is calculated from the use of primary energy materials, basically the volume of oil, coal and gas. The *gross energetic end use* is based on the total energy use of all end users, this does <u>not</u> include the use of primary energy for non-energetic purposes, for instance oil as a raw material for the chemical industry and does not include the losses in generating and transporting electricity. As an illustration: the Netherlands have a *total primary energy use* of 3200 PJ, the *gross energetic end use* is 2200 PJ. The 2020 goal of the Netherlands is 14%, based on the end use of 2200 PJ this would be: 308 PJ. Germany has an

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*Endenergieverbrauch* of approx. 9000 PJ, the 18% goal for 2020 is: 1620 PJ. Both countries try to reduce the end use, the Netherlands has set its own goal to reduce at least 100 PJ by 2020. If the end use can be reduced to 2000 PJ, the 14% 2020 goal drops from 308 PJ tot 280 PJ.

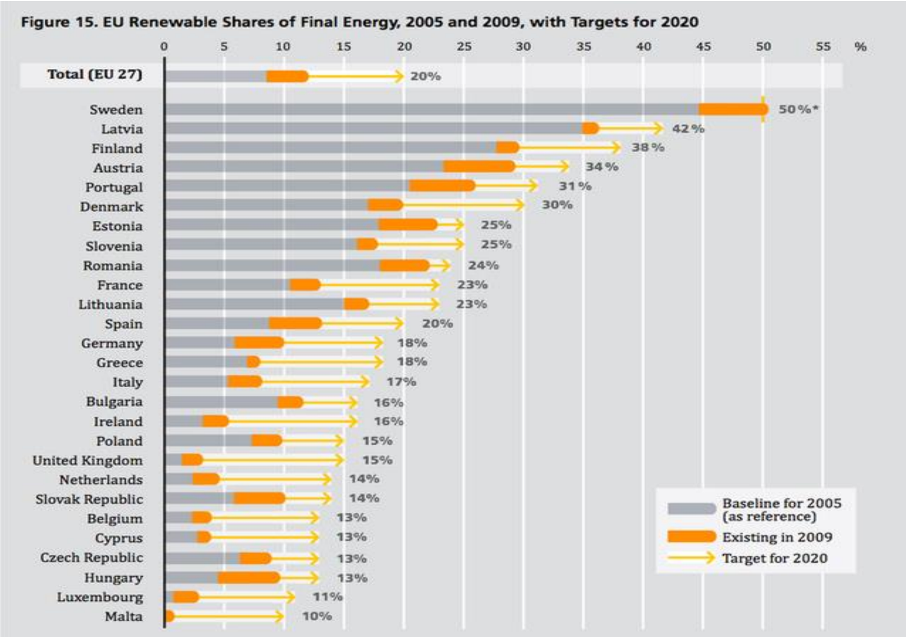


*Table 1. The EU targets for 2020 and the status quo in 2005 and 2009.*

It must be stated that energy use is closely related to the growth of the economy. The Netherlands that now have a *primary use* of 3200 PJ, used in 1960 approx. 1000 PJ. In 1980 its use crossed the 3000 PJ line. The last few years due to the economic crisis and the efforts to reduce energy most European countries managed to stabilize or even reduce their total energy demand. The world wide trend is that the more developed countries stabilize or reduce their energy demand, the new economies still have a strong growth of their demand. E.g. In 2012 was the fourth year since 2008 that the G7 countries' energy demand shrunk: 1.6% in 2012. N.b.: the demand in Germany and the Netherlands rose slightly.

Although the theme of energy reduction and the switch to a sustainable production has a high political and public profile and is supported with large budgets, the actual reduction and the alternative production is not yet impressive in both Germany and the Netherlands.

In this paper we discus some aspects of the stagnation, public support or acceptance is one of the aspects that will get attention in this paper.

Based on the assumption that problems and threats not only lead to stagnation but also to new approaches and concepts, we analyse an interesting case of "neue Kombinationen" in which local governments and commercial developers try to find a new way to serve the cause of the sustainable energy.

## 2. A bumpy road

The transition towards a sustainable society is a complex process. Policymakers, companies and the people share the vaguely defined ambitions, but the "drivers" behind the ambition (why do we want this?) and the concrete steps forward, lead to intensive discussions. At this moment every windmill or fermenter seems to be a "battle ground" where societal forces clash. The road towards sustainability is a bumpy one and it is littered with broken dreams, disappointing failures, inspiring successes and promising breakthroughs.

An interesting phenomenon is that society as a whole seems to agree on the goal, there is, in general, consensus on the question *What Do We Want*: decarbonize, less use of fossil fuels, less dependency on external sources. The consensus is less on the question *How can we Do It*? E.g.: legislation to reduce energy leads to effective resistance from target groups; the development of wind power or biogas plants lead to intensive controversy in the production regions. The consensus on the basic question *Why Do We Want This* is not developing well either. Four ”drivers” behind this *Why* question are:

1) Climate change.
   The production green house gas must be stopped.

2) Supply security
   One day oil and gas will not be available anymore, and our dependency on suppliers of fossil fuels make us vulnerable, therefor: we must now invest in sustainable production.

3) Environment
   Many of our environmental problem are related to the production, transport and use of fossil fuels. We must stop that.

4) New economic chances
   The transition towards sustainable energy provides opportunities for new economic activities and jobs in our countries.

This mixture leads to complex discussions, polarised positions and shifting arguments. Developments in Ukraine or the Middle East lead to more appreciation of point 2; extreme weather conditions or IPCC reports shift the focus to 1; success or failure of new industries influence the importance of 4; problems with shale gas, problems in the nuclear industry or a blow out in the Mexican gulf brings nr. 3 back into the focus. In the heated debates the opponents use strong arguments (*it is 5 minutes to twelve….)* leaving the public and the political leaders behind in confusion.

To develop an effective strategy towards a sustainable society it is important to have a broader consensus and a consistent communication on those three questions: *Why* do we want this, *What* can we do to reach our goals; *How* can we do this. These are also important in the development of local initiatives or individual projects.

## 2.1. How can we do it?

The use of sustainable energy is, in the public eye, mainly the use of sustainable electricity. In Germany approx. 25% of electricity consumption is produced with sustainable systems, for the Netherlands it is 10%. But the energy use is much more than just electricity: transport fuels and energy for heating must also be taken into the account.

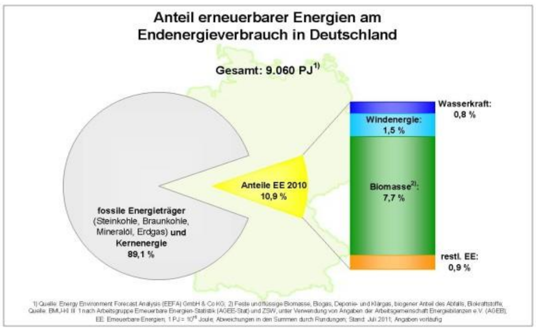


*Table2: The percentage of renewable energy, based on the end use, in Germany 2010*

The above illustration about the status quo in Germany (2010) indicates the dominance of fossil fuels. The 10,9% sustainable energy is 987 PJ or 274 TWh.

For instance the impressive development of windpower “only” brings in 1,5% (38 TWh), the enormous amount of solar power installations produced a volume energy that is too small to represent with a visible slice of the pie. n.b. The wind in production in Germany and the Netherlands kept on growing after 2010

| year | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|
| Installed GW windpower in Germany | 27 | 29 | 31,3 | 34,6 |
| Produced TWh | 37,8 | 48,8 | 50,6 | 53,4 |
| Produced TWh in Netherlands | 4,5 | 4,7 | 4,9 | 5,5 |

*Table 3: The production of wind energy in Germany and the Netherlands.*

The illustration below represents the situation (2011) in the Netherlands, the sustainable slice is only 4%. The 2014 situation is not very different, the Netherlands still hovers around 4,5% (95 PJ)

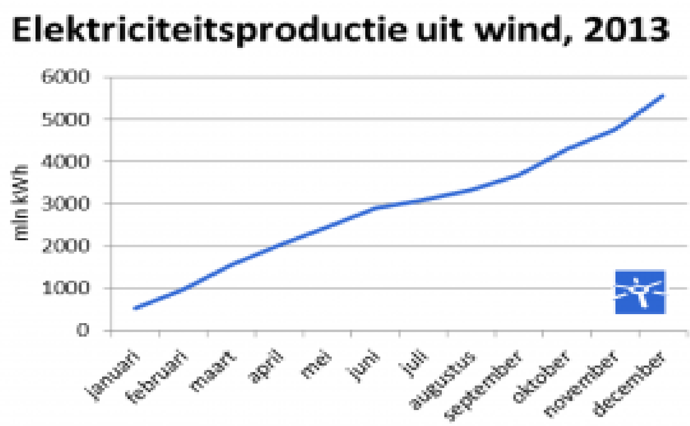


*Table 4: The production of wind energy in 2013 in the Netherlands*

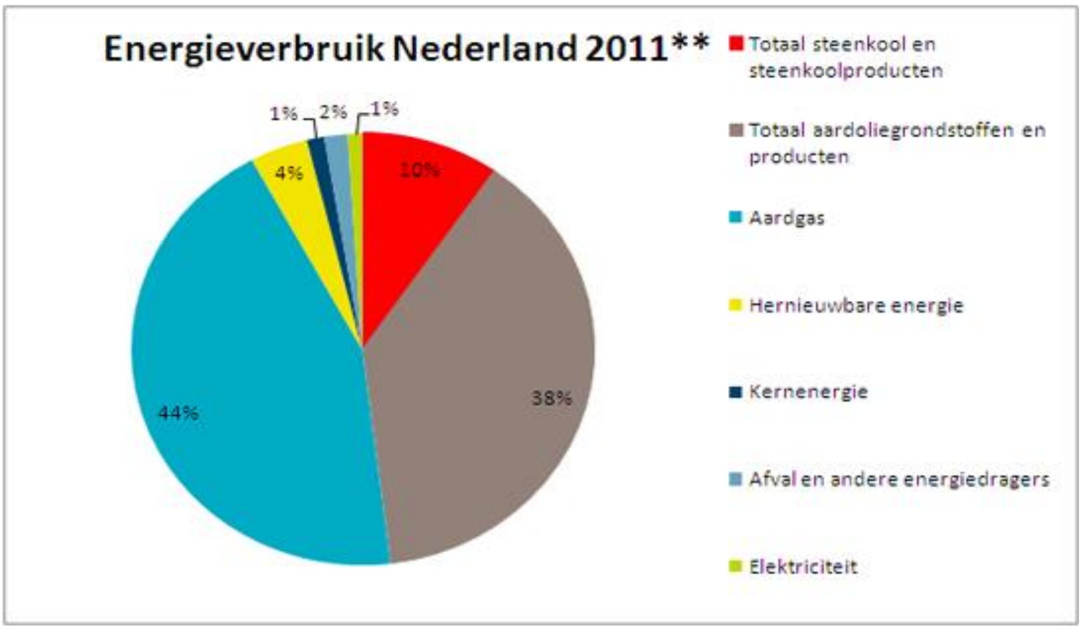


*Table 5: The end use of energy in the Netherlands and its sources.*

In both countries biomass is the dominant source of sustainable energy (Belgian is also presented hereunder), more than 70% is biomass based.

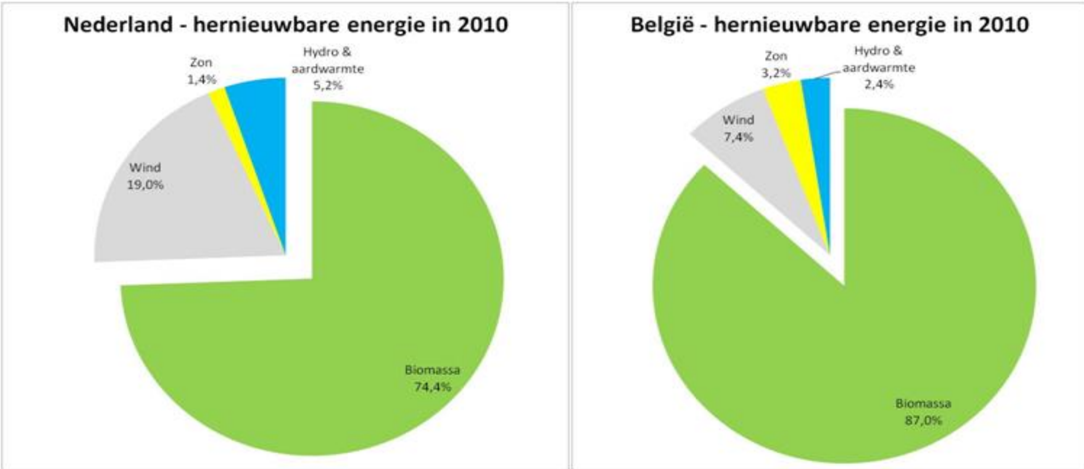


*Table 6: Renewable energy in the Netherlands and Belgium in 2010.*

Biomass use can be wood to co-fire the coal firing electricity plants, or it is waste that is burned in incineration plants, or wood burning in households, or digestable materials that are used in fermenters to produce biogas, or ethanol or biodiesel as transport fuel. The illustration below indicates the versatile use of biomass in Germany: 45,5% is used to produce heat, 12,1% produces electricity, 13% produce transport fuels.

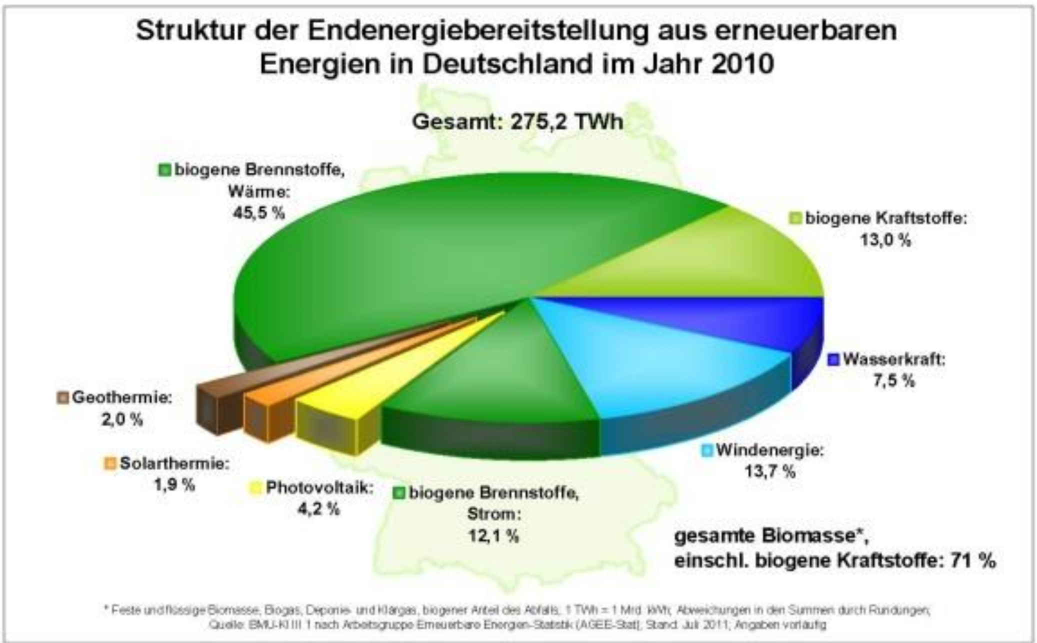


*Table 7: Renewable Energy in Germany in 2010*

### 2.2. Biogas

One of the biomass conversion routes is the fermentation into biogas, this can be used in a gas motor (heat power combination) that drives a generator to produce electricity or it can be upgraded to natural gas standards and distributed through the natural gas infrastructure. The illustration below indicates the rapid growth of the number of biogas systems in Germany and its capacity towards approx. 3.500 MW in 2013. These systems produce approx. 23 TWh electricity, comparable to roughly 50% if the wind power production.

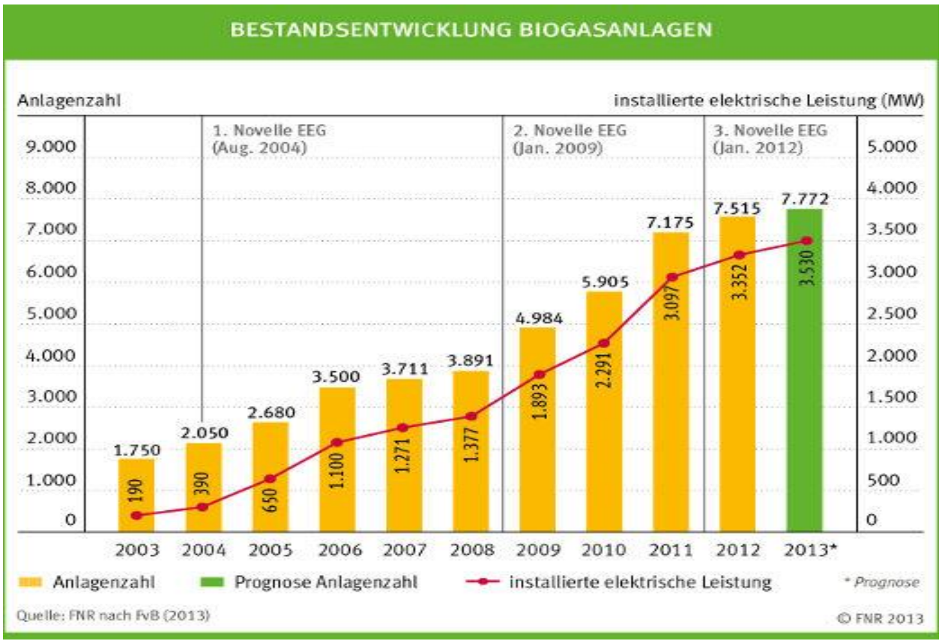


*Table 8: Biogas systems in Germany.*

In the Netherlands the number of installations grew rapidly after 2005, but stagnated after 2010, the number is approx. 110 with a capacity of 110 MW and a production of approx. 0,7 TWh. This production has not changed much since 2010.

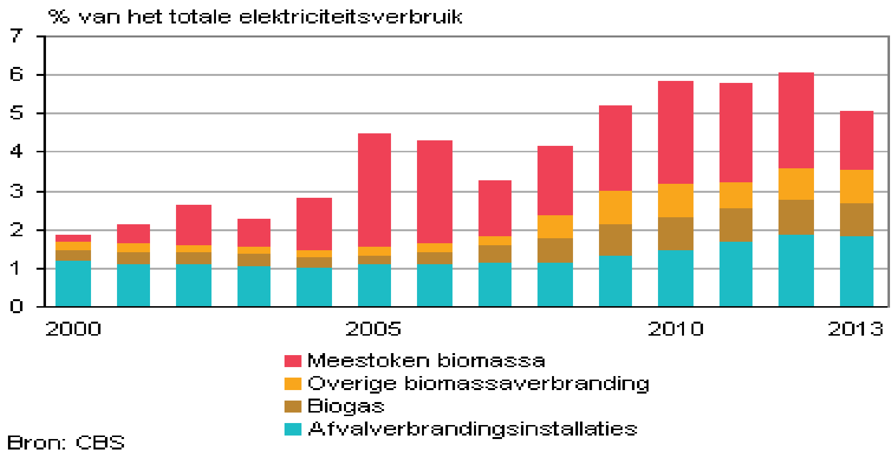


*Table 9: Renewable electricity production in the Netherlands 2000-2013*

### 2.3.1 Stagnation of the biogas industry

The rapid growth of the biogas industry took place, mainly, in the agriculture industry. Farmers started to ferment agri-waste products like manure and crops like maize or sugar beet. To be able to have a viable business case, subsidies were needed to support this development. The kWh price could go up, in Germany, to 30 cents per kWh if all bonus possibilities were used. The rapid growth of the installed capacity in Germany led to several effects: the land lease prices increased; the landscape changed due to the increase of maize production; the traffic of input and output transport in the rural areas increased; technical problems, like fermenter explosions, were new and attracted much public attention; the price of input materials rose – the footloose biomass traders took advantage of the biogas plant owners. Other reasons behind these effects can also be identified, e.g. the growth of the intensive animal production also contributed to the "Vermaizung"; the increase of commodity prices on the world market also inflated the lease prices, but the negative aspects and connotations "stick" to the biogas industry.

Next to these negative aspects were the impressive contribution to the *Energie Wende*; new economic activities started and grew out to export business for the world market; extra income for the farming community. The recent discussion about the support instrument, the EEG[3] , indicates that the biogas industry cannot grow as brisk as before. The growth will be "capped" to an annual growth of 100 MW, the bonus system will be reduced, the payout per kWhe will be reduced to 13,39 cent per kWh for the larger systems up to 20 MW, up to 500 kW the "Vergütung" is 15,26 cent.

The SDE[4] in Netherlands is a somewhat different subsidy system but in general it is the same: it provides for a long period (12 – 15 years) a guaranteed price per kWh. For the SDE the annual budget (€3,2 $10^9$ in 2014) is limited, the government wants to promote a "scramble" for the budget to get the most kWh per Euro. In the SDE system one can tender in tranches, in the first tranches the price is low but the chance to get the 12 year contract is high, in the next tranches the price is higher but the chance is smaller. For electricity production (in SDE 2014) with fermentation the first tranche is 19,4 cents per kWh, in the third tranche it is 22,7 cents per kWh. Most new applicants decide to produce green gas, and not electricity. The SDE 2014 price is 48,28 cent per $m^3$ (tranche 1) to 60,1 cent per $m^3$ (tranche 3), in kWh (based on 8,61 kW per m3 gas): 5,6 cents per kWh to 6,9 cent per kWh.

The described stagnation is an example of developments that interact with the observations described under2: an effective strategy towards a sustainable society calls for a broader consensus on three essential questions: *Why* do we want this, *What* can we do to reach our goals; *How* can we do this.

### 2.4.2 New chances, a way out…

Although the growth of the digester industry will slow down, the question can be asked if the transition towards a sustainable energy system can be successful without the production of biogas. The technology will continue to improve and the amount of fermentable biomass in modern countries is too large to ignore the potential of fermentation.

Some new developments may offer new opportunities for the fermentation technology. Three relevant developments are mentioned hereunder.

1) The peak production of wind power and solar power calls for a backup capacity that can be activated on short term notice. The biogas units can be switched on and of rapidly, provided that they can store the biogas production for some time.
2) The fermenters are not only energy systems, they are also systems of biomass conversion. They can be used as nutrient production facilities. In the Netherlands there is a great need for manure and slurry processing so that the surplus of Phosphate and Nitrogen can be concentrated and be made exportable.
3) The development of Liquid Natural Gas (LNG) as transport fuel is promising. LNG has many advantages over Diesel: it has a high energy value: 50 MJ/kg (diesel: 30 MJ/kg); lower

[3] The Erneuerbare Energie Gesetz provides the frame work for the financial support for sustainable energy production. The costs are socialised, each company (except the ones with exemption) and household pay an annual fee.

[4] *Stimulering Duurzame Energie* is the main instrument to stimulate the production of sustainable energy.

emission of fine particles than diesel; gives less motor noise and is cheaper. LNG is liquefied natural gas, through lowering the temperature (-162$^0$C) . LNG made from biogas is purer $CH_4$ than LNG from natural gas, the fraction of longer CH molecules like ethane, propane, butane, pentane, hexane is smaller. The Green LNG (also called bio LNG or LBG) may be a good conversion route for biogas.

These aspects may provide opportunities for new developments.

### 2.5..3 Sustainable Supply Chain Manager

To support new developments a software tool called Sustainable Supply Chain Manager has been developed as a "deliverable" of the Interreg NSR IVA project Groen Gas/ Grünes Gas D-NL by the Carl von Ossietzky Universität of Oldenburg. Three cases were used to validate the tool: the case *Gemeinde Dornum* (D), the case *Gemeinde Westerstede* (D) and the case *Energy-Transition-Park in Coevorden* (NL).

The SSCM model is split in five different stages, which represents different working steps in the supply chains of the biogas plant. Stage 1 stands for the material supply value. Stage 2 for each part of the logistic needed to feed the biogas power plant with substrate or take the digestate back to the fields. Stage 3 shows the operating figures of the production. Stage 4 is reserved for the grid distribution and stage 5 for the usage of the biogas energy. The last stage is called A*ctions* and there the user can enter different models in terms of sustainability.

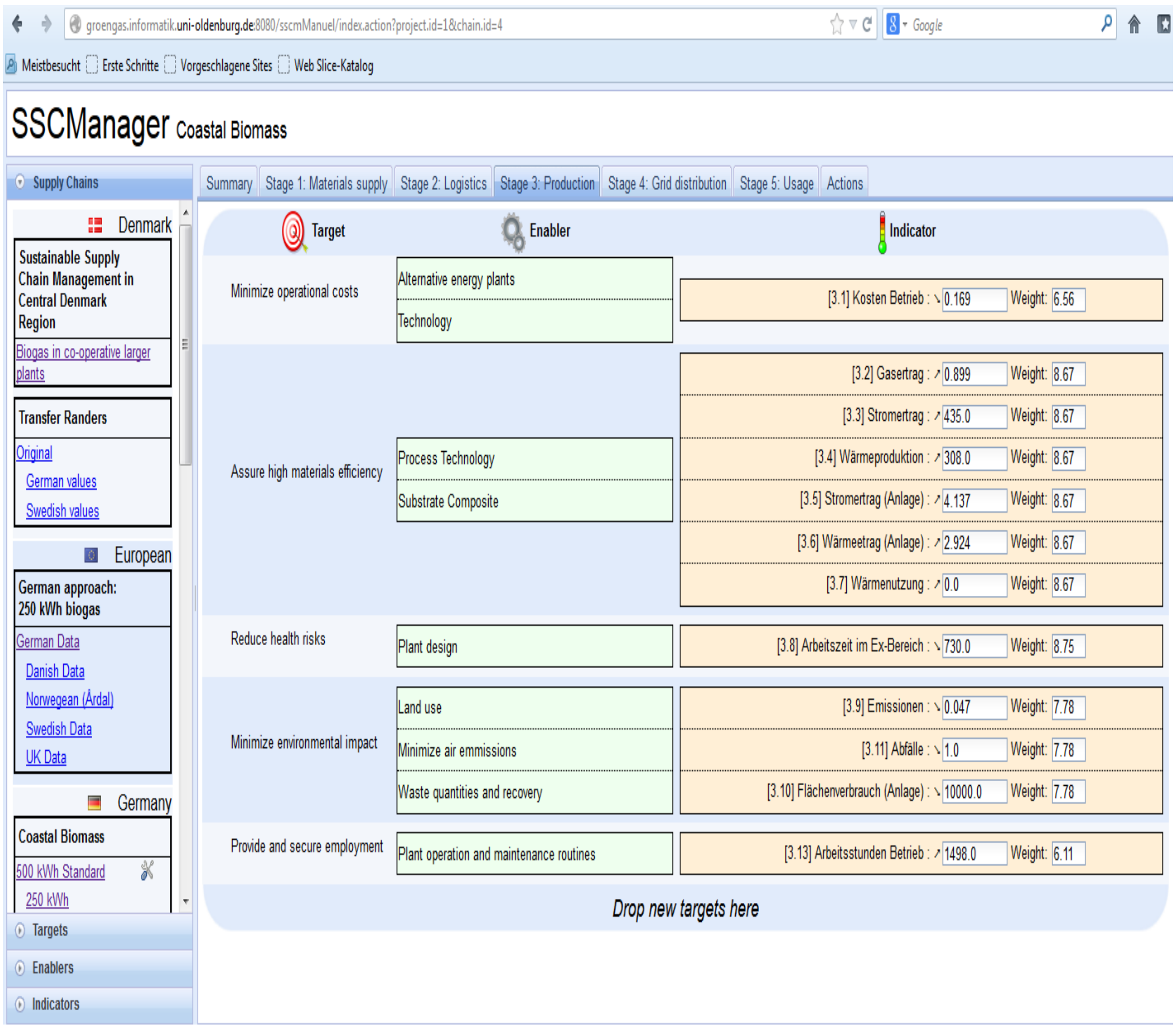


*Illustration 10: Screenshot of the SSCM tool: Stage 3*

The collected data are assigned to a model called "base chain". This can be used to compare alternatives and to find the most sustainable solution based on the assessment the user decides for. By asking the preferences of people in area the social acceptance can be raised, the people in the area will be able to add their opinions about the importance (in the model the term is *weight*) of key figures.

The SSCM software tool simulates and enables the development of digester configurations with the highest sustainability (also economic sustainability) and acceptance with the help of the importance (weight) of the different indicators (or key figures) selected by the questionnaires. The indicators can be changed to provide a tailor made tool for the user.

These changes represent modified operational procedures in the supply chain of the digester and will be simulated with the help of the questionnaires and Promethee multi-criteria decision-making algorisms (MCDA). These create a ranking graph on the different digester models and their different specifications, to show the user, which changes will provide a sustainable solution under the decisions made previously.

MCDA is a discipline of operations research that explicitly considers multiple criteria in decision-making environments. Whether in our daily lives or in professional settings, there are typically multiple conflicting criteria that need to be evaluated in making decisions. This will help us to understand the complexity of the developments in the field of sustainable energy.

## 3. Energy Transition Parks - The case in Coevorden

One of the policy themes in the Northern provinces of the Netherlands is the development of energy transition parks. The policy is based on the presumption that different methods of energy production can be organised in synergetic combinations in which energy of different levels of exergy and materials can be exchanged and brought to value.

In Coevorden the local government, together with the Province of Drenthe, wants to stimulate these synergetic combinations. The following case is an example of promising co-development. The parties involved develop a concept that is different from the standard concepts: not small but large; not farm based but on industrial scale; not stand alone but with intensive interactions with neighbouring activities; not producing biogas ánd trading in input and output materials – but concentrate on biogas production; looking for the highest added value.

A German investor (hereunder called A) wants to use the experience and knowledge of the German fermenter industry and develop a fermenter on an industrial scale on the Dutch side of the German-Dutch location *Europar*k. The biomass input is mainly manure from the agriculture industry in the Netherlands (0,5 milion tons) and an additional input of maize (0,1 million tons). After the fermentation the digestate will be separated into a solid fraction and a liquid fraction. The solid fraction is then dried, this will be exported as a (P rich) fertilizer, the liquid fraction will also be used as a (N rich) fertilizer. The biogas is upgraded to natural gas standards and injected in the German gas system, with support from the EEG arrangements.

In this configuration the system needs an external source for the heating of the fermenters and the digestate drying process. A nearby wood pellet plant, with a surplus of heat, is able to provide the heat.

Company A. does not want to get involved in the logistics of input and output materials, he outsources this completely to a third party that brings in the biomass and looks after the digestate fractions, without charging costs.

The large amount of biogas (40 miljoen $m^3$) attracts the attention of a company (hereunder called B) that wants to develop a large scale bio LNG plant. The bio LNG will be delivered to the market by truck. Company B. calculated that a viable business case can only be developed if the biogas volume is 100 million $m^3$. A and B get into contact with another company ( herunder called C) that is also preparing the development of a large scale fermenter in Coevorden. A and C together can produce 80 million $m^3$, this is enough for B to start a project.

For A and C the benefit of the tri partite configuration is that they do not need to invest in the unit for upgrading the biogas and in the unit for pumping the gas into the grid. Delivering the gas to the LNG plant can be done without subsidy, so there is no subsidy dependency.

The case with A, B and C is promising, but the "triangle" also has its dilemma's: The LNG producer B wants to be sure that both A and C will start their production; but A and C wait until they are sure that B will start. The positions are not equal: B cannot go ahead without A and B, but A and C can go ahead with their fall back scenario's: individual green gas production. To prevent stagnation because of the complex dependencies between the three, A. starts with the scenario of producing green gas and pumping it in the local Dutch gas grid, supported with SDE subsidy, with the intention to sell the gas to B. once B. is ready for it. B. starts with a scenario that his plant is not based on direct delivery of biogas from A and C. but on a certified volume of green gas, with the physical input of naturel gas. In a later stage the virtual green gas delivery can be changed into a "real", direct delivery of the biogas.

The total complex will be able to convert approx. 1.2 million tons of biomass into fertiliser for agriculture, produce approx. 40 million kg of bio LNG (about 2 PJ) and approx. 20 million kg of "green" $CO_2$. The total investments will be around €120 million.

This project would not be possible without his intensive cooperation between the three main parties. New approaches and synergetic combinations can create large steps forward on the road of energy transition.

The material from this case is used to support the further development of the SSCM tool.

## 4. Outlook

The future of the biogas power plants is non-specific. The *Energie Wende* gives Germany and Netherlands the chance to build their sustainable energy infrastructure. Both countries have different laws and policies to reach their goals, but more and more the countries will need to integrate their policies; energy production and distribution is a cross border activity.

In the Interreg NSR IVA project Groen Gas/ Grünes Gas D-NL the partners try to learn from each other's successes and failures. The SSCM will be a tool to model digesters in both countries and to compare them with each other under the weights set before by the user of this software tool. With new projects the SSCM can be developed further, also for other research fields in which supply chains need to be compared for their sustainability.

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# An Equation-Based Approach to Transition Specifications in Material Flow Networks

Andreas Moeller[1]

## Abstract

Material flow analysis (MFA) describes a class of methods that allow analysing and designing material and energy flow systems like supply chains, eco-industrial parks or production sites. Material flow networks are one of the methods in the field of MFA. Based on the Petri nets, the material flow network make it possible to conduct static MFA (steady-state modelling) as well as dynamic MFA (continuous and discrete-event simulation). In this contribution focus will be on the important building blocks of material flow networks: transitions. Transition specifications can be regarded as parameterized sub-models, which may exhibit nonlinear behaviour. Linear transition specifications that consist of fixed production coefficients are always not adequate to represent the sub-models. In the following a more powerful equation-based approach to process flowsheeting is discussed. The equation-based approach makes it possible to specify a transition with aid of a system of non-linear algebraic equation including parameters, design specifications and loops.

## 1. Introduction

Material flow networks as a modelling framework provide different means to specify unit processes that represent material and energy transformations. In the Petri net terminology these processes are called transitions. In software systems like Umberto®, which are based on material flow networks, the default overall solver implements a sequential modular strategy to calculate all material and energy flows, stocks and other performance indicators of a given material flow model.

The solver considers the transition specifications as sub-models with their own solvers. These solvers of the sub-models are called to calculate all input and output flows as well as other performance indictors of a single transition. Such a modular approach provides a very flexible and simple interface to sub-models:

1) Specifications with aid of production coefficients (‘Linear Specifications’): This kind of specification is common in life cycle assessment (non-linear specifications are not allowed) so that libraries like EcoInvent support this kind of specification.
2) Much more flexible are specifications that allow using user-defined expressions (‘User-Defined Functions’). The expressions are assigned to identifiers that represent input and output flows. The whole specification consists of a set of assignments. Non-linear expressions are possible.
3) The most flexible approach is to provide a solver that allows specifying the solution with aid of programming languages like Python (‘Scripting’).

Other solvers are reasonable, for instance an Excel-based approach (‘Spread sheet mind-set’). In this contribution, a method is presented that is very common in chemical engineering: a system of non-linear algebraic equations and variables specify a transition. Such an equation-based approach is similar to ‘user-defined functions’ but more powerful and flexible. Moreover, it allows applying equation-based overall solvers, similar to equation-based strategies for process flowsheeting. On the other side, an equation-based approach is not always in line with our sequential mental models so that it is not easy to specify a transition in such a way. For instance, the degree of freedom for

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the equation system must be zero. Special algorithms are required to identify fully determined, over-determined and under-determined parts of the system.

## 2. Approaches to Process Flowsheeting

Process flowsheeting is a computer-based design process in chemical engineering. “As used here the term ‘flowsheeting’ is the use of computer aids to perform steady-state heat and material balancing, and sizing and costing calculations for a chemical process” [1]. In fact, the application context and the engineering problems are very similar to material flow analysis (MFA) so that the approaches and algorithms can be applied here too.

The purpose of software tools is to support modelling experts to construct the models, to validate them and to calculate results. The most important category of results in the field of MFA is the category of material and energy flows. For a given material and energy flow model, which consists of a flow diagram or net, process or transition specifications, already known flows and stocks and design or scenario parameters, the software tool calculates all material and energy flows in a consistent way.

Data sources of the calculation procedures are transition specifications. Transition specifications are sub-models that allow calculating the input and output flows for a single transition. As mentioned above, software tools can implement different approaches. From a computer science perspective, the sub-model is an algorithm that determines all inputs and outputs for a given sequence of input parameters. In engineering, it is very common to specify a sub-model by a set of model equations.

Software tools to process flowsheeting implement different design images, for instance the sequential modular approach (or ‘sequential modular strategy’) or the equation-based approach (or ‘equation oriented strategy’) [1, 2, 3]. The sequential modular approach regards the sub-models as black-boxes that implement software interfaces. The solver uses the interface implementations to calculate material and energy flows. “There are subroutines for the flash unit, distillation columns, absorbers, a variety of reactor types, compressors, pumps, valves, and so forth. One constructs a complete process model by wiring up an appropriate set of these building blocks. The flowsheeting system then solves the total process model by calling each of the unit models in turn, according to how they are wired together, iterating where necessary to converge complex process models” [3]. The solver starts with given ‘feed streams’ or ‘manual flows’. Then the solver checks the transition specifications. If all input parameters are already assigned and fixed, the subroutine will be called. As a result of such a subroutine call, more flows are calculated. The resulting main loop is iterated as long as all material and energy flows are calculated or no more subroutines can be called For example, the default solver of the MFA tool Umberto® implements the sequential modular approach [4].

The main problem of sequential modular strategies is the handling of loops (recycling). The major approach to deal with loops includes flowsheet ordering, tearing and the application of convergence methods [1, 3]. An advantage of the sequential modular approach is that the calculation procedure is in line with our ‘sequential mind-set’. This makes model validation easier. Another advantage is that it is a modular approach. It is not necessary that the overall solvers know how the calculation of single processes or transitions is implemented. This makes it easier to realize a flexible plugin-in based software system. The main disadvantage is that the modelling experts construct not only the material and energy model, the sequential modular approach normally requires manual support, in particular manual tearing and initial guesses [5]. The model specification is not only declarative but also procedural [3].

Software systems that implement the equation-based approach expect that single processes or transition specification provide a set of nonlinear algebraic equations as model equations, based on a overall grammar (specification language), so that the solver can evaluate the equations: collection of variables used in the equations, calculation and maybe symbolic differentiation to obtain the derivatives [6]. So, "the final flowsheet is represented by a collection of nonlinear equations which must be solved simultaneously. The equations include the model equations and connection equations" [1], and "additional specifications are added until the degrees of freedom for the equation system are zero and a well posed mathematical problem remains" [2], for instance manual flows, scenario parameters and material properties.

To solve a system of nonlinear algebraic equations [7], the compiled system of equations is transformed into a root finding problem (the left side of all equation contains an algebraic expression, the right side zero). The left sides of all equations is regarded as a multi-dimensional function f, and the purpose of multi-dimensional root finding algorithms is to find an assignment to all variables (vector x) so that $f(x)=0$. In other words, "the heart of any equation oriented simulator is the multidimensional root finding code" [2]. However, to reduce the number of equations, a preparatory step seems to be beneficial. Such a step divides the system of nonlinear equations into a sequence of components. The solver determines all variables of the system by calculating the components in a sequential manner so that the root finding algorithm must be applied to the components and not to the whole system. These calculation steps and appropriate algorithms are described in the following.

## 3. Equation-based Approach

An overall solver that implements the sequential modular approach integrates two levels of calculation: the calculation of single processes or transitions and the calculation of flowsheets or networks. "In fact, the sequential modular approach can be best interpreted as a decomposition approach in which a two level nested iteration is established. The outer iteration uses a tearing approach to converge, and the inner iteration uses the unit module specific methods to converge. Further, the variables in the outer iteration (the tear variables) are chosen so that the inner iteration breaks down into a series of subproblems (corresponding to the unit modules) that can be solved sequentially" [2]. In other words, the sequential modular approach as an overall strategy can be combined with the equation-based approach on the level of single transitions. In the following, such a combination of the two approaches is introduced. As a side effect, the number of nonlinear equations is limited and does not incorporate all life cycle stages from raw material extraction to waste disposal.

As mentioned above, a solver for single processes or transitions that implements the equation-based approach consists of two different steps: Block decomposition as a preparatory step and root finding for each component.

### 3.1. Block decomposition

The purpose of the block decomposition step is to divide the whole system of algebraic equations into a sequence of strongly connected components. The strongly connected components are "those minimal subsets of units that must be solved simultaneously" [2]. These components constitute again systems of nonlinear equations but of lower degree. The sequence of strongly connected components can be solved step-by-step. Block decomposition includes the validation of the system.

Block decomposition consists of two steps [2, 8]. The first step constructs a directed graph that represents the dependencies between the equations. Therefore, all not already fixed variables of all equations are determined. Based on the collections of variables for each equation, an occurrence matrix m is derived, one column per variable and one row per equation. If a variable j occurs in equation i, the value of m(i,j) is 1 otherwise 0. With aid of Duff's algorithm, that calculates a maximum transversal of a matrix [9], the digraph representation of the system can be constructed: As a result of Duff's algorithm one variable can be assigned to each equation, and the edges of the directed graph represent the dependency from other variables or equations respectively. Thereafter, Tarjan's algorithm is applied to obtain the strongly connected components and a precedence order is applied [2, 10, 11]. The root finding problem is reduced to each of the strongly connected components.

### 3.2. Root Finding

Root finding is the core component of any solver for systems of non-linear equations. Therefor, all equations of a given strongly connected component $g_i(x) = h_i(x)$ are transformed to $g_i(x) - h_i(x) = 0$ (where i is the index of the equation, n the number of not already fixed variables and x the vector of not already fixed variables). This yields the multi-dimensional function

$$f: R^n \rightarrow R^n \tag{1}$$

with the components $f_i := g_i - h_i$. A solution of the system of nonlinear equations can be determined by finding the roots of f (1). Here, mainly the multidimensional Newton's method or a Quasi-Newton method like Broyden is applied [1, 2, 3, 6, 12].

Starting with an estimation $x_0$ for all variables, Newton's method results in an iterative procedure

$$x_{i+1} = x_i - f(x_i)(J(x_i))^{-1} \tag{2}$$

where $J(x_i)$ is the Jacobian matrix of all partial derivatives of $f$. If possible, the derivatives can be obtained by symbolic differentiation. An alternative is to use finite differences as an approximation [6]. The second alternative is more flexible because this allows user-defined functions, implemented e.g. with aid of scripting languages like Python. But this could be a time consuming task. Another time-consuming procedure is to obtain the inverse of $J(x_i)$.

Broyden's method tries to avoid the determination of the Jacobian matrix in all iterations [13, 14]. Instead, so-called update formulas are used to derive the Jacobian (or the inverse) of iteration i+1 from the Jacobian of iteration i.

Another challenge is to estimate the starting vector $x_0$. It can happen that it is not possible to determine a root with aid of Quasi-Newton methods even if a root exists. This depends mainly on a good first estimation. However, in particular in material flow analysis the model equations exhibit normally a non-problematic behaviour; many process specifications are linear. In such a case, root finding may start with values that occur normally in the material and energy flow model (for instance typical flow values). Of course, modelling experts need the opportunity to specify first estimations.

## 4. Integration

The different options to specify transitions have their advantages and disadvantages. For instance, linear specifications are normally the starting point and easy to understand whereas Python scripts require knowledge in software programming. To specify a transition as simple as possible, it is reasonable to combine the different options within a single transition specification, for instance the combination of the equation-based approach with linear production coefficients (emission factors for hundreds of emissions) or the use of Python functions in equations. This can be considered as 'manual block decomposition': The whole specification consists of different section, for instance sections to specify Python functions, direct assignments, equations or linear coefficients. The solver calculates the sections step-by-step. Finally, all variables should be calculated in a consistent manner.

## 5. Example

The 'Ammonia Process' described in [15] is used to illustrates the application domain of the new type of transition specification. The flowsheet model (figure 1) consists of three unit processes: mixer, chemical reactor and a separator unit. The separator unit is necessary because the conversation rate of the chemical reaction is assumed to be about 25%.

$$1N_2 + 3H_2 \leftrightarrow 2NH_3$$

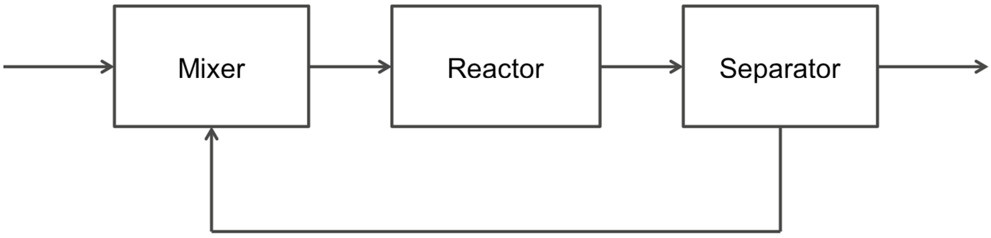


*Figure 1: Flowsheet of an ammonia process [15]*

The feed stream on the input side of the mixer consists of 100 kMol $N_2$ (nitrogen) and 300 kMol $H_2$ (hydrogen). This example is easy to validate because we can expect about 200 kMol ammonia as an output stream (in steady state the overall conversion rate is almost 100%). However, the separator unit cannot remove all nitrogen and hydrogen from the output stream.

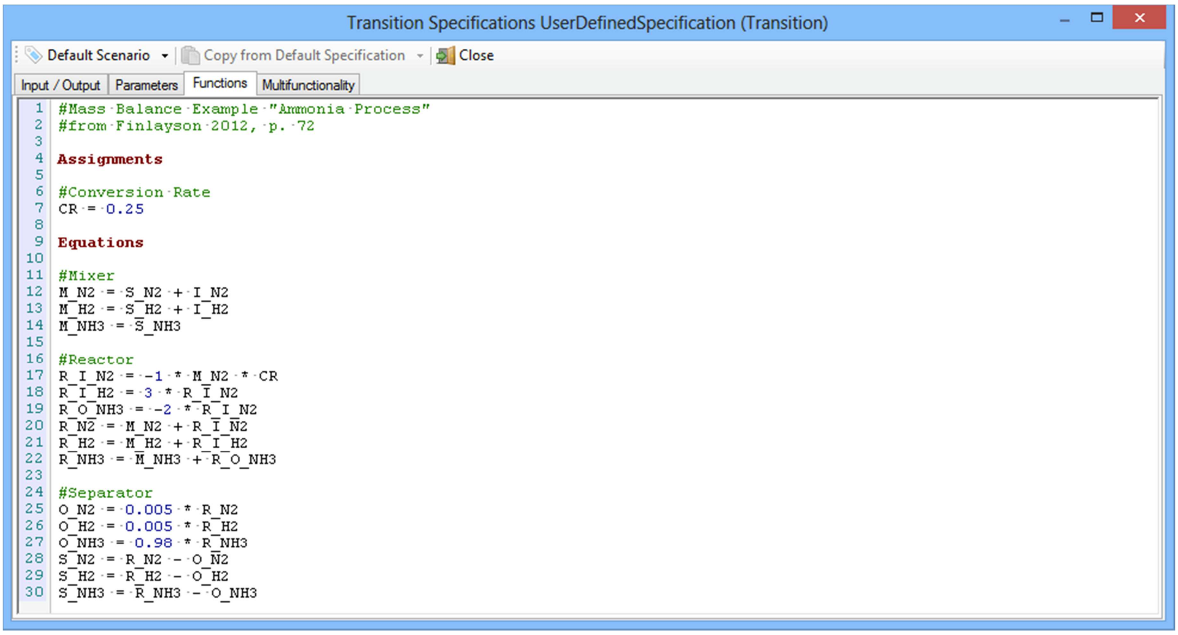


*Figure 2: Transition specification of the ammonia process [15]*

Figure 2 shows the resulting transition specification. It consists of two sections, the specification of the conversion rate and equations for the mixer, chemical reactor and the separator unit. The variables of input flows (fixed feed streams N2 and H2) use the prefix I_ and the output flows O_. The internal variables use the first character of the unit process that produces them, for instance M_N2, M_H2 and M_NH3 are the output streams of the mixer process.

An application of a sequential procedure to calculate all variables is not possible. In particular the variables S_N2 and S_H2 occur in line 12 or 13 and again in 28 or 29.

The calculation engine of the modelling tool analyses the system of equations, determines the collection of variables for each equation and constructs the occurrence matrix. The following table shows the first row and columns of the occurrence matrix (all equations of the mixer). The variables I_N2 and I_H2 do not appear in the matrix because they are already fixed variables (I_N2 = 100000 and I_H2 = 300000).

| | S_N2 | M_N2 | S_H2 | M_H2 | S_NH3 | M_NH3 | … |
|---|---|---|---|---|---|---|---|
| S_N2 + I_N2 – (M_N2) | 1 | 1 | 0 | 0 | 0 | 0 | … |
| S_H2 + I_H2 – (M_H2) | 0 | 0 | 1 | 1 | 0 | 0 | … |
| S_NH3 – (M_NH3) | 0 | 0 | 0 | 0 | 1 | 1 | … |
| … | … | … | … | … | … | … | … |

The block decomposition step yields the following strongly connected components. It is interesting to understand how Tarjan's algorithm has divided the system into strongly connected components. The first component can be called the 'nitrogen', the third 'hydrogen' and the last 'ammonia', with two 'connecting' components between them:

```
Strongly connected component 1:
0.005 * R_N2 – (O_N2)          # assigned variable = O_N2
-1 * M_N2 * CR - (R_I_N2)      # assigned variable = R_I_N2
 S_N2 + I_N2 - (M_N2)          # assigned variable = M_N2
 M_N2 + R_I_N2 - (R_N2)        # assigned variable = R_N2
 R_N2 - O_N2 - (S_N2)          # assigned variable = S_N2

 Strongly connected component 2:
 3 * R_I_N2 - (R_I_H2)         # assigned variable = R_I_H2

 Strongly connected component 3:
 R_H2 - O_H2 - (S_H2)          # assigned variable = O_H2
 0.005 * R_H2 - (O_H2)         # assigned variable = R_H2
 M_H2 + R_I_H2 - (R_H2)        # assigned variable = M_H2
 S_H2 + I_H2 - (M_H2)          # assigned variable = S_H2

 Strongly connected component 4:
 -2 * R_I_N2 - (R_O_NH3)       # assigned variable = R_O_NH3

 Strongly connected component 5:
 R_NH3 - O_NH3 - (S_NH3)       # assigned variable = O_NH3
 0.98 * R_NH3 - (O_NH3)        # assigned variable = R_NH3
 M_NH3 + R_O_NH3 - (R_NH3)     # assigned variable = M_NH3
 S_NH3 - (M_NH3)               # assigned variable = S_NH3
```

Thereafter, Broyden's root finding method is applied to each strongly connected component. Because no first estimations are specified, all coefficients of the starting vector $x_0$ are 1. The following figure shows the calculation log. The algorithm needs 3 iterations to determine the variables for the most strongly connected components. This includes O_NH3, O_N2 and O_H2 but internal variable may be important performance indicators too. For instance, the sum of R_NH3, R_H2 and R_N2 could serve as a performance indicator to estimate the energy consumption.

The example shows a typical application domain of the new type of transition specification: chemical processes as sub-models in material flow networks. The basic idea behind is to use the material flow networks as a modelling approach on a higher level and to combine the material flow networks with process flowsheeting on the level of single transitions. The flowsheet models become sub-models in such a modelling environment.

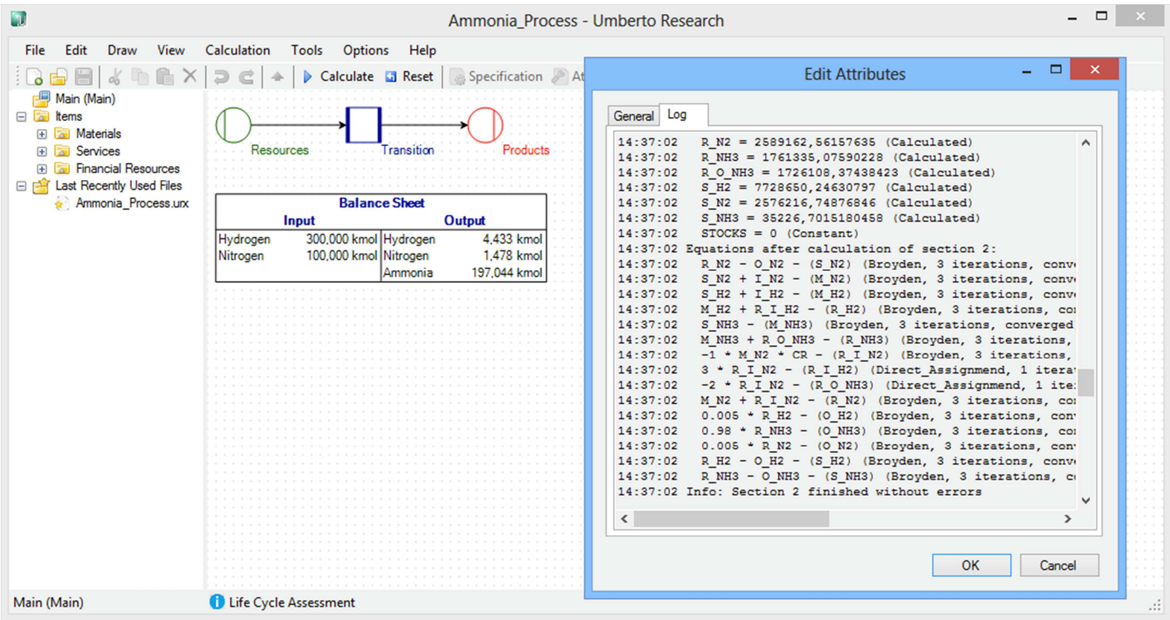


*Figure 3: Input/output balance and calculation log of the software tool*

A next implementation step could be to develop an appropriate user interface so that users can construct the flowsheet with aid of a graphical user interface. Nevertheless, such an extension of MFN tools cannot replace specialized process flowsheeting systems.

## 6. Outlook

The extension of transition specifications options combines the most important approaches to steady-state modelling: the sequential modular approach on the level of whole material flow networks and the equation-based approach on the level of single transitions. It seems to be attractive apply the equation-based approach to whole material flow networks as an alternative to the sequential modular strategy. However, this works fine for small networks, which consist of user-defined transitions and equation-based transition specifications as described above. So, it is likely to implement this on the level of sub-nets.

One of the problems is that the interface between the overall calculation engine and the transition specifications is different. Modular approaches expect that the transition specifications include a solver. This makes it possible to implement a flexible and extensible interface, including Excel® or process flowsheeting tools as a transition specification plugins. Another option is to implement a wrapper to computer-based corporate information systems, in particular ERP systems. A solution to this problem could be to implement an approach that tries to combine the advantages of the sequential modular approach and the equation-based approach: the simultaneous modular strategy [1, 5].

A second challenge is that the material flow networks support dynamic MFA. Here, emphasis is on the development and future availability of stocks. Before applying the equation-based and the simultaneous approach to whole material flow networks, it is necessary to combine the approaches to steady state modelling with approaches in the field of continuous simulation. This results in a two-level calculation engine: steady-state approaches for the inner loop, integration methods for the outer loop.

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# Towards a Complete Tool Chain for Eco-Balancing Governmental Buildings

Clemens Düpmeier[1], Oliver Kusche[1], Tanja Brockmann[2], Stefan Rössig[2], Andreas Ciroth[3], Tobias Lode[4]

## Abstract

With the Assessment System for Sustainable Buildings for Federal Buildings (BNB), Germany is pioneering the implementation of certification systems for Sustainable Buildings in Europe. Using BNB methodology and tools, building products are not assessed as individual products, but looked at within the context of the entire building and its parts. The most important impacts of the building on the global environment (i.e. environmental burdens like ozone depletion or consumption of resources like energy and water) are assessed by means of Life Cycle Assessment (LCA) methodology and are calculated according to the Type III Environmental Product Declarations (EPD) standard for building products described in ISO 14025 and EN 15804.

This paper will describe the tool chain needed to first calculate EPD data sets in LCA tools, store them in a central repository, the ÖKOBAU.DAT, and how the EPD data sets can then be used in other tools for calculating the environmental footprint of an entire building.

## 1. Introduction

With the Assessment System for Sustainable Buildings for Federal Buildings (BNB) of the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), Germany is pioneering the implementation of certification systems for Sustainable Buildings in Europe. It is one of the few countries where the state requires a binding sustainability assessment for its federal construction projects. Most European Countries use such certification systems only on a voluntary basis, if at all.

Using BNB methodology and tools, building products are not assessed as individual products, but looked at within the context of the entire building and its parts. Particularly with respect to Ecological Quality, building materials form an essential part of the overall assessment. The most important impacts of the building on the global environment (i.e. environmental burdens like ozone depletion or consumption of resources like energy and water) are assessed by means of Life Cycle Assessment (LCA) methodology. In addition to the construction phase of the building materials and components, also their use phase and end of life aspects are taken into account in the process models which are used for the calculation of the needed assessment indicators. These calculations are performed according to the Type III Environmental Product Declarations (EPD) standard for building products described in ISO 14025 and EN 15804.

The Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), a research institution under the portfolio of the BMUB, has initiated and is maintaining the ÖKOBAU.DAT - a database of life cycle assessment (LCA) data sets for generic and specific construction materials and components which provides the essential data sets needed for the

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assessment of buildings according to the Type III Environmental Product Declarations (EPD) standard for building products described in ISO 14025 and EN 15804. Both, the technical database system which is used to store the ÖKOBAU.DAT data sets, i.e. soda4LCA (service oriented data base system for LCA) [6], which is developed by the Institute of Applied Computer Science (IAI) of the Karlsruhe Institute of Technology (KIT), and the technical data format used for the EPD data sets have been described in a paper presented at the EnviroInfo 2013 conference in Hamburg [7].

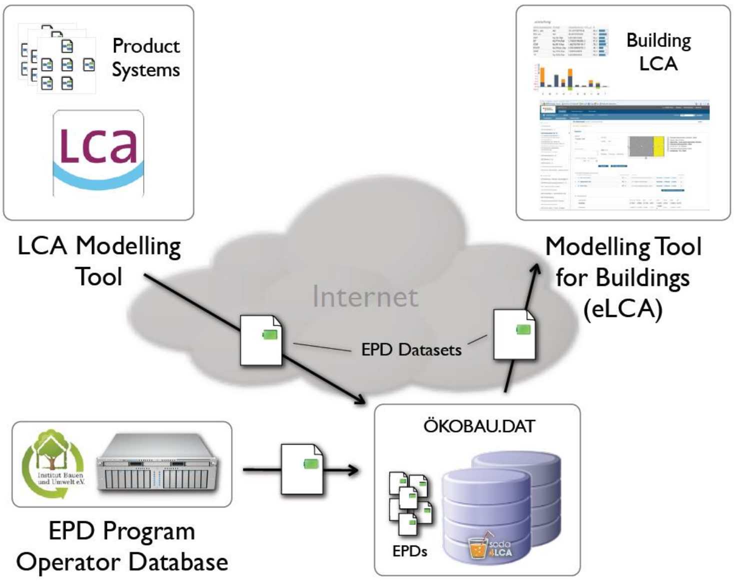


*Figure 1: EPD data set tool chain*

This paper will therefore not focus on the EPD format and EPD data storage itself, but rather on the complete tool chain (see Figure 1) needed to first calculate EPD data sets in a LCA modelling tool, then transfer and store them in the ÖKOBAU.DAT and finally access the data sets with another tool for calculating the environmental footprint of the entire building. In a project financed by BBSR and led by IAI called “ÖKOBAU.DAT Interfaces”, this tool chain was explored in deeper detail to analyse deficiencies in the EPD data format, in the calculation of such data sets, in the service API for accessing and storing data sets in the ÖKOBAU.DAT, and to identify and eliminate issues which pose problems for the final calculation of the entire building footprint in the modelling tool used by the architects.

While the GaBi LCA tool by PE International AG was used for the calculation of most existing EPD data sets provided by the ÖKOBAU.DAT, it was decided within the mentioned project to enhance the open source LCA software tool openLCA [5] developed by GreenDelta GmbH, which at that time had no support for EPD calculation, to fully support the calculation of EPDs and use openLCA for analysing the EPD calculation process within the tool chain. This decision was made because in openLCA the required algorithms can be implemented as closely as possible according to the EPD standards and the open source nature of openLCA allows it to easily examine the implemented algorithms and can therefore provide guidelines and best practices for other vendors how to implement the EPD calculations within their own LCA tool. Furthermore, openLCA has already a very good integration with the soda4LCA database system used for the ÖKOBAU.DAT so that calculated EPD data sets can be directly stored within ÖKOBAU.DAT from the openLCA tool.

The eLCA tool implemented for the BBSR by beibob is a web based tool used by architects for the calculation of a BNB conform environmental footprint of governmental buildings. Prior to the “ÖKOBAU.DAT Interfaces” project, the eLCA tool already used EPD data sets for its calculations, but was based on a previous and not standard-conform format definition for EPD data sets. This led to many problems in eLCA which were addressed by the redesign of the format in the “Fortschreibung ÖKOBAU.DAT” project which is described in [7]. In the “ÖKOBAU.DAT Interfaces” project, eLCA was adapted to the new format and fully integrated with the ÖKOBAU.DAT using the REST-based service API of soda4LCA [2]. This led to a more consistent and easier use of the EPD data sets in eLCA and a much more flexible modelling approach for the complete building model.

In the following chapters the implementation and central concepts of EPD data set calculation in openLCA and the usage of EPD data sets in eLCA will be described in more detail. Also the interaction between openLCA, the ÖKOBAU.DAT and eLCA via the service API are explained. Finally, some lessons learnt and further work to be done will be discussed.

## 2. Implementing EPD calculation in LCA tools

openLCA [5] developed by GreenDelta GmbH is a freely available, open source LCA modelling tool for professional Life Cycle Assessment and footprint modelling which supports all common modelling options, such as parameterization and complex mathematical models for unit processes, describing complex process and product models graphically as connected process chains (see Figure 2), supporting different kind of allocations and system expansions and even uncertainty calculations. Calculation capabilities include LCI and LCIA result calculations for arbitrary common LCIA methods and visualization options of the results, like Sankey diagrams to visualize hotspots.

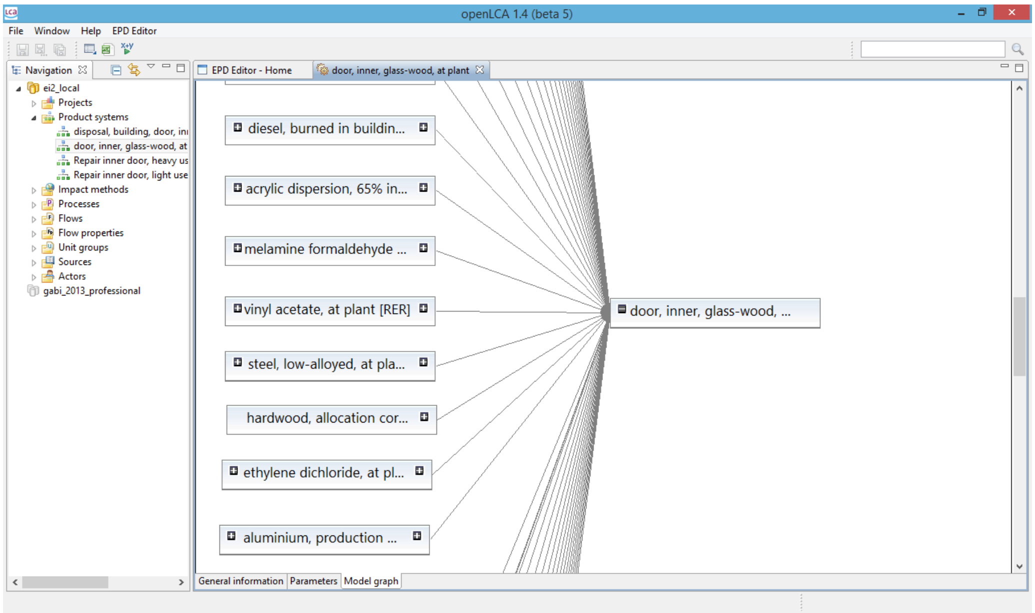


*Figure 2: openLCA tool showing a process chain (product system) modelling the production life cycle phase of a typical inner house door made of glass and wood*

Because openLCA is based on the Eclipse Rich Client (RCP) application platform, it can be easily extended by writing new Eclipse plugins for the platform [1]. Therefore, the EPD generation support was implemented in openLCA as an additional Eclipse plugin. The main home screen of this plugin in openLCA is shown in Figure 3. It provides controls for the creation of new EPDs, for configuring the connection to a soda4LCA server [2] (i.e. the ÖKOBAU.DAT) and searching for EPD datasets within the EPD repository. The plugin provides further functionality to change the configuration of indicators which should be calculated and for defining additional material properties which authors can use to attach such properties to EPD products for the later use by the building calculation tool.

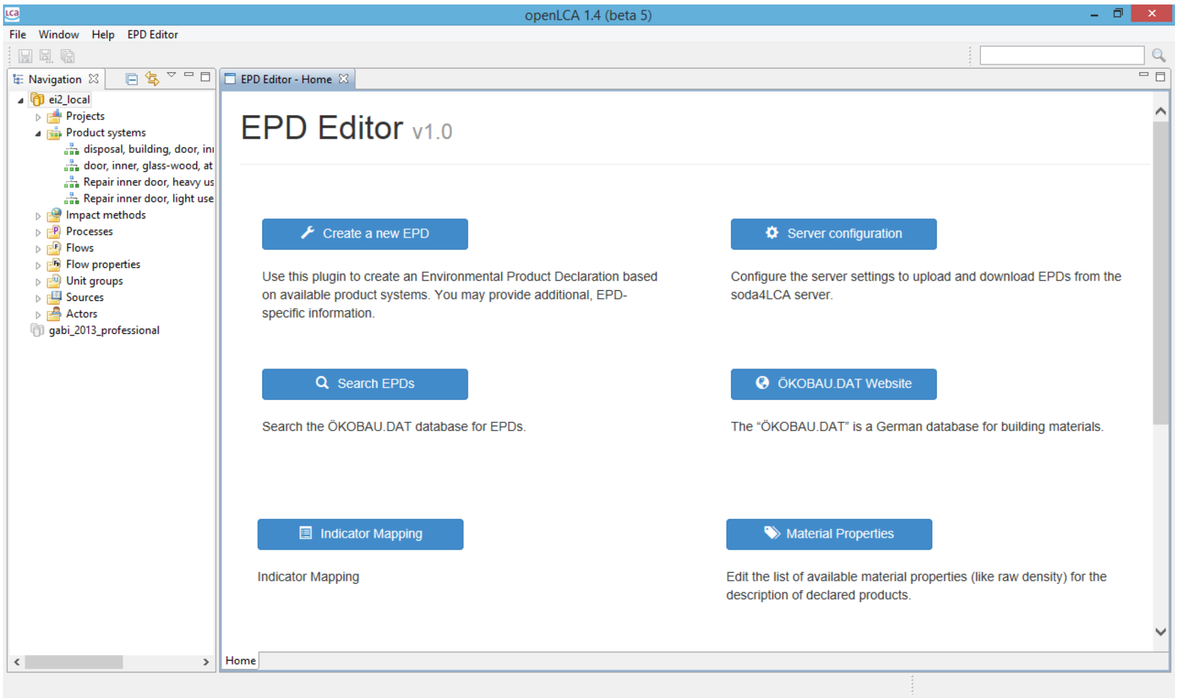


*Figure 3: openLCA plugin providing support for EPD editing and calculation*

Since the EPD format is based on the ILCD data format [4,8] and openLCA already supports the ILCD format as well as arbitrary LCI and LCIA result calculations based on ILCD method data sets which contain machine readable calculation procedures for LCI and LCIA indicators, EPD support can be easily implemented in openLCA.

The main addition which had to be implemented for openLCA was a new calculation project context which allows to group several product systems describing the process models of a construction material or component in the different life cycle phases (production of the material, installation, use phase, end of life) as well as rules for calculating the EPD LCI and LCIA indicators along the specified life cycle product chains into one calculation project context.

To create a new EPD calculation project, the process models (product systems) of the different life cycle stages (production phase, transport, use phase, disposal) have to be created first. Figures 2 and 3 show that product systems ("disposal, building door, inner, glass-wood" to model the disposal stage, "door, inner, glass-wood, at plant" for the production stage and two scenarios for the use stage "repair inner door, heavy usage", "repair inner door, light usage" for modelling heavy and light usage of the door) are already available for a generic construction product "door, inner, glass-wood, at plant", which is a door made out of glass and a wooden frame.

A new EPD project using these product systems can now be created by clicking on the "Create a new EPD" button at the home screen of the EPD plugin in openLCA (see Figure 3). The plugin will then show a creation wizard which asks for the name of the new EPD project, a description text and the reference product for the EPD. In our example, the reference product will be "door, inner, glass-wood, at plant".

After finishing the creation wizard, openLCA will show a screen which looks like that shown in Figure 4 but with empty upper and lower tables at the right part of the screen. The modeller will then define in the upper table of the screen which product systems will cover what kind of life cycle stage of the product (e.g. “A1-A3” for the production stage, “B3” for usage and “C4” for the disposal. In the case that several scenarios are modelled in different product systems, an identifier for the corresponding scenario should be attached to the product system entry as well.

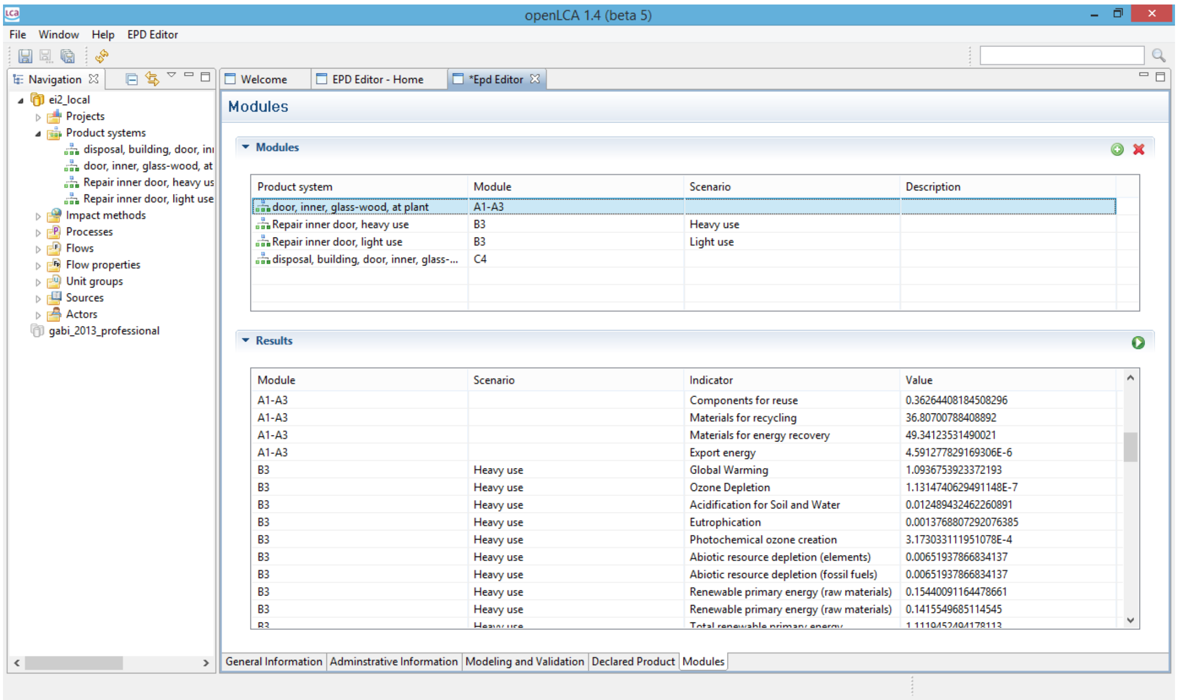


*Figure 4: EPD calculation screen after calculation of the values*

After defining in the upper table of Figure 4 which product systems should be used for calculating the indicators for the different life cycle stages, the calculations can be performed by pressing the calculation button.

The information which calculations have to be performed is stored in a calculation project profile which will be loaded when a modelling user creates a new EPD calculation project. The LCA tool can then access the calculation rules through corresponding LCIA method data sets and perform the calculations along the process chains attached to the calculation project by the modeller. The calculated results will then be shown in the lower table seen in Figure 4. As already described before, the calculation profiles can also be edited in openLCA. This can be used to create other forms of EPD calculations like those which are used in the construction sector.

Besides calculating the values of the indicators of an EPD based on available product systems modelled, the EPD editor of openLCA allows also the manual input and updating of result lines in the lower table of Figure 4. Thus, openLCA can be used as a simple EPD editor when the calculations are already performed with another tool and only an EPD conform dataset has to be created.

After calculation and quality control of the EPD dataset, it can be saved from within the openLCA directly into the ÖKOBAU.DAT EPD repository which is based on the soda4LCA software [6]. soda4LCA supports the creation of separated data stocks (storage container) in which datasets can be stored [3]. Normally, a LCA tool like openLCA should be configured to store new EPD datasets in ÖKOBAU.DAT in a data stock called “inbox”. The maintainer of ÖKOBAU.DAT can then first review the datasets when arriving in the inbox and perform quality control. If datasets are of sufficient quality they can then be moved to a certain production data stock (i.e. a special released version of the ÖKOBAU.DAT). Otherwise they are rejected and the submitter will be notified that certain aspects of the dataset have to be corrected.

Tools, that merely use EPD datasets, should only access data stocks in ÖKOBAU.DAT which contain released EPD datasets (i.e. they work with one of the released version of ÖKOBAU.DAT). One of these tools is eLCA, which will be described next.

## 3. eLCA – Using EPD data sets for assessing governmental buildings

A first step in using EPD datasets from ÖKOBAU.DAT in eLCA is the import of all EPD datasets of a certain version of ÖKOBAU.DAT into the internal database of the tool. In eLCA this import can be easily achieved because it uses the soda4LCA REST API to access the ÖKOBAU.DAT (see Figure 5). Via the API the user can first select a version of ÖKOBAU.DAT from the list of available release data stocks (e.g. in Figure 5 the data stock "ÖKOBAU.DAT 2014" was selected) and can then start the import process.

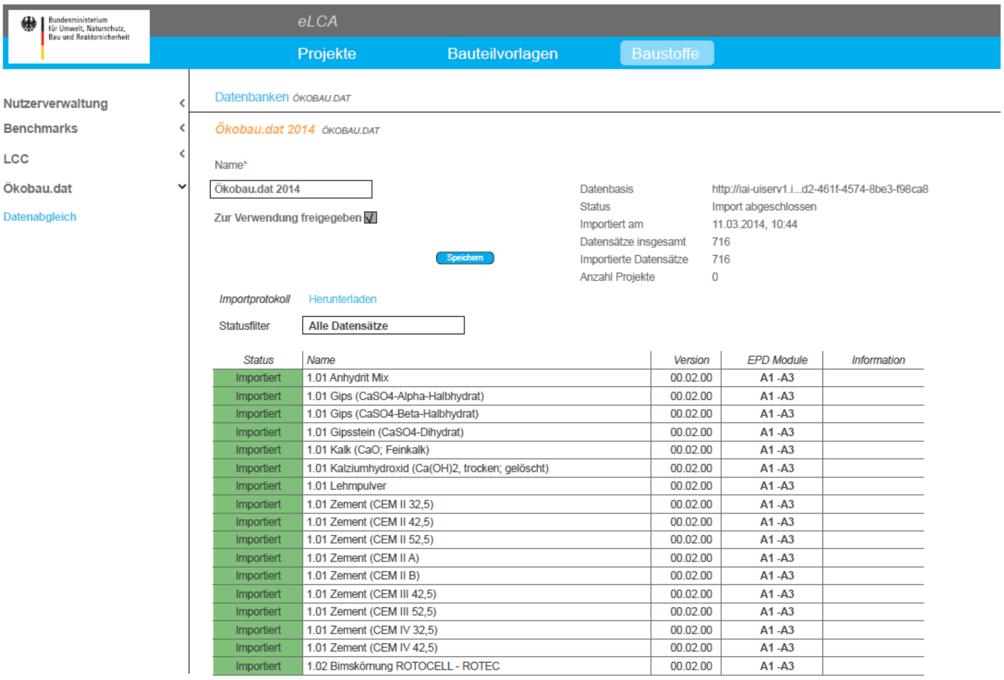


*Figure 5: Import screen of eLCA*

eLCA will then import all data sets from the given release data stock and will perform some comparison and sanity checks to make sure that the imported datasets will be of good enough quality as well as compatible and usable within the tool. The results of these checks will then be presented to the importing user (see Figure 5) who can then decide if the datasets should be made available for modelling.

To ease the modelling of buildings for assessing an entire building, the eLCA tool provides the architect with functionalities to build and use a modelling library of higher level compound construction components. For example, if the architect needs to specify the outside walls of the building, he would use a wall component which is a compound component modelling the complete outside wall, i.e. consisting of a brick of a certain type, insulating material, and finery and used glue materials (see Figure 6). If the architect needs to specify windows or doors, he uses compound objects consisting of a frame of a certain material, like wood, and a certain type of glass and corresponding fittings.

Figure 6 shows the compound component editor of eLCA. The compound component shown models an outer wall of a building as mentioned above. The graphic attached to the compound component model shows that the wall consists of seven subparts. Each subpart can be either another compound component or a basic construction material which is the reference product of an associated EPD dataset from the ÖKOBAU.DAT.

The higher level compound components allow the architect then to model the entire building by specifying a list of used compound parts and basic construction materials and their amount according to a reference unit like square meters.

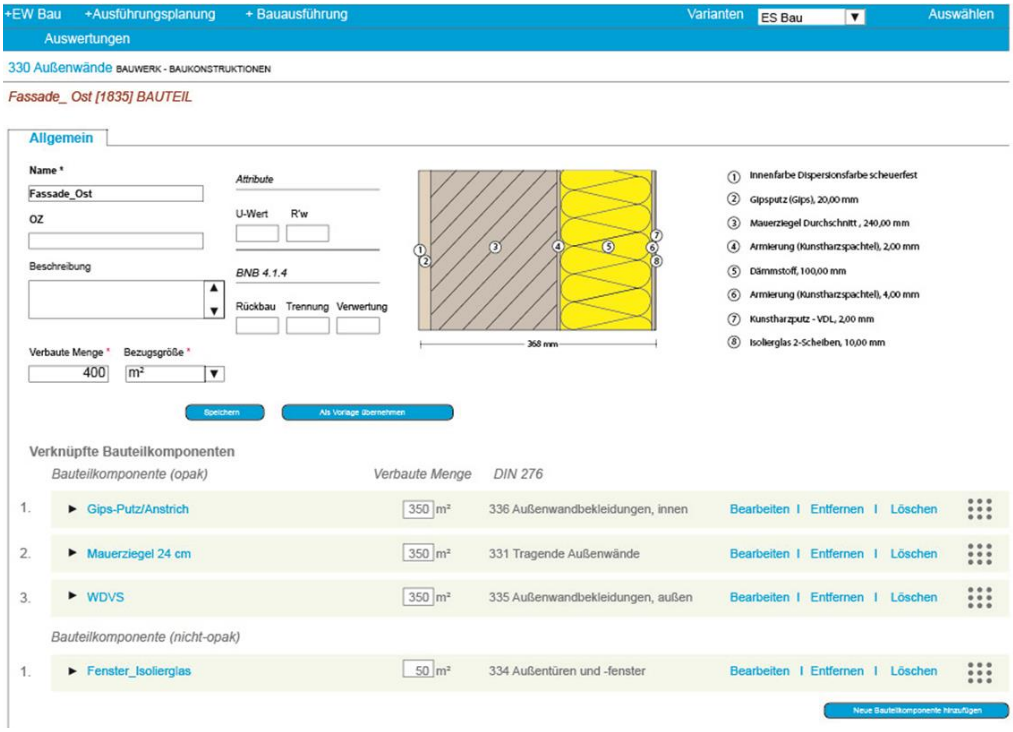


*Figure 5: eLCA screen showing the model of a complex construction component (outer wall of a building) which is composed of several construction materials*

To perform the assessment calculation, the eLCA tool has to analyse the internal composition of the compound object and then perform separated calculations for all sub materials which will then be summed up. Each base material used in a compound component has associated EPD data sets within the ÖKOBAU.DAT which can be used for the calculation of the indicator values contributed by this material. The indicator values in the EPD data set are normed to a certain amount of the material and have to be scaled by the total amount of this material contained within the entire building. This calculation has to be done with all materials contained in the compound components and after that the contribution of all materials has to be added to get the final values for the entire building.

## 4. Conclusions and Outlook

First results of the "ÖKOBAU.DAT Interfaces" project have shown that the described tool chain can be used to efficiently create and use EPD datasets for the assessment of buildings. The soda4LCA database software with its REST API [2] seamlessly integrates EPD calculation and building modeling tools as producers and consumers of EPD datasets with the central repository for EPD datasets, the ÖKOBAU.DAT. The EPD editor and calculation tool implemented for openLCA is easy to use and calculates all needed indicators for the different life cycle stages in one go and the compound component model of eLCA makes it easy for its users to build libraries of reusable building construction components so that models of complete buildings can be efficiently created.

The procedure can be streamlined and optimized by the integration of better quality control mechanisms and workflow like feedback mechanisms. For example, eLCA already checks in its import procedure if there are some quality problems in EPD datasets which hinder their usage in eLCA calculations. Currently, the results of this analysis have to be communicated back to the author of the corresponding EPD data set manually. In the future, the necessary quality control should already be performed within the ÖKOBAU.DAT when EPD datasets are uploaded to its “inbox”. The maintainers of the ÖKOBAU.DAT should have the possibility to quality control all relevant aspects of incoming EPD datasets before they are moved into release data stocks. Furthermore, analysis results of rejected data sets should automatically be communicated back to the authors. This can be accomplished by enhancing the soda4LCA API to incorporate information that allows it to send emails to dataset authors or provide a message stream within the tools integrated with the soda4LCA software as feedback mechanism.

Another issue observed in the integration project is the necessity to have mechanisms to communicate extensions of different reference data back to tools using this data. E.g. for eLCA it’s really important that the reference system of available construction products and the accompanying categorization of building construction materials in ÖKOBAU.DAT is synchronized with its internal notion of building construction materials. Currently, the mapping of ÖKOBAU.DAT and eLCA product notions is maintained manually in eLCA. As a result, every extension to the products and their categorization in ÖKOBAU.DAT has to be manually added to eLCA and vice versa. In the future one can imagine that products and categories will be maintained and extended in ÖKOBAU.DAT and automatically communicated back to tools via the soda4LCA service API.

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# Climate Change Adaptation and Interactive Participation of Stakeholders - first Results of the Project "KLIMPASS AKTIV"

Martin Scheinert[1], Hardy Pundt[2], Andrea Heilmann[3]

## Abstract

During the two foregoing years, a guideline for the development of local climate change adaptation strategies was developed in close cooperation with various stakeholders within a specific district in middle Germany. Based on this guideline, specific adaptation measures have been selected to be realised. This paper gives insight into a new website which is developed in a follow-up project, called KLIMPASS AKTIV. The website serves as information platform for actors involved in the implementation of climate change measures. Textual and map-based information is provided in a convenient way. Apart from the purpose of raising awareness of climate change issues on the local level, the website enables actors to participate actively in planning processes which result from the local adaptation strategy.

## 1. Introduction

Climate change can have a significant impact on the social, economical and ecological level and the adaptation to these changes is a key to react adequately on climate- and weather-related hazards. However, to successfully adopt measures that could help to cope with climate change impacts, the awareness of these problems needs to be enhanced and coordination on the administrative level to be improved. The aim of the project “KLIMPASS AKTIV” is to support the drivers of successful climate change adaptation. Based on a study by Heilmann and Pundt [1], which proposes a guideline for the development of local adaptation strategies, a web interface has been developed which allows to access climate change related information in a convenient way. It provides a platform for interaction and exchange of knowledge among concerned stakeholders, thus scaling down results and knowledge to the local level, where decisions concerning *concrete* climate adaptation measures have to be made. This platform aims to increase the awareness of potential climate change risks and foster the adaptation of adequate techniques and solutions to cope with these risks.

## 2. The Role of Local Actors

"Local actors are the key to achieving real impact on the ground. While international donors and agencies and national governments play important roles in establishing effective enabling environments and channelling resources and technical support, ultimately effective adaptation takes place through the dynamics of local governance, civil society engagement, and economic development building from the actions of local authorities, civil society organizations, and private sector businesses" [2].

The local actors must cover the different sectors which have to be taken into account when dealing with climate change adaptation on the local level. First of all, the local administrational units have to be considered, but the private economy, including industry, as well as organizations and citizens should be involved in the discussions as well. Administration and other organizations include, for

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example, sectors such as regional planning, forestry, agriculture, water management, soil protection, but also sectors like traffic infrastructure, industrial production, health, nature protection, and many others.

Within the framework of the development of a local climate change adaptation strategy in close cooperation with a pilot administrative district in Saxony-Anhalt (Landkreis Mansfeld-Südharz), the local stakeholders from the different sectors were invited to explain their specific requirements and make suggestions on the adaptation process. This was done during the project KLIMPASS, which was carried out prior to the KLIMPASS AKTIV project described here [1]. Figure 1 gives an overview of concerned actors which were participating in the project.

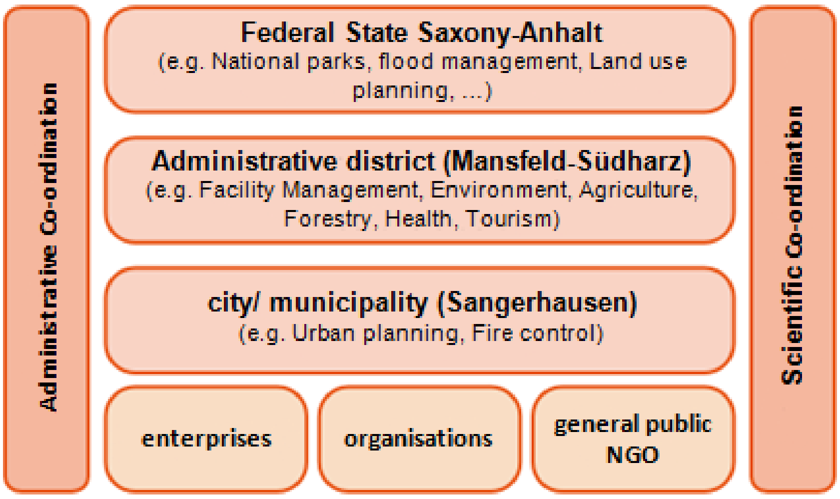


*Figure 1: Actors and stakeholders within the KLIMPASS AKTIV project*

At the end of the KLIMPASS project a guideline was published which represents a general strategy for local administrations to develop climate change adaptation strategies. The goal of such a strategy, however, is to define as concrete as possible which measures should be implemented to prepare for potential climate change-induced events, such as storms, flooding, mudslides, heat, drought, and others.

The next step after publication of the guideline has been the implementation of specific goal-settings defined in the local adaptation strategy of the "Landkreis Mansfeld-Südharz". To achieve this goal, a follow-up project was established under the name KLIMPASS AKTIV. The project includes the conception and implementation of an interactive website which should provide thematic information and help the stakeholders to coordinate their actions. The next sections explain the technological approach and the current state-of-the-art within KLIMPASS AKTIV.

## 3. Tools and Techniques for a local website on climate change adaption

The technical implementation of the previously developed conceptual design of the KLIMPASS AKTIV website is accomplished by Joomla3, a well-established content management system (CMS) [3]. The Joomla module "Kunena" is used as an interactive forum extension to the system, and "DokuWiki" is applied as documentation module. Furthermore, the calendar module "JEvents" is integrated in order to provide information on forthcoming dates, such as workshops, presentations or other project related events. Another core component to stimulate the interactive exchange of knowledge is the provision of vulnerability maps and accompanied examples of good-practice measures to deal with climate change risks. The integration of maps was done based on the JavaScript API "OpenLayers" [4], which is an open library for digitally presenting geospatial data. Customized, as well as newly programmed, API components were developed to specifically address the particular needs of the climate adaptation project and to improve the user-experience on that matter. The usage of KML-files [5] and web map services (WMS) [6] is intended to enable an appropriate implementation and exchange of data. In a next step, a user-controlled interface is currently designed, which allows an integration of vulnerability maps. The RISKA information system, which was developed as part of the Nordwest2050 KLIMZUG project (see www.nordwest2050.de), serves as an orientation. However, some features to improve the interactive, web-based communication on maps and measures will be considered more intensively, compared to RISKA.

Using such a technological environment the overall aim of the project KLIMPASS AKTIV should be reached. This involves the provision of most important facts about local, climate change-related issues, including maps, and to establish a forum that serves as a discussion platform, as well as to facilitate the decision-making process which leads to concrete climate change adaptation measures.

## 4. The KLIMPASS AKTIV Website

The overall aim is to provide textual and map-based, current knowledge about climate change on the one hand, and important local information on the sectors, as well as on concrete climate change adaptation measures, on the other hand.

### 4.1. Online participation of stakeholders

To enable actors from diverse sectors to participate in the development of the adaptation strategy, a forum or wiki (see figure 2), which can be operated easily and intuitively, assists in cooperating and integrating the knowledge and relevant information. The actors and stakeholders included in the project represent a multitude of interest groups and levels of governance, so that numerous fields of action are covered (figure 1). They orient themselves at the states’ adaption strategy of Saxony-Anhalt [7], but acknowledge the need to break down the suggestions made there, on a states’ level, to the local level [8]. For each of these fields of action information and brief descriptions of climatological facts are provided, as well as good-practice examples of already implemented measures. These good-practice examples result from partner-projects, and local actors which were and are encouraged to bring in their practical experiences. In order to provide the information via the website, they find a special form there. Using this form, they can explain, in a standardized way, which measures were already implemented or how the implementation will look like in future. Via the forum, other concerned people can react or give further suggestions. In such a way, the discussion can reach more people, including the public, and is carried out on a broader basis.

Additionally, the provision of information about vulnerable areas within the concerned region (e. g. a “Landkreis”), is an important part of the website. Vulnerability maps, for instance, enable stakeholders, to recognize in which areas high pressure for adaptation measures exist.

Specific, exemplary vulnerability maps were designed in the project KLIMPASS. Within KLIMPASS AKTIV, more sophisticated maps will be provided. Here, GIS technology can be used in a convenient way, because a strength of GIS is to integrate data from different sectors, assumed that they are in line with a common spatial reference system. This supports a more holistic approach to the complex area of climate change, thus enabling to integrate, to give only one example, data layers about rivers, soils, digital elevation model, and traffic infrastructure to carry out overlay analyses and identify areas where roads are endangered by potential flooding, or mudslides [9] (see also section 3).

In general, the KLIMPASS AKTIV website should enable administrational employees, stakeholders, and the public to comment on regions which are identified as being vulnerable, and to acknowledge positively or negatively existing or planned adaptation measures and thereupon provide new proposals (figure 2).

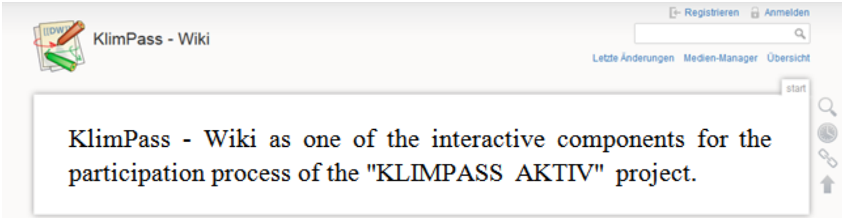


*Figure 2: KlimPass - Wiki as an interactive component to enable the participation of stakeholders*

### 4.2. Integration of Vulnerability Maps

As mentioned before or described, for instance, in [12], the identification of vulnerable areas on a local level should result in the provision of vulnerability maps on the new website. The cross-sectoral approach taken in the KLIMPASS project enabled the project team to collect spatial data sets from different sectors. The spatial data sets were provided by local, regional, and states' agencies. The datasets cover different sectoral areas, such as topographic, hydrological, ecological, forest, land cover, and information on soils, as well as climatological and socio-economic data. The climatological data result from a regional simulation model ("RaKliDa", http://141.30.160.223/RaKliDa_WebServlet) which interpolates climate data such as temperature and precipitation on a 1000m² resolution. This is adequate for local studies and enables stakeholders to integrate the climatological data, and further, sector-specific datasets for GIS-supported overlay analysis.

The maps will be provided using an OpenLayers module which has been integrated into the website (see section 3). Coming from a map which shows, for instance, the complete area under investigation, e. g. the "Landkreis", users can zoom into smaller regions and investigate if there are local vulnerabilities (in such a case they could click a marker, after which the vulnerability map occurs), or if there are concrete climate change measures planned or already implemented (again, they can click a special marker after which images and textual descriptions of the measure occur as shown in figure 3; here the invasion of neophytes due to changing temperatures is presented).


*Figure 3: Detailed pop-up information about some project related measures*

The OpenLayers API has been extended to some visualization and grouping capabilities. In addition, a grouping and scale dependent display function within the LayerSwitcher component has been integrated. The LayerSwitcher control displays a table of contents for the map. This causes a clear presentation and arrangement of the various BaseLayers and Overlays within the map visualization. It is complemented by an adaptation option to allow user-defined symbolization of feature and coverage data based on the Styled Layer Descriptor (SLD) implementation Specification [13] for the representation of Web Map Services (WMS).

The map application represents one of the interactive components to display the project results. According Gullotta & Schulz [14] they provide a convenient means to sensitization. Figure 4 shows an example from the current KLIMPASS AKTIV website, showing the Landkreis Mansfeld-Südharz, thus presenting the geographical area, concrete climate adaptation measures within this area (“Klimaanpassungsmaßnahmen”), and more specifically, measures that were implemented in the water management sector (“Gewässerentwicklung”). In such a way, users can easily access the relevant information on all climate change-related measures within the area. Using the forum, and wiki, they can react, make suggestions, criticize, etc.

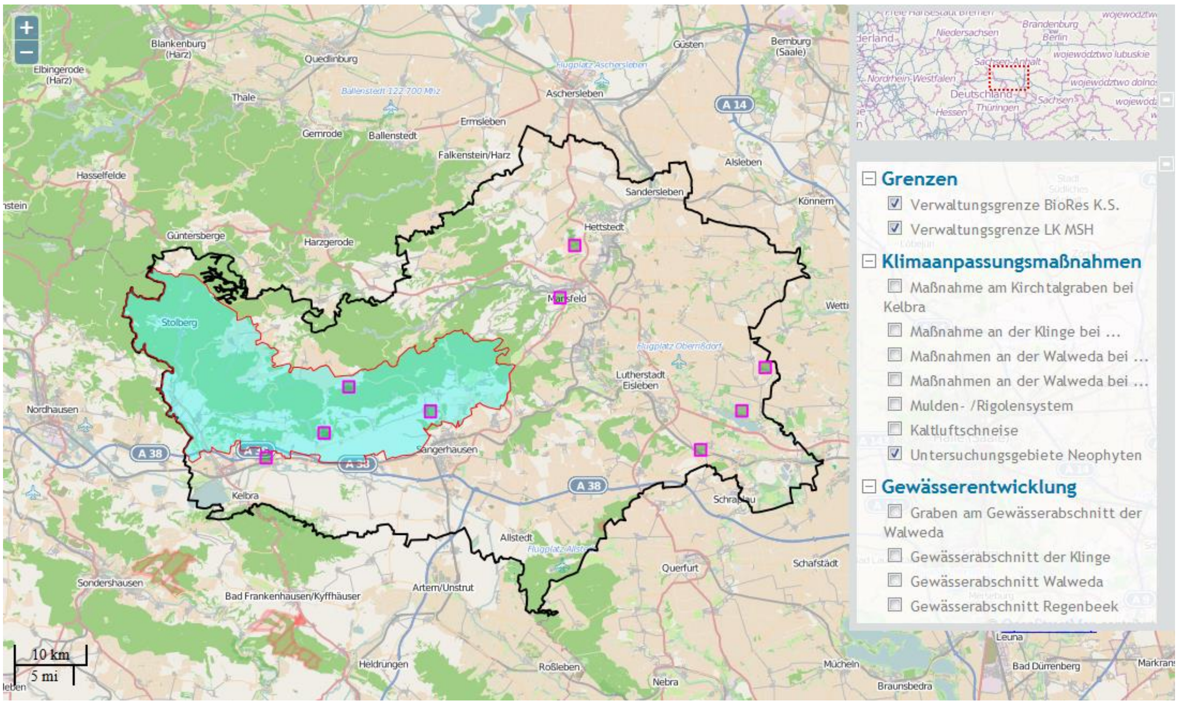


*Figure 4: Integrated interactive Map to visualise the climate change adaption measures*

## 5. Analysis of acceptance and usage

The evaluation of the project is accompanied by a two way website analysis function of Google Analytics [10] and Stalytics2 [11]. The main reason for this double analysis, is the fact that Stylytics2 can't be blocked easily by users. 5.177 page views were registered since the evaluation starts in the End of January 2014. Overall 168 users from 10 different nations have used the web portal. 447 Sessions and thus about 96% of the accesses occurred from locale stakeholders around the region of Mansfeld-Südharz in Germany. A filtering of the IP-address space of the Harz University ensure an eligible evaluation process. Most peaks which are listed in the typical page view analysis, as shown in figure 5, correlate with the achievement of various milestones and project activities. The highest increase, for example, reflects the call for submissions of good-practice examples and interesting thematic news in a KLIMPASS AKTIV-related newsletter between 20th and 22th May 2014.

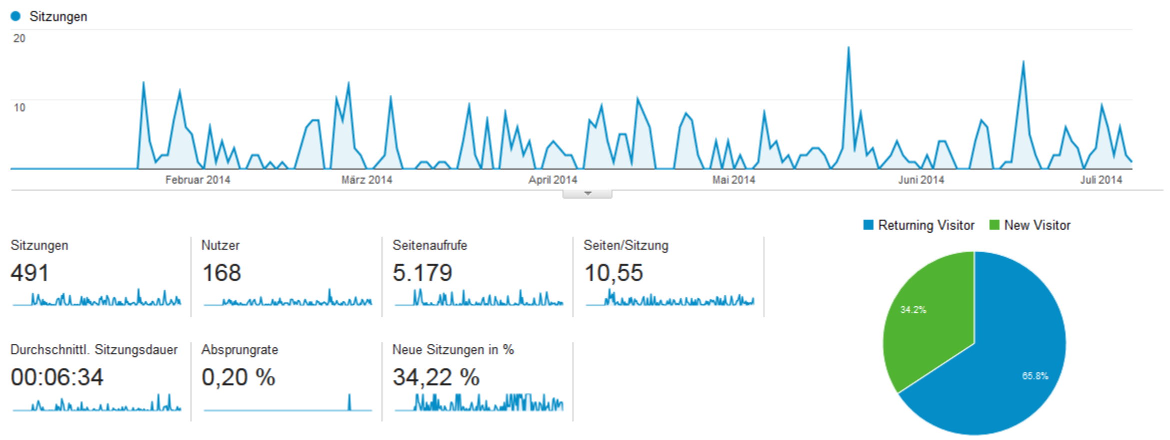


*Figure 5: Analysis of the acceptance and usage of the KLIMPASS AKTIV website with Google Analytics*

The continuous adaption of the web portal is supported by different workshops and presentations. Thus, all actors and stakeholders are involved in the development process and comments will be taken into account seriously.

## 6. Conclusion and Outlook

The KLIMPASS-AKTIV website is aimed at supporting user interaction concerning the challenges of *local* climate change adaptation. On the local level, decisions about concrete adaptation measures have to be made. Therefore, large-scale knowledge and experience is quite important. Examples of already implemented adaptation measures, as well as vulnerability maps, can help stakeholders to understand the situation and participate in the development of a local adaptation strategy. However, stakeholders in other regions can possibly profit from such a website to develop their "own" concepts. Users should have the opportunity to comment and criticise current developments, which is enabled through the website. The website, however, will also be opened, at least partly, for the public. Local citizens may have both, substantial knowledge on local conditions which should be considered during decision-making, and the capability to make concrete proposals on how to proceed with climate adaptation in a sustainable manner in future.

On the basis of the regular usage of the KLIMPASS-AKTIV website, data processing by Google Analytics and other services, the evaluation of the project will be continued. Based on this evaluation and feedback from administrational, and other, stakeholders, a constant adjustment process is established and will be optimized. Furthermore, the website should help to raise the overall, public awareness for climate change and the necessity for everyone to prepare for the changes that might happen in the future.

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# Portal for the collection of electrical devices with a suspected planned limited useful life

Nadine Kolley[1] , Romy Morana[2] , Stefan Schridde[3], Stefan Ebelt[4]


## Abstract

The aim of the project is to develop a web-based system for the collection of cases of electrical devices with planned obsolescence by the public as well as their statistical preparation and analysis.


## 1. Planned obsolescence

Shorter product lifetimes and the consumption of electrical devices lead to an increase of the production and also to a higher resources consumption as well as to a larger waste accumulation. Often the suspicion is raised that producers would shorten the lifetime of their products deliberately (planned obsolescence) ([8] S.2). Already in the 1920s there were first signs of planned obsolescence, which were much later defined as such cases. One of the oldest examples of such a planned lifetime reduction is the PHOEBUS bulbs cartel. In 1924, the manufacturers General Electric, Philips, Osram and Compagnie des Lampe agreed that their bulbs should glow only 1000 hours instead of the possible 2500 hours. The companies involved in the cartel controlled most of the market and were able to reduce the lifetime to increase their sales ([2] S.13 ff.).

The term "planned obsolescence" was probably first published in Bernard London's text “Ending the Depression Through Planned Obsolescence” from 1932. Here he describes planned obsolescence as a “plan for ending the depression”. He claims that “People everywhere are today disobeying the law of obsolescence. They are using their old cars, their old tires, their old radios and their old clothing much longer than statisticians had expected on the basis of earlier experience.” ([6] S.2)

The first known definition of obsolescence occurred in an article on "Purposeful obsolescence" of P. M. Gregory in 1947: “Purposeful obsolescence exists whenever manufacturers produce goods with a shorter physical life than the industry is capable of producing under existing technological and cost conditions; or whenever manufacturers or sellers induce the public to replace goods which still retain substantial physical usefulness.” [3].

Karl-Heinz Hillmann describes planned obsolescence in 1977 as an environmental and social problem: “Die Obsoleszenzstrategie (…)des geplanten Verschleißes umschließt mehrere Möglichkeiten, auf die bereits Vance Packard hingewiesen hat (1964, S. 6o-61). (…) Durch planmäßige Reduktion der Nutzungsdauer yon Gebrauchsgütern den Ersatz- und Erneuerungsbedarf der Verbraucher zugunsten unternehmerischer Wachstumsmöglichkeiten zu beschleunigen. (…) Inzwischen ist nun aber im Zusammenhang mit der lebensbedrohlich ausufernden Wachstums- und Umweltkrise eine einschneidende Veränderung des gesamtgesellschaftlichen Rahmens der Erscheinung geplanten Verschleißes eingetreten.“ ([4] S. 49).

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G. Wortmann recognizes in 1983 that the existence of certain obsolescence strategies in today's market activity can no longer be denied [9].

Nowadays, the term "planned obsolescence" is used and described more and more often:

- „Obsoleszenz meint die „natürliche“ Alterung eines Produktes aufgrund material- und nutzungsbedingter Qualitätsverluste, wodurch bestimmte Funktionen schwächer werden, das Produkt seinen Zweck nicht mehr im gewünschten Ausmaß erfüllt oder es gar nicht mehr funktioniert. Von „künstlicher“ Produktalterung (geplanter Verschleiß) wird gesprochen, wenn ein Produkt vorzeitig, also vor der erwarteten natürlichen Alterung seine Funktion verliert oder wenn die Einführung eines neuen Produktes bzw. einer neuen Technologie, dazu führt, dass ein noch funktionstüchtiges Produkt die Erwartungen des Nutzers/der Nutzerin nicht mehr erfüllt und dieser daher ein neueres kaufen will oder muss.“ ([5] S. 3)
- „Unter „geplantem Verschleiß“ oder „geplanter Obsoleszenz“ wird der geplante, vorzeitige Verschleiß von Produkten, die eigentlich viel länger halten könnten, verstanden. ([7] S.5)

Planned obsolescence concerns strategies and proceedings of the manufacturers and the trade because they want to increase their profit by shortening the product lifetime and boost the purchase of new products. It is not about rated break points, which are for the protection of devices and users. Planned obsolescence is not easy to identify. But it can be made verifiable and visible with the help of the collection and analysis of different cases of damage. From the social perspective it is necessary to collect information on typical defects, damaged components and the repairability of products.

Planned obsolescence can be classified into different dimensions. Not always the end of lifetime of a product plays the most important role in the use of the term "planned obsolescence":

| | | End of product lifetime | |
|---|---|---|---|
| | | No | Yes |
| End of the useful lifetime of the product user | No | use<br>(no obsolescence)<br>The product is usable and current user want continue using it.. | use interruption<br>(technical obsolescence)<br>The product no longer satisfies the requirements, but the user really want to use it any longer and let it repair etc. |
| | Yes | use interruption or end<br>(psychological obsolescence)<br>The product is usable, but its user wants / needs it no more, the product is made available for other users or thrown away. | end of use<br>(technical obsolescence)<br>The product no longer satisfies the requirements. The user does not want to use it longer.<br>a) the product is still repairable (end of the useful lifetime, but not of the lifetime)<br>b) the product is not repairable (end of product lifetime |

*Table 1: Useful lifetime and product lifetime (by [5] S. 15)*

Technical obsolescence means:

- Design-related shortening of the useful phase (example: permanently installed, non-replaceable battery in a product)
- Component-based approaches (example: undersizing of electrolytic capacitors in electronic products)
- Qualitative obsolescence (example: in printer built-in counters that trigger a notification for a need for service, although none is required).
- Functional obsolescence (example: the operating system of a computer is obsolete when a new, much needed software no longer works with it)

Psychological obsolescence means:

- New models and new technologies (fashion cycles) should bring old products to obsolescence.

([7] S.25 ff.)

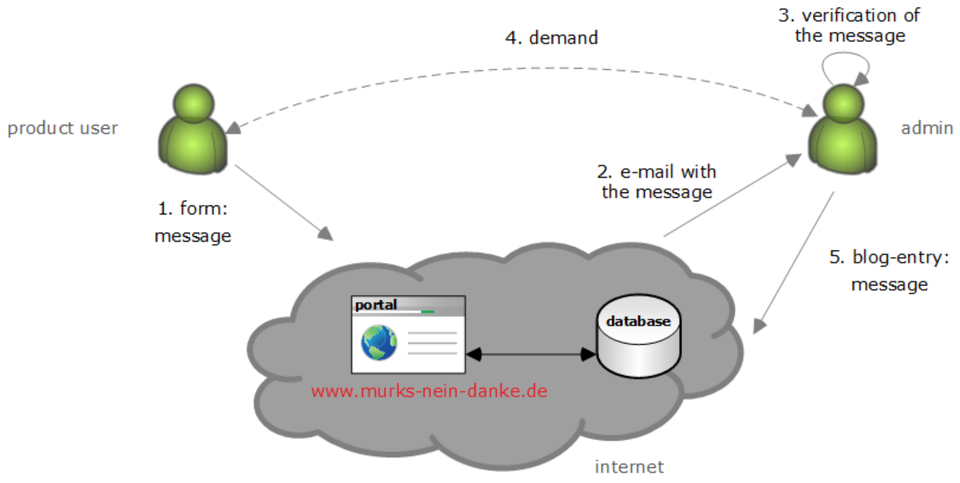
## 2. Actual state of the portal

Since February 2012 “MURKS? NEIN DANKE!”, a civic movement, works against planned obsolescence, which campaigns for sustainable product quality and product responsibility. The online presence of “MURKS? NEIN DANKE!” allows a first collection of cases of planned obsolescence by the public. Since its launch in February 2012 product users can report defective products (http://www.murks-nein-danke.de/murksmelden/murksmelden/).

The website of the Association "MURKS? NEIN DANKE!" is located on a web server on which the free software WordPress is installed to manage the content and serves primarily as a content management system (CMS).

A new message is previously stored as follows in the database and displayed on the website in the form of a blog:

1. The form on the page http://www.murks-nein-danke.de/murksmelden/murksmelden/ should be filled in and "sent".
2. An e-mail with the message is automatically generated and sent to the Wordpress administrator.
3. The administrator checks the message on the accuracy of the information (manufacturer, e-mail address, content plausibility)
4. In case of any questions, the sender will be contacted.
5. Otherwise, the administrator creates a blog entry on http://www.murks-nein-danke.de/murksmelden/die-meldungen/
6. Simultaneously this message will be stored as a new database entry.




*Graphic 1: Leave a message (actual state)*

On the current website of "MURKS? NEIN DANKE!" you can report “botch” and see all the previously reported messages as well as receive information about planned obsolescence, supports the registered association and get in touch with the initiator. Furthermore, there is a tag cloud as a kind of “Murksbarometer 1.0”, which represents the frequency of the emergence of manufacturers in the messages with different font sizes.

Currently 181 messages with relevant comments from other reporters are visible on the website, reported in the period from 27/02/2012 to 24/03/2014.

## 3. Challenges of the pilot portal

The existing portal of “MURKS? NEIN DANKE!” is a first approach to collect cases of electrical devices with planned obsolescence. But it can be extended to some useful features which make the site easier to use and easier to read.

Improvement suggestions are shown below:

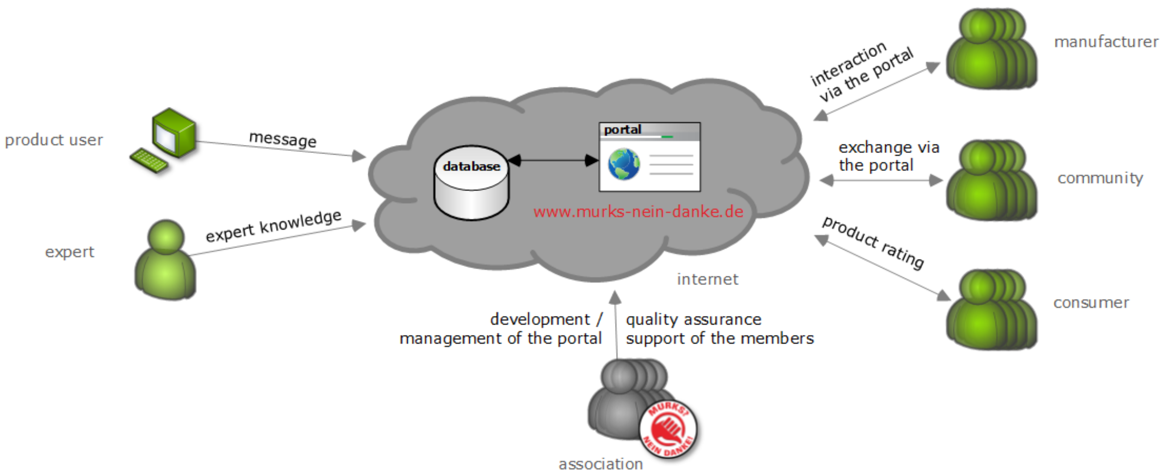
1. Firstly, an improved editing in transferring the messages would be desirable. All messages must currently be checked and entered by hand as a blog entry by the portal administrator from the incoming e-mails (see chapter of actual state).
2. Because the blog is composed of entries that are listed unsorted, the existing messages are shown unclear. Besides a search function there is only one filter option for the entries via the tag cloud. This means until now, not many statistics, for example, about the number of messages per year / device type / manufacturer can be made with the information in the database.
3. In the current portal comments can be written under each blog entry. This is a first approach to a controversial discussion with experts as well as between message senders or the manufacturers of electrical appliances, but may still be extended by a clearly arranged discussion forum.
4. The newly designed portal could be extended to various tools such as online repair manuals or repaircafé details.

## 4. Concept of a rating portal

To implement these suggestions of improvement a rating portal should be developed during the project “Portal for the collection of electrical devices with a suspected planned limited useful life (planned obsolescence)” at the HTW Berlin.

Generally rating portals such as for travels, hotels, restaurants and other products have the purpose to inform the consumers about the product features. It is assumed that the users' experiences are more believable than the promises of the manufacturer: “They appear as a counterpoint to the whitewashing of the advertisement”. The portal is intended to serve as a component of environmental procedures for better raw material efficiency and waste avoidance so that portal users are informed and made aware in connection with the issue of planned obsolescence. The aim of the portal is to offer an opportunity for the consumer to mention cases of planned obsolescence, and thus to give him a voice. With these "voices" the political pressure on the producers and distributors should be increased. Thus reviews by consumers can affect the sales of manufacturers and for example cause sale decrease because reviews are decision guidance for other consumers ([1] S. 1).

In this research project an online community should be developed where users can exchange information with producers and distributors of electrical devices and support each other. This portal is designed to help to improve the dialog between users, repairers and manufacturers of electronic devices in order to develop solutions for a sustainable product design (a longer usability and a better repairability). The result is an online dialog between consumers, service companies, manufacturers and distributors of electrical devices as well as experts and people who work in research and science (see Graphic 2):




*Graphic 2: dialogue-oriented rating portal*

As part of this portal many important data about a product (product information such as the name / device type / year of manufacture / manufacturer and distributors, etc.) and causes of damage should be collected and stored in a database. This should be done by the public in form of reports which are also supplemented by documents such as repair manuals, self-help offers and user experiences for repairability. A report should be independently entered by the product user with the help of a query form. This report should be checked with the help of the community and by the interaction and participation of the users of the portal. A message is thus an evaluation of a product. With the help of the query form the damaged products are classified by the consumers according to predefined and extensible product and damage categories so they have a better gradation and can be easier evaluated. Product categories and categories of damage must be previously defined.

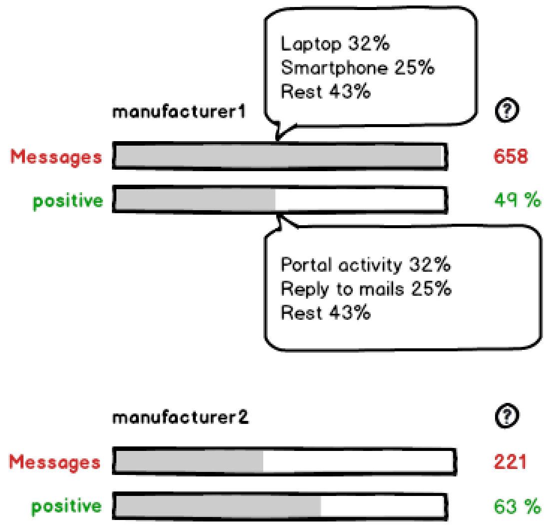
The portal should always be developed further and new applications can be added. New ideas should be proposed by and discussed with the users. New applications can expand the portal in the form of so-called widgets. One of these applications should be the widget extension “Murksbarometer 2.0”. Furthermore, the portal wants to initiate, support and connect RepairCafés, free repair shops and community service groups. It might be created a widget which allows portal users to find a RepairCafé with address, phone number and website easily.

It is intended that the rating portal is developed with the help of a free content management system (CMS). Thus, the development and maintenance of content (information) can still be separated. In addition, several people from the "MURKS? NEIN DANKE!" can edit content with different access rights, without having to deal with the programming, as it is already possible at the pilot portal. For the realization of the rating portal, the most popular CMS (Contao, Drupal, Joomla, Typo3 and Wordpress) were evaluated to find out which is the most suitable software. The underlying evaluation criteria were.

- complexity of the software
- dissemination
- field of application
- extent of the extensions
- suitable extensions for the portal (forum, forms, connections to social networks, ...)
- scalability
- content creation (blog system and multilingualism)
- user management (user groups, rights)

## 5. “Murksbarometer 2.0”

All manufacturers that appear in the messages should be shown in an extended “Murksbarometer” (2.0). The manufacturers are sorted in a list, so the manufacturers with most messages are at the top of this list. But as compensation there should also be a positive evaluation of the manufacturer. The “Murksbarometer 2.0” should look like this:




*Graphic 3: "Murksbarometer 2.0"*

The red bar shows how many messages with assumed product planned obsolescence have been reported about a manufacturer in the portal. In order to evaluate not only negative but also positive aspects of the manufacturer, in the “Murksbarometer 2.0” also a green bar is visible. This is meant to indicate, for example, the online activity of a manufacturer, e.g. how often a representative of the manufacturer visited the manufacturer profile per week / month etc. As a positive evaluation of a manufacturer, the frequency of responding to e-mails that have been sent via the portal, or visible product improvements can be shown. An exact algorithm for the calculation of the green bar as well as for sorting (the quantifier of the red and the green bar) is still being worked out.

The aim of the “Murksbarometer 2.0” is to encourage the manufacturers to make a statement and cause a product improvement using the rankings. The function of the “Murksbarometer 2.0” is to support the consumer of electrical devices in the quick, visual identification of all manufacturers and to encourage the manufacturers to an interaction in the portal.

Because the portal ensure a maximum of self-regulation of the community and because the moderation effort should be kept as small as possible, the “Murksbarometer 2.0” is based on absolute numbers, because the use of relative numbers would have to be calculated using a basis of calculation that needs to be determined for each producer individually.

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# An approach of a data-driven Spatial Decision Support System to manage the effects of Climate Change on agriculture

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## Abstract

Climate change is an important challenge of our era. Enhancing resilience to climate change, particularly to reduce its effects on agriculture is crucial to improve food security and achieve sustainable development.

Persistent drought and extreme weather events affect the agricultural calendar and crops, particularly in developing countries. Crop harvesting is being affected due to higher air temperatures that reduce the daily temperature variability and increase plagues and sicknesses. Sea-level rise and frequent flooding are other factors that threaten food security and efforts to eradicate poverty and achieve sustainable development. Land degradation is one of the indirect effects of Climate Change.

Within the framework of the Project “Environmental Bases for Local Alimentary Sustainability”, sponsored by EU and UNDP (2012-2017), this work is aimed to provide decision-making tools to support new Climate Change adaptation policies. Particularly, a decision support solution to analyze land degradation as one of the driving force Climate Change effects is discussed. An index of degradation is computed by a weighted sum according to Saaty prioritization mechanism.

Common spatial analyses from Geographical Information Systems have been used in the study area to combine different factors (layers) and produce the layer of degradation indexes. Such a layer is used as input data to the ETL component in a Business Intelligence solution. As a typical data-driven Spatial Decision Support System, other components as data warehousing, OLAP and spatial reporting are also presented; as well as, the software tools developed to support this BI solution.

Key words: Climate Change, Agriculture, Data-driven Decision Support System, Business Intelligence, Spatial Decision Support System

## 1. Introduction

Any discussion on technical support for decision-making in different domains should consider a holistic approach to human problem-solving, the concrete environments in which decision support systems (DSSs) will be used, and the acceptance of the system by the user. The ultimate goal is a system under which international organizations, governments, local authorities, and individuals are able to conduct negotiations as well as coordinate and evaluate their own independent decisions.[1]

This paper deals with this problematic situation, providing an approach of a data-driven Spatial Decision Support System to characterize spatially the combination of agriculture vulnerabilities. It could contribute to provide possible adaptation scenarios for the impact of Climate Change on agriculture.

Particularly relevant for this paper is to highlight, from these researches, some key definitions:

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*Decision Support System*: Vercellis defined DSSs as “an interactive computer-based application that combines data and mathematical models to help decision makers solve complex problems faced in managing the public and private enterprises and organizations”.[2]

*Data-driven Decision Support System*: data-driven DSSs emphasize access to and manipulation of a time series of internal company data and sometimes external and real-time data. Data-driven DSSs with online analytical processing provide the highest level of functionality and decision support that is linked to analysis of large collections of historical data.[3-9]

*Business Intelligence*: The term BI is a popularized, umbrella term coined and promoted by Howard Dresner of the Gartner Group in 1989. It describes a set of concepts and methods to improve business decision making by using fact-based support systems. In general, business intelligence systems are data-driven DSSs.[10]

A first part of this work deals with a multi-criteria evaluation based on an Analytical Hierarchical Processing (AHP) technique. As a result, a land degradation index spatially distributed is obtained. Second part of the paper is dedicated to describe the methodological issues of a Business Intelligence solution to complement the SDSS. According to a data-driven SDSS classification, different components for a Geospatial Business Intelligence Platform are described in integration with business needs, potential reports, spatial visualization tools and analytical results.

### 1.1. BASAL Project

The project “Environmental Bases for Local Alimentary Sustainability” (BASAL) aims to support Cuba’s adaptation to Climate Change and contribute to the country's continued and sustainable economic and social development by improving the national food security. More specifically, the project aims to decrease the vulnerabilities of the national agricultural food production related to climate change and variability; through:

- The identification and reduction of Climate Change impacts which affect major national food production;
- The promotion of good/best practices and provision of useful and accessible information which eventually help farmers produce food in a sustainable manner;
- The provision of scientific- and experienced-based tools and recommendations which enhance the decision making capacity in relation to the Climate Change challenge of key actors at all relevant levels.

This project is targeted to 3 municipalities with different characteristics and important relevance in the economy of Cuba. Güira de Melena is one of them and will be the selected study area for this paper. This mainly rural municipality on the Southern coast of the province Havana produces a large part of the food (fruits, vegetables and meat) reaching the 2M inhabitants of the province, including the capital city of Havana. It is affected by coastal flooding and saline intrusion as far as 6 km from the sea, coastal erosion, and land degradation.[11]

Land degradation in Güira de Melena is the result of the combination of different factors. By determining their priorities regarding soil and vegetation factors, this work builds a solution of Business Intelligence with the view to make diverse analyses supporting decision making.

## 2. Methods and Tools

Institute of Soil together Institute of Geophysics and Astronomy in Cuba undertakes often different studies to support decision making in this field. However, less frequently they have conducted studies to determine a land degradation composite index. Developing a study to support this problematic becomes in a key factor into the framework of BASAL.

In consultation with experts, the following variables, shown in the Table No. 1, were identified as factors to determine land degradation.

| Soil | Vegetation |
|---|---|
| Effective depth | Vegetation Formation |
| Rockiness | Intervention Degree |
| Stoniness | Vegetation density |
| Slope | |
| Soil Erosion | |
| Salinity | |
| Saturation | |
| Soil sub-type | |

*Table 1: Factors identified in the model.*

## 2.1. Mathematical Model. Analytic Hierarchy Process Method

The eigenvalue method for assessing attribute weights and single-attribute value functions is part of a general methodology called "Analytic Hierarchy Process"; it consists in structuring the decision problem in a hierarchical manner, constructing numerical evaluations associated with all levels of the hierarchy and aggregating them in a specific fashion, formally a weighted sum of single-attribute value functions.[12]

To make a decision in an organized way to generate priorities we need to decompose the decision into the following steps:

1. Define the problem and determine the kind of knowledge sought.
2. Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives).
3. Construct a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.
4. Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Then for each element in the level below add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained.[13, 14]

Following the AHP proceeding, the main decision objective was identified as follows: "*determining spatially a degradation index in the municipality Güira de Melena*". To determine such an index, a set of factors grouped in two classes (soil and vegetation) were identified.

Saaty´s scale is usually divided into 9 intervals, as depicted below in the Table No. 2.

| Value | Definition | Explanation |
|---|---|---|
| **1** | Equal Importance | Two activities contribute equally to the objective |
| **2** | Weak or slight | |
| **3** | Moderate importance | Experience and judgment slightly favor one activity over another |
| **4** | Moderate plus | |
| **5** | Strong importance | Experience and judgment strongly favor one activity over |

| | | |
|---|---|---|
| | | another |
| **6** | Strong plus | |
| **7** | Very strong or demonstrated importance | An activity is favored very strongly over another; its dominance demonstrated in practice |
| **8** | Very, very strong | |
| **9** | Extreme importance | The evidence favoring one activity over another is of the highest possible order of affirmation |

*Table 2: Saaty´s scale to prioritize criteria (Source: [13])*

If one wants to apply AHP in a multiple criteria decision problem, pair-wise comparisons of the alternatives must be performed for each criterion; criteria must also be compared in a pair-wise manner to model their importance.

By executing the Saaty mechanism, weights were determined in each level of the AHP hierarchy. The tables No. 3, No. 4 and No. 5 show the values given by experts considering factors identified above.

| Degradation | Soil | Vegetation | Eigenvalue |
|---|---|---|---|
| Soil | 1 | 5 | 0,636986 |
| Vegetation | 1/5 | 1 | 0,258285 |

*Table 3: Matrix of pairwise comparisons for the top level of Land Degradation Hierarchy (Consistency Index = 0,047725)*

| Soil | Effective depth | Rockiness | Stoniness | Slope | Erosion | Salinity | Saturation | Soil Subtype | Eigenvalue |
|---|---|---|---|---|---|---|---|---|---|
| **Effective depth** | 1 | 2 | 3 | 5 | 5 | 5 | 7 | 9 | 0,341260 |
| **Rockiness** | ½ | 1 | 2 | 3 | 3 | 5 | 5 | 7 | 0,219196 |
| **Stoniness** | 1/3 | 1/2 | 1 | 2 | 3 | 4 | 5 | 5 | 0,156623 |
| **Slope** | 1/5 | 1/3 | 1/3 | 1 | 1 | 3 | 4 | 5 | 0,096792 |
| **Erosion** | 1/5 | 1/3 | 1/3 | 1 | 1 | 2 | 3 | 3 | 0,077594 |
| **Salinity** | 1/5 | 1/5 | 1/4 | 1/3 | 1/2 | 1 | 2 | 3 | 0,049920 |
| **Saturation** | 1/7 | 1/5 | 1/5 | 1/4 | 1/3 | ½ | 1 | 2 | 0,034017 |
| **Soil Subtype** | 1/9 | 1/7 | 1/5 | 1/5 | 1/3 | 1/3 | ½ | 1 | 0,024598 |

*Table 4: Matrix of pairwise comparisons Land Sub-criteria (Consistency Index = 0,041883)*

| **Vegetation** | **Vegetal formation** | **Degree of Intervention** | **Density of Vegetation** | **Eigenvalue** |
|---|---|---|---|---|
| Vegetal formation | 1 | 3 | 5 | 0,636986 |
| Degree of Intervention | 1/3 | 1 | 3 | 0,258285 |
| Density of Vegetation | 1/5 | 1/3 | 1 | 0,104729 |

*Table 5: Matrix of pairwise comparisons for vegetation criteria (Consistency Index = 0,047725)*

After this process, it is necessary to evaluate functions $u_i$ that evaluate the alternatives on each criterion i and in coefficients of importance ki. Each alternative a is then assigned an overall value v(a) computed as:

$$v(a) = \sum_{i=1}^{n} k_i \, u_i(a)$$

and the alternatives can be ranked according to the values of $v$.[13]

To develop AHP for land degradation, some tools of Geographical Information Systems (GIS) were used. Raster calculation tools from ArcGIS were particularly useful. As a result, a layer of cadastre parcels associated with each land degradation index and other attributes was obtained.

Portrayal of land degradation index layer in a map was itself a contribution to decision makers. Nevertheless, they needed any kind of visual tool where they could manage dynamically different views (maps, tables, graphs) at the same time, filtering or aggregating information for time, land use, territories, etc.

For this reason, the research includes also elements of Business Intelligence, by building a multidimensional structure (data warehouse) capable to provide different analyses (OLAP) with their corresponding visualization tools. Considering effects of Climate Change occur in long period of time, these BI tools could become in a crucial support to decision making.

## 3. Results

A data warehouse (or smaller scale data mart) is a specially prepared repository of data created to support decision making. Data are extracted from source systems, cleaned and scrubbed, transformed, and placed in data stores[15].

The design of data warehouses and data marts is based on a multidimensional paradigm for data representation that provides at least two major advantages: on the functional side, it can guarantee fast response times even to complex queries, while on the logical side the dimensions naturally match the criteria followed by knowledge workers to perform their analyses [2]. The multidimensional representation is based on a star schema which contains two types of data tables: dimension tables and fact tables.

According to the application scenario, land degradation can be interpreted as the “fact” in the data warehouse design. In the same way, time, location and land use would represent “dimensions”. Figure 1 shows a star schema for the data warehouse design.

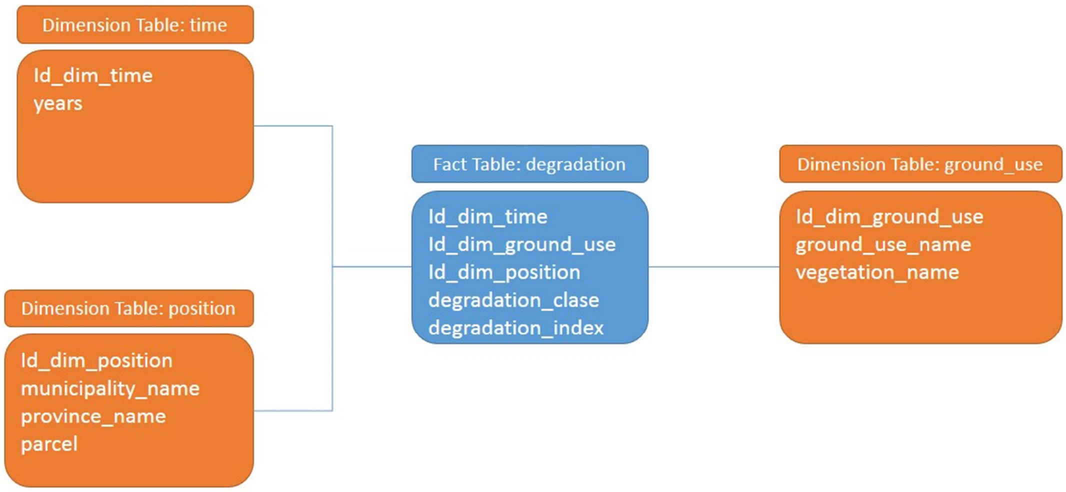


*Figure 1: Data warehouse design.*

The general architecture for the proposal BI/data-driven SDSS solution is depicted in the Figure 2 below.

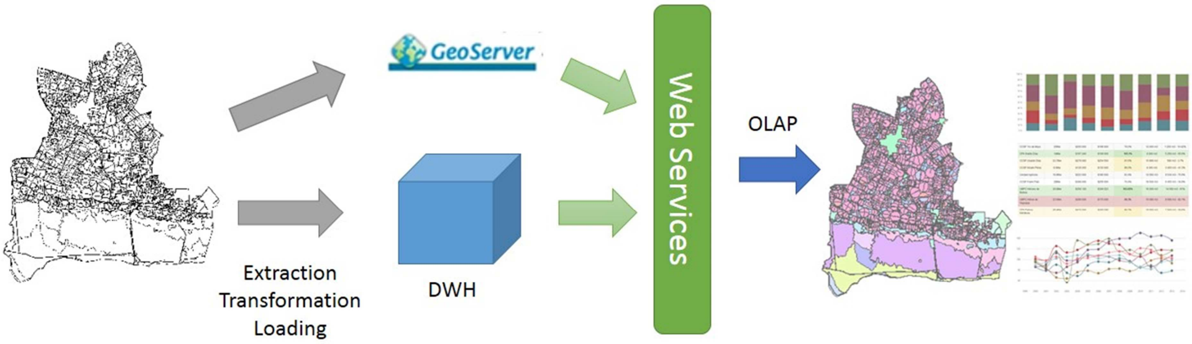


*Figure 2: Architecture of the data-driven Spatial Decision Support System*

Primary data source were the layers of degradation indexes obtained for each time period following the AHP technique explained above in this paper. ETL proceedings were developed to load data into the data warehouse, by means of Pentaho Data Integration 5.0.1. This powerful tool facilitates extracting, transforming and cleaning; as well as loading data into a data warehouse.

*Extraction:* During the first phase, data are extracted from the available sources (GIS for the example). The subsequent incremental extractions allowed update the data using new data that become available over time. The selection of data to be imported is based upon spatial database design, which in turn depends on the information needed by business intelligence analyses and decision support systems operating in the specific application domain.

*Transformation:* The goal of the cleaning and transformation phase is to improve the quality of the data extracted from the different sources, through the correction of inconsistencies, inaccuracies and missing values.

*Load:* Finally, after being extracted and transformed, data are loaded into the tables of the spatial data warehouse to make them available to analysts and decision support applications. [16]

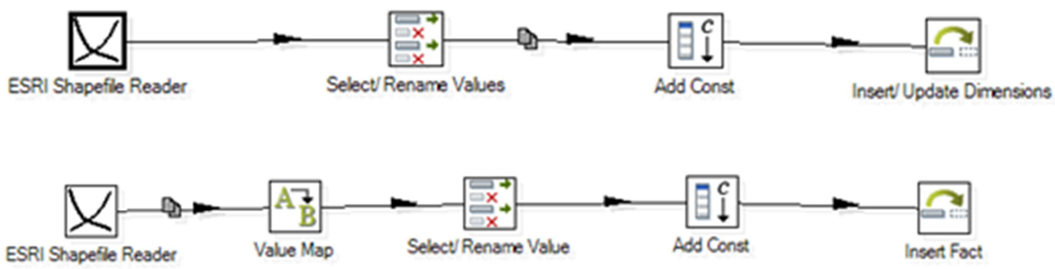


*Figure 3: Some ETL proceedings used for load data in data warehouse*

Part of this process corresponds to publish the layer of land degradation in the Map Server GeoServer. GeoServer has implemented the main OGC specifications [17-19]: WMS, WFS, WCS y WPS. GeoServer is also useful to visualize output maps, since it uses OpenLayers, an opensource viewer for OGC specifications.

With the view to develop MDX queries on the data warehouse, a specific Web Service was built. This allows the OLAP analyses and the unification of non-spatial and spatial information consumed from the Map Server GeoServer, compatible with OGC (Open Geodata Consortium). This Web Service includes logic for reports and analyses, making transparent for users work with the data warehouse.

A client application was developed as the BI user interface to support queries and visualization. This application invokes the Web Service developed to facilitate spatial and OLAP analyses regarding land degradation. JavaScript libraries like OpenLayers (to manage and visualize geospatial components), Jquery (to build graphs and tables) and JPivot (to support OLAP operations as Drill-down, drill-up, Pivoting, Slice) were included into the client interface.

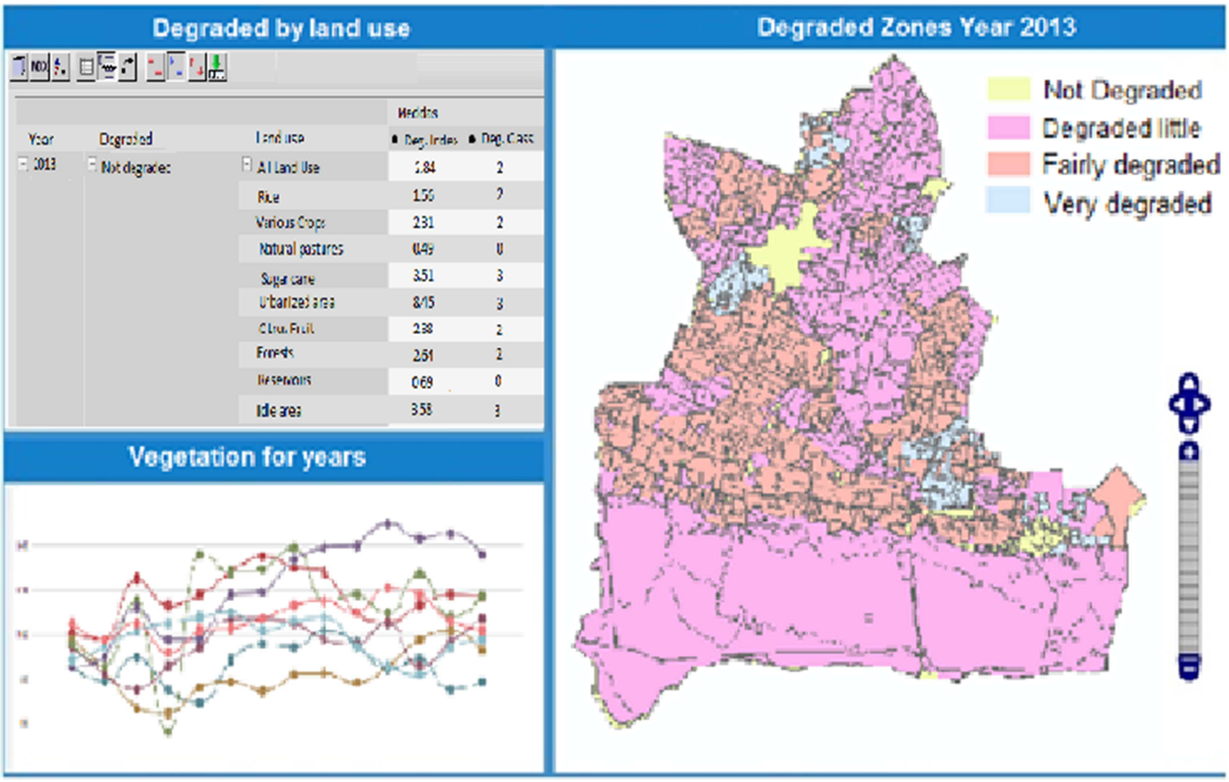


*Figure 4: A view of the client application developed to visualize analysis of land degradation*

Figure 4 shows the web application developed for the analysis of land degradation with a view of an OLAP query engine, statistical data and information on a map. Achieving calculate a degradation index per parcel or unit of land is very important to local authorities in Güira de Melena. Having this tool local governments can achieve greater effectiveness in actions to combat land degradation.

## 4. Conclusions

A land degradation index has been calculated in a GIS based on multi-criteria AHP techniques. The new map of land degradation temporary disaggregated serves as input data to a Business Intelligence solution.

OLAP analyses on the data warehouse built around the degradation allow diversify queries considering different dimensions as time, location and land use. A powerful spatial visual tool which integrates mapping of degradation using different views by means of OLAP analyses will allow supporting decision making processes on sustainable agriculture in Güira de Melena.

Climate Change is a driving force or indirect cause for land degradation. A spatio-temporal study of land degradation and its correlation with similar future studies of climate variability will support decision makers in order to create new policy actions regarding food security.

This work is part of a bigger Project entitled “Environmental bases for local sustainability of food production” (BASAL) and constitutes a first approximation to a data-driven Spatial Decision Support System to manage Climate Change effects on agriculture.

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# Electronic waste risk assessment and management in Ghana

D. Nukpezah[1] , H.A Okine,[1] M. Oteng-Ababio2 and B.D Ofori[1]

## 1. Introduction

Electronic waste is the term used to describe old End Of Life (EOL) electronic appliances that have been disposed of by their original users [1]. Such appliances may include broken cell phones, old computers, TV sets, iPods and other obsolete gadgets that no longer serve relevant purpose [2]. Most common in e-waste streams are computers. Globally 20 to 50 million tons of e-waste are generated annually [3,4]. Many electronic products contain numerous toxic chemicals and materials including heavy metals such as arsenic, antimony, berrylium, cadmium, chromium, copper lead, mercury, nickel, zinc and organic compounds of chlorine and bromine. These pose risk to health and environment when disposed of [5]. Typically EOL computers have approximate distribution of e-waste as follows: glass (24.8 wt%, plastics (23 wt%), precious metals (0.02 wt%), Iron (20.47 wt%), lead (6.3 wt%), aluminium (14.17 wt%), copper (6.93 wt%) and others (4.3 wt%) [6].

Inspite of the opportunities that exist for returning EOL computers and other e-waste to the supply chain through recycling, in developing countries unlike developed countries, the lack of robust institutional, regulatory frameworks and human capacity undermine such initiatives. Further due to the relatively high cost involved in managing e-waste in developed countries compared to developing countries, Used Electrical and Electronic Equipment (UEEE) have found final resting place in many developing countries [7]. Compliance with environmental regulations increases the cost of e-waste disposal in developed countries and intense pollution activities tend to migrate towards developing countries where such robust regulations do not exist [8]. Between 50 to 80% of e-waste from industrialized countries is exported to recycling centers in developing countries [9] because environmental regulations are relatively weak and recycling and disposal practices often take place in largely inappropriate and unregulated manner with little or no concern for potential impacts on human health and environment [10,11].

In Ghana, the demand for computers and accessories is phenomenal as a result of increasing electronic literacy. The government's ICT policy which sought to increase computer literacy saw an increasing import of used computers into the country as a result of the fact that many Ghanaians are unable to afford brand new computers. Very often, most of these computers are near their end of life (EOL) and are a threat to the environment when finally discarded. Despite this, many underemployed people have found an opportunity in making a living through metal recovery from this discarded e-waste. However the approach used is crude.

The overall objective of this study is to investigate through a systematic review of the literature and through primary research the sources and flow of UEEE import into Ghana and the environmental risk associated with material handling and metal recovery from e-waste as currently practiced in Ghana. The specific objectives include the following:

- Document the sources and flow of UEEE import into Ghana
- Investigate scrap yard and current e-waste recycling and disposal practices in Ghana

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- Assess the environmental risk associated with e-waste collection, recycling and disposal in Ghana
- Make recommendations to improve e-waste management in Ghana

## 2. Literature Review

It has been reported that 85% of UEEE imports into Ghana came from the EU [12,13]. The problem of transboundary movement of e-waste is due to lack of national regulation and weak enforcement of law in member countries that have ratified the Basel convention [14]. The Basel convention regulates transboundary movement of hazardous waste and prohibits the transboundary shipment of hazardous waste to countries that do not have the capacity to manage them in an environmentally sound manner [15]. Although the importation of UEEE offers Ghanaians the opportunities to acquire and use these appliances, most of such appliances are eventually disposed of within a year [13]. This suggests that some of the UEEE imported into the country are already near EOL and may imply weak or inadequate custom control. Another law controlling the movement of hazardous waste which may be contained in electronic waste is the Bamako convention which bans the importation of hazardous waste into Africa and seeks to regulate the transboundary movement of hazardous waste within Africa [16]. Ghana is a signatory to the Bamako convention but has not transposed its provisions into National law. Existing national legislation regarding UEEE and e-waste is the Energy efficiency regulation (LI 1932) of 2008 which bans the importation and sale of used refrigerators and air conditioners into Ghana. However this law is targeted more at energy efficiency and phasing out of ozone depleting substances and is not targeted at hazardous substances contained in UEEE/E-waste per se. Specifically therefore there are no laws in place to regulate the importation of second hand computers which has been a menace in the country [17].

There are health and environmental effects associated with e-waste. For example exposure to lead dust or fumes causes multiple disorders such as neurological, cardiovascular and gastrointestinal diseases and exposure to cadmium fumes or dust can result in kidney and respiratory system malfunctioning [9]. In Ghana increased levels of polychlorinated biphenyl (PCB) and polybrominated diphenyl ethers (PBDEs) found in breast milk have been linked to informal e-waste recycling activities [18].

Scrap metal workers typically work between 8.5 and 12 hours a day, 7 days per week [19]. Daily revenues vary greatly between US$ 0.22 and US$ 9.50. Clear stratifications within the scrap metal business were identified: collectors freely collect available waste (e.g. on waste dumps) and find themselves at the lower income side while recyclers tend to have their own workshops to store and sell scrap metal and are typically at the higher income side. Regarding value creation, it was estimated that countrywide activities in refurbishing and scrap metal collection and recycling (including e-waste) generate between US$ 106 and 268 million [20].

However despite the economic benefits for such e-waste workers, many work on average six years and then exit the industry [17]. The crude methods used during metal recovery and the concomitant health effects have been blamed for the high turnover rate of e-waste workers [17]. This fact informs this study to ascertain the risk exposure of e-waste workers.

## 3. Conceptual framework

Used electrical and electronic equipment when imported into the country are sold to wholesalers who in turn sell to retailers who then sell to the end user. However on arrival some of these gadgets are none functional which are sent for refurbishment and sold to the end user. Some of the imported UEEE are already at EOL and are either disposed off in open waste dumps or channeled through an inefficient recycling process. Here crude methods such as use of hammers, chisels, stones and screw drivers are used to separate plastic casings from cathode ray tubes (CRT). Plastics are burnt for metal recovery-Al, Fe and Cu and sold at the supplier market. In the process, hazardous substances are released into the soil and the environment and might be washed into streams thereby contaminating the aquatic ecosystem. Based on our framework, we posit that to effectively manage e-waste, one must understand the flow into the country and the risk to health and environment among others. An understanding of the flow pathways can inform the design of a framework to minimize risk due to e-waste exposure.

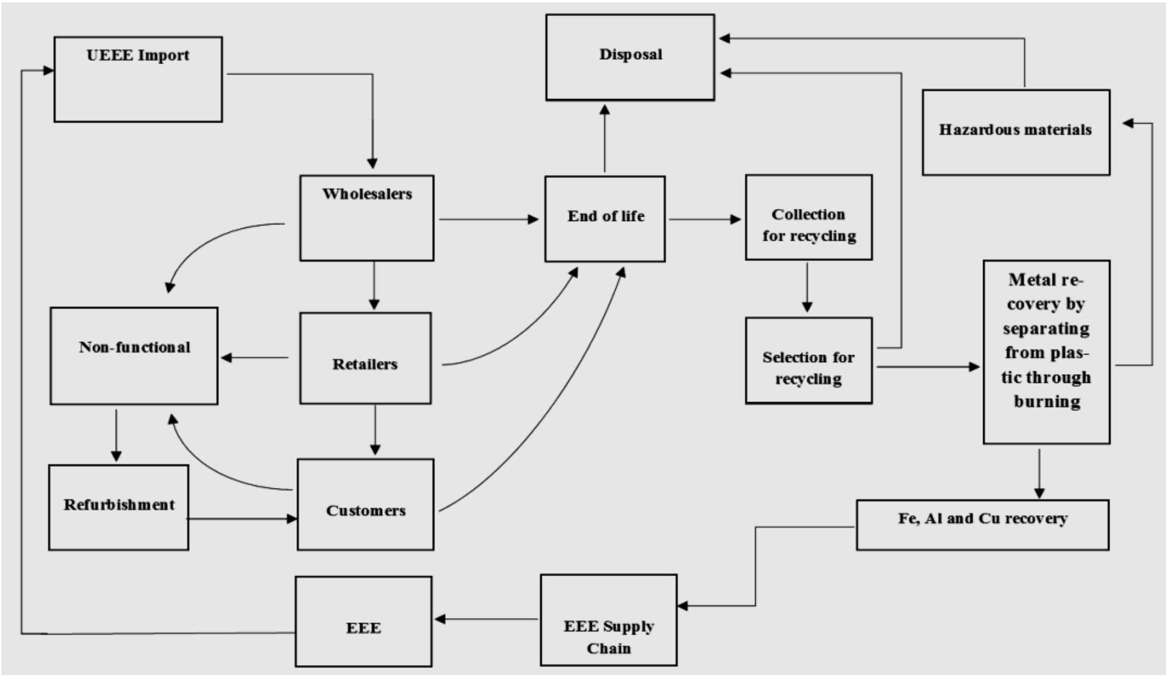


*Figure 1: UEEE flow pathway in Ghana*

## 4. Methodology

### 4.1. Study Area

Agbogbloshie has become infamous for its sea of discarded e-waste. It is located in Accra, Ghana on the western coast of Africa. While there are other e-waste sites in Ghana, Agbogbloshie is the main hub for trading activities related to e-waste. Such activities include, dismantling, recycling and disposal. Agbogbloshie's reputation as the hub for e-waste activities may be due to its peculiar characteristics. It is made of up of migrant communities of different ethnic origin occupying land whose ownership has not been properly defined. Thus against a mindset of being temporary residents coupled with lack of regulation of their activities due to undefined land rights, it is a free for all place where e waste is dumped and burnt for metal recovery with potential threat to human health and the environment.

### 4.2. Sources and Types of Data collected

Data collected is based on multiple sources. In this study we used a mixed method approach to collect primary data. Qualitative methods such as participant observation and focus group discussion have been used in addition to quantitative methods especially in the determination of heavy metal concentrations in soil and urine samples of e-waste workers.

### 4.3. Determination/Analysis of UEEE flow

Source data for imports of UEEE (volume and country of origin) came from secondary source- the customs excise and preventive service (CEPS) documentations of imports. This was then analysed for trends, volumes, sources by country and region.

### 4.4. Determination of Heavy metals in soil and urine samples of e-waste workers

To assess the level of environmental and human exposure to hazardous chemicals contained in E-waste, environmental and biological samples were collected and analyzed in the laboratory in July, 2013. Heavy metal levels in soil and urine were determined using VARIAN AA 240FS Atomic Absorption Spectrophotometer and results expressed in mg per kg. The values were compared to a control site at Mataheko, 3 km away in order to establish clearly whether contamination is due to e-waste activities.Ethical clearance was sought and permission granted for the urine samples to be analysed. All metals analysed have known uses in electrical and electronic equipment and therefore globally associated with e-waste for which they are likely to be released into the environment during e-waste recycling processes such as open burning.

### 4.5. Interviews and participant observation

Through focus group discussions and participant observation undertaken in May 2014, we were able to observe and document first hand hazards and potential risk associated with collection, dismantling, recycling and disposal. Observations unlike interviews where data obtained is based on the perception of interviewees, produces data based on the observer’s insight and perceptual sense [21]. Thus we used observations to ascertain practices of e-waste workers and how those practices are consistent with or deviate from expected practice with a view of bridging the gap between expected practice and what is being done currently.

## 5. Results and Discussion

### 5.1. UEEE flow

Most of the UEEE imported into Ghana originate from Europe and North America. Indeed among the top 5 exporting countries to Ghana, the United Kingdom leads with 36.41% of the total flow among these 5 countries (Figure 2). Between 2004 and 2010, cumulative total flow of 49,651,508.3kg of UEEE was imported into Ghana. Many importers are of the view that some UEEE imported into the country are non-functional. This agrees with estimates that in 2009, 30% of UEEE imports into the country were non-functioning and effectively e-waste [19]. Import of non-functioning UEEE into Ghana is inconsistent with the Basel convention which prohibits export of e-waste into regions where its management in an environmentally sound manner is not guaranteed [15]. It behooves therefore on both country of export and import to ensure that no international law in relation to transboundary movement of waste is contravened.

Analysis of UEEE flow into Ghana by region reveals that between 2004 and 2010, over 86% of e-waste/UEEE flows into Ghana come from Europe and North America. On the other hand, of a total of 74,014,545.90 kg of UEEE, the Carribean contribute only 0.02% of this flow into Ghana (Figure 3).

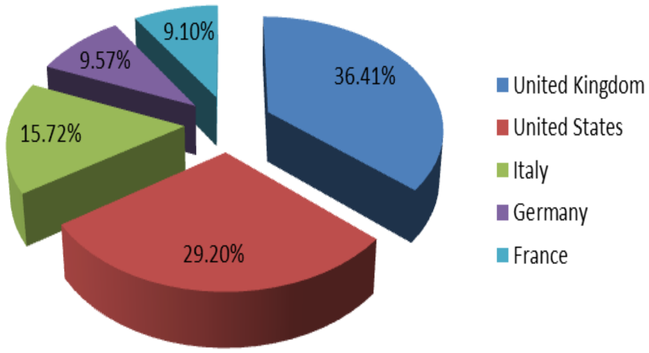


*Figure 2: Flow of used computers into Ghana among the top 5 exporting countries (2004-2010)*

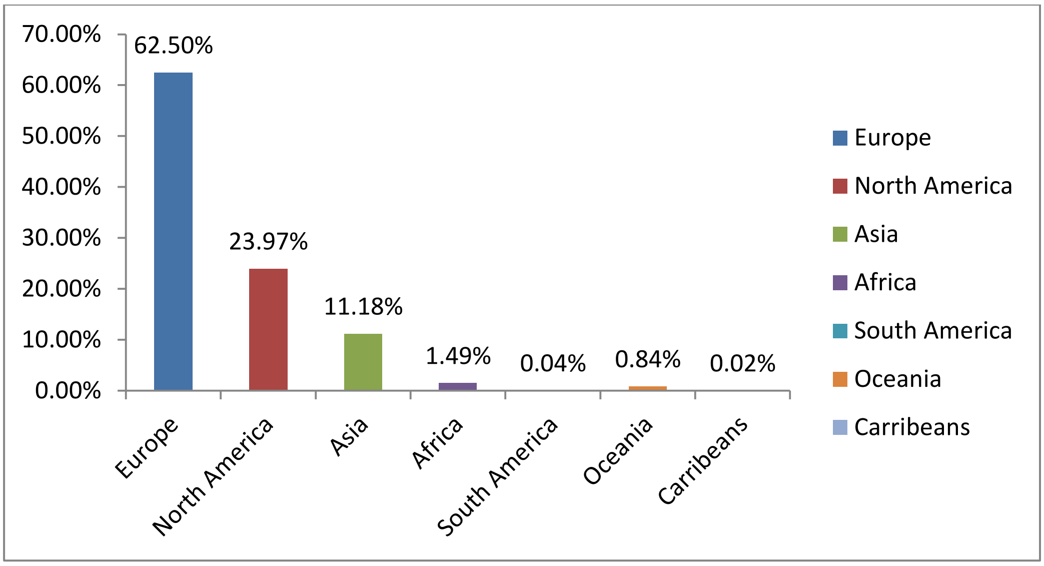


*Figure 3: Flow of used computers into Ghana by regions (2004-2010)*

### 5.2.5.2. E-waste Risk assessment

Risk of contamination to environment and humans increases when there is a hazard. Hazard exists when there is any source of potential damage, harm or adverse health effects on the environment or human under certain conditions. Hence substances such as Pb, Cd etc may pose a hazard under certain conditions. Risk on the other hand is the chance or probability that a person or the environment will be harmed or experience an adverse health effect if exposed to a hazard. Hence in situations where it becomes easier for hazardous substances to come into contact with humans and the environment, the greater the risk. To assess the level of environmental and human exposure to hazardous chemicals contained in E-waste, heavy metal levels in soil and urine of e-waste workers were determined.

Heavy metals concentration in soils at Agbogbloshie were significantly higher than at the control site (Figure 4) This suggest that the high levels of heavy metals at Agbogbloshie compared to Mataheko is not due to high background level and suggest the soil contamination is due to dismantling and disposal practices at the site.

Similarly, urine samples of 8 e-waste workers at Agbogbloshie compared to 8 none e-waste workers at Mataheko reveals high levels of Zn, cu and Pb compared to none e-waste workers. This suggest a higher risk exposure at Agbogbloshie e-waste site compared to none e-waste workers at Mataheko.

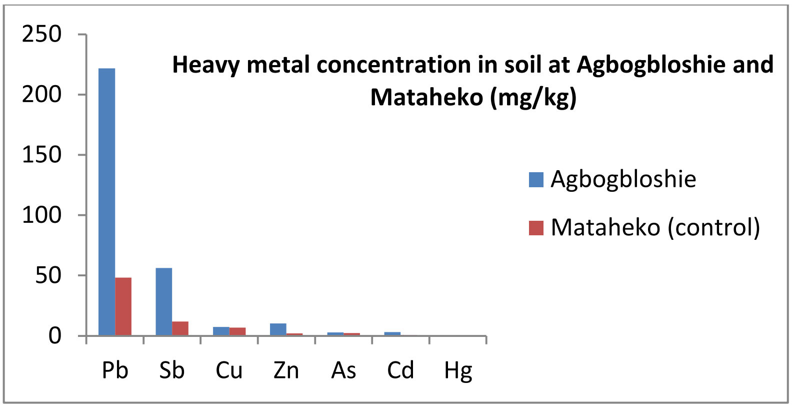


*Figure 4: Heavy metal concentration in Agbogloshie e-waste site compared with control at Mataheko*

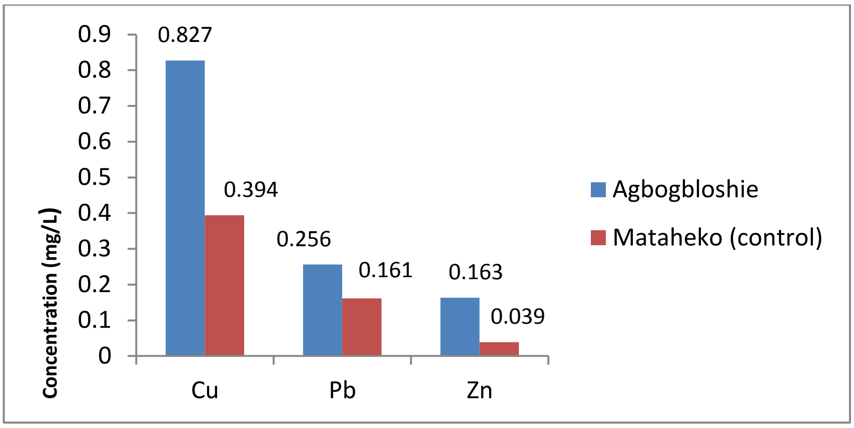


*Figure 5: Heavy metals in Urine of e-waste workers at Agbogbloshie and a control site*

## 5.3. Risk Due to Handling and Disposal practices

Based on participant observation and focus group discussion of 15 e-waste workers at Agbogbloshie during collection, dismantling/recycling, refurbishing and disposal we identify factors including collection with rudimentary equipment and manual dismantling using rudimentary equipment such as stones, chisels and hammers as well as long working hours with little or no personal protection as contributing to the high exposure and risk of e-waste workers to hazardous substances.

| E-waste activity | Characteristic of the practice | Potential risk to health and environment | Risk reduction strategy |
|---|---|---|---|
| Collection | Collection with rudimentary technologies; moving around buying/ searching discarded e-waste in push-carts, sacks and basic tools for several hours without PPE | Some exposure to hazardous chemicals; potential risk to skin due to cuts, Exposure to Pb dust fumes etc | Use of PPE, |
| Dismantling/ Recycling | Manual dismantling, use of rudimentary equipment such as stones, chisels and hammer to separate plastic casings; poor working environment. Long contact peri- | Exposure to hazardous chemicals; potential risk to skin due to cuts, Exposure to Pb dust fumes known to cause multiple | Reduce long contact hours<br>Use PPEs<br>Worker rotation if activity is formal- |

| | | | |
|---|---|---|---|
| | od, open burning of cables and wires to gain copper metals for sale. No PPE | disorders etc | ized<br>Automate system and isolate worker |
| Refurbishment | Cleaning computers, repair works, No PPEs | Exposure to dust fumes etc | Use PPEs, Good house keeping |
| Disposal | Open waste dumps, Intense open burning for value recovery from e-waste. | Exposure to dust fumes, Potential cuts by sharp objects, burn, inhalation of dust fumes, dermal contact | More efficient value recovery through increased recyclates to reduce disposal<br>Landfill instead of open dumping |

*Table 1: Observed e-waste related activities, risk exposure and suggested risk reduction strategies*

## 6. Conclusion

The current management practice regarding e-waste is not the best. Mostly crude methods are used for e-waste dismantling and material recovery. Flow of E-waste into Ghana comes mostly from Europe and North America. Activities in the e-waste recycling chain include manual dismantling, open burning to recover metals and open dumping of residual fractions. Such practices release hazardous chemicals into the environment. Indeed comparing heavy metals concentration in urine of e-waste workers with those of the control group, it was observed that urinary Cu (mean 0.827 mg/L) and zinc (mean 0.63 mg/L) levels for Agbogbloshie e-waste workers were significantly high compared with those of the control. Considering the fact that e-waste trading and recycling activities provide participants with livelihood opportunities, and considering the risk posed to health and environment, we make the following recommendations:

- Need to improve enforcement of related transboundary regulation in both countries of destination and countries of origin
- Enactment of national e-waste legislation and improvement of enforcement of existing legislation
- Strategies aimed at extending product life cycle of used computers such as formalizing repairs and refurbishment of UEEE through training and loan grants to small businesses involved in UEEE repairs
- Restricting the age limit of UEEE imported into country to minimize near end of life computer imports
- Sharing of information, experience and intelligence among relevant enforcement agencies in tackling issues of transboundary e-waste shipment.
- Mainstream education on e-waste impact among scrap dealers with a view to establish a culture of risk reduction through the use of Personal Protective Equipment (PPE)

Establish a national formal e-waste management system in place with sound environmental management framework since e-waste contains both beneficial and toxic substances. In summary therefore, consideration should be given to formalizing the current e-waste recycling regime in the country since it provides people with livelihood alternatives. Legislation regulating the import of UEEE and restriction of those near EOL, provision of personal protective equipment (PPE's), regulation of the activities of scrap dealers and increased port security to reduce the import of none functional UEEE's could help reduce the current menace e-waste inflicts on the Ghanaian society.

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# Improving of a Target System for a strategic Eco-Controlling

Miada Naana[1], Jorge Marx Gómez[2]

## Abstract

The compensation for undesirable outputs resulting from operational activities requires measurement applications and control systems to reduce material and energy consumption and to protect the indispensable natural resources as well. In general environmental management applies the Eco-controlling system to ensure its tasks. The controlling tasks of strategic, tactical and operative management have led together to the formation of a specified management function. A requirement arises for the support of strategic decisions about the long-term balance between economic and ecologic dimensions in the environmental management, due ecologic challenges as well as economic requirements for increasing margins and profits. The task of using the Eco-controlling system at strategic level is to identify environment-related information at an early stage, to coordinate strategic planning and control and subsequently to adapt the results to the wanted strategic targets to ensure the organisation of long-term decisions related to the environmental management. This taxonomy offers an active organisation to increase efforts in environmental management and in regards of sustainability to get an optimally realistic target. Thus the modelling and implementation of different strategic economic and environmental objectives become necessary. For this purpose ecologic and economic target catalogues are compiled. Strategic, ecologic and economic targets in this are formulated, though they have scarcely been regarded together. By this a combined ecologic-economic target system has to be constructed and to be integrated in the organization’s complete target system. Furthermore the establishment of a concrete target system within the sustainability-oriented design provides the organisation with strategic clarity.

## 1. Introduction to a strategic Eco-Controlling

Environmental management should keep strict concern on the correlation of economic activities and ecological effects to get better standards of sustainable development. The crux is that an expansion of the target concept on ecological command variables for business reasons is regarded as a predisposition to ensure an avoidance and reduction of environmental impact in planning, implementation and control of economic activities [5]. The issue limits of eco-systems for natural resources on the one hand and an increase of economic profits on the other hand has to be considered in this. Concerning this, initially environmentally efficient command variables are developed and depicted as ecologic and economic targets [3]. Taking economic categories into account, production-oriented environmental protection strategy does not suffice though strategic management will also have to focus on harmful environmental effects resulting from the production of goods. Due to deficiencies of the environmentally strategic dimension within the management system, it will be hard to combine any of the approaches for increasing margins and profits. This is required to support strategic decisions about the long-term balance between economic and ecologic dimensions in the corporate environmental management. For that, harmony between environment-related strategic measures planning and control of the operative activities is needed. It will be hard to combine both approaches.

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In general environmental management at large applies the Eco-controlling system to ensure its tasks [2]. The better an operation is strategically ensured, the more successful it will be [10]. With regard to concretizing and controlling the enterprise strategy, especially long-term environmental management strategy, a strategic Eco-controlling concept can be used [8].That is to say that the task of using the Eco-controlling system on strategic level is to identify environment-related information in an early stage, to coordinate strategic planning and control and subsequently to adapt the results to the wanted strategic targets to ensure the organisation of the environmental management of long-term decisions [6]. This system needs to improve the adaptation area which can ascertain early-stage recognition for strong and weak points as well as futuristic chances and risks. Hence, the adaptation area is an engine of Eco-controlling, because it gives new suggestions, new knowledge of chances and risks, particularly for being at hand from the ecological domain [1]. Additionally, it reports the coordination area with important changes of the indicators or recognition of weak signals.

## 2. Goal of a strategic Eco-Controlling

For the identification and definition of long-term environment protection strategy the application of a strategic Eco-Controlling system is indispensable. It takes into consideration the needs of relevant stakeholder and the fulfilment of the environment protection and bigger competitive chances to leading innovations [9]. In addition, the main purpose of the strategic Eco-controlling is to guarantee the sustainable environmental resources protection in the long term. It is known by the requirements in- and outside the enterprise [9]:

- With regard to the internal use the strategic Eco-controlling can be able to provide strategic environmental information with the environmental aspects of the enterprises for decision-maker. It aims at decreasing the environmental costs and the environmental impacts and the improvement of production processes. These purposes serve to reach:
  - Qualitative productiveness,
  - Ecologic investment advances, and
  - Guarantee of the enterprise existence.

In addition, this system supports the strategic planning management in the enterprise by the control of the enterprise results and the recognition of the weak points as well as the creation of predicting activity.

- In relation to the external use, the protection of the environment, especially of natural resources and the communication abilities with external stakeholder as well as the external financing possibilities, are the aim of the strategic Eco-controlling.

For that, in the context of the environment protection, the above purposes of environment-oriented enterprise requirements are confronted. They describe the strategical environment protection, the guarantee of the enterprise existence, and the consideration of certified requirements of the society. Then, the strategic Eco-controlling is able to make predictable and controllable strategic information, to support environment-related enterprise purposes which lead to a long-term oriented environmental policy in all enterprise areas as well as to improve environmental achievements of the enterprise. The strategic Eco-controlling must recognize environmental problems and figure divergences early, before they are reflected on operative figures. It describes the strategic meaning depending on the purposes and activities of the enterprise [7].

## 3. A Target System for a strategic Eco-Controlling

In the focus of the functionality of strategic Eco-controlling, the formulation of ecologic and economic targets is an important step for the realization of the tasks of strategic Eco-controlling. Moreover, it must be able to measure the success and failure of the enterprise. The economic efficiency of an environmental measure is determined with given objective by how low the middle application is to reach a certain ecologic purpose. In addition, ecologic purposes must be concretized and quantified to make them checkable and able to create the criteria for success and failure. Hence, the modelling and implementation of different strategic ecologic and economic objectives have become necessary.

Based on the above demands a target system for a strategic Eco-controlling will be presented. For that, varied strategic ecologic and economic targets which detected from the organisation strategic objectives (e.g. profit-maximisation and environmental protection) are formulated. Moreover, these targets should be integrated in the target system of enterprise. Strategic ecologic and economic targets so far have scarcely been regarded together. If the tasks of the strategic Eco-controlling shall serve these targets, these targets necessarily have to be structured, transparent and complete. For the sake of clarity and reduction of complexity, economic and ecologic dimensions of sustainability are not related to an entire organisation but a part of sustainable design of production has been chosen instead. By this a combined ecologic-economic target system has to be constructed and to be applied into the organisation’s complete target system. In relation to this, the answer to the question on how corporate environmental initiatives can influence complex structured industrial sectors can be found.

For this purpose, ecologic and economic target catalogues are compiled and deducted from references and practices. The economic target catalogue contains different strategic targets, generally derived from the strategic management’s policy. The ecologic target catalogue contains different strategic targets, derived from the strategic targets in environment protection. These targets consider enhancement of environment protection and reduction of environmental impact, especially improvement of production design. Furthermore the relationship of both purposes is proved to clearly define a sustainability-oriented target system and by this to interrelate the targets named above in complementary, neutral or contrary relations [4]. In the case of the complementary targets, the pursuing of the ecologic target supports getting to the economic target. In neutral relations between the targets ecologic and economic targets are independent and do not influence each other. They have to be separately pursued. On the basis of the contrary targets, research is done on the question whether the economic or the ecologic single target should be given up in favour of the other. It is necessary to value each single target relation and to estimate the resulting consequences calculated by qualitative analysis by expert interviews. For this purpose a matrix is developed summing up three different target relations which are to be regarded as contrary, neutral or complementary targets. In the development of a target system important target conflicts must be solved and strategic ecologic-economic target relations will be harmonized. The interviews with specialists in five enterprises in Germany und in one enterprise in Tunisia, the target relations in practice are tested on how the economic and ecologic targets are to be carried out. Table 1 presents the outcome of an interview which has been conducted to assess the relationships between strategic ecologic-economic Targets.

On the basis of the results of these interviews the relation between the ecologic and the economic aspects is analysed and by this the discussion between them determined.

In figure 1 the relation between the economic purpose of innovation activity and the ecologic targets is showed. For example, the relationship between innovation activity and the ecologic targets of the vitality of resources and environmental finance and development is 100% complementary. The reason for this fact is the development of the used arrangements as well as the improvement of the production processes raises the vitality of the resource application. Moreover the innovation activity oriented to the ecologic targets (resources supply, resources protection, recyclability, disposal potentials) to 50% complementary and to 50% contrary. The production-oriented innovation is connected to the environment protection-related development, though these processes raise at the same time the environmental costs.

| | | Ecologic Targets | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Environmental Production Processes (EPP) | Environmental Performance (EP) | Vitality of Resources (VR) | Resources Supply (RS) | Resources Protection (RP) | Recyclability (RA) | Disposal Potentials (DP) | Environment-oriented Finance & Development (EOFD) | Eco-Improvement Proposals (EIP) | Emission Control (EC) | Risk Reduction (RR) | Risk Avoidance (RA) | Environment-oriented Rights & Laws (EORL) |
| Economic Targets | Innovation Activity | + | + | + | - | - | + | + | + | + | + | - | - | - |
| | Personal Training | + | + | + | - | - | - | - | + | + | + | + | + | + |
| | Profitability | + | - | + | - | - | + | - | - | + | - | - | - | o |
| | Competitive Potentials | + | + | + | - | - | + | - | + | - | + | - | - | o |
| | Value-enhancement | + | - | + | - | - | + | - | + | + | o | o | o | - |
| | Personal Productivity | - | - | - | - | - | - | - | - | + | - | o | o | o |
| | Resources Cost Reduction | + | + | + | - | o | + | - | - | + | + | - | - | o |
| | Market-related Goals | - | - | - | - | - | - | - | - | - | + | - | - | - |

*Table 1: Relations of strategic ecologic-economic Targets*

| | | |
|---|---|---|
| Complementary Relation (+) | Neutral Relation (o) | Contrary Relation (-) |

The economic motivation behind personal training is related to ecologic targets (environmental production processes, environmental performance, environmental finance and development, risk reduction, risk avoidance, environment-oriented rights and laws) in a completely integral appreciation. Specifically, the environment protection purposes within the training program of stuff are investigated as can be depicted in figure 2.

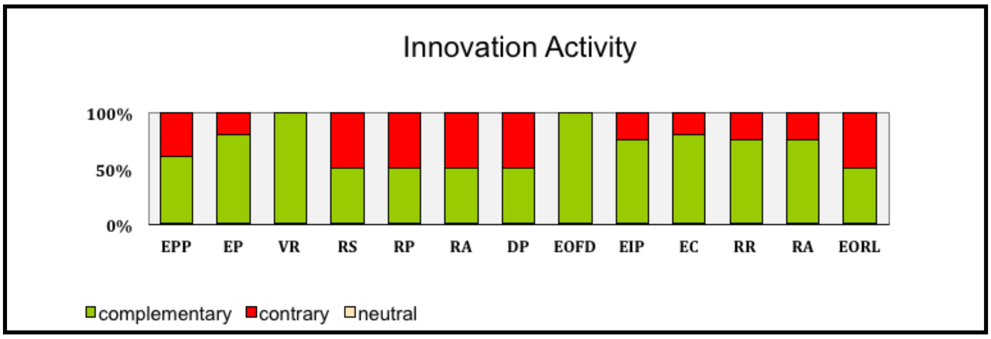


*Figure 1: Relation of Innovation Activity with ecologic Targets*

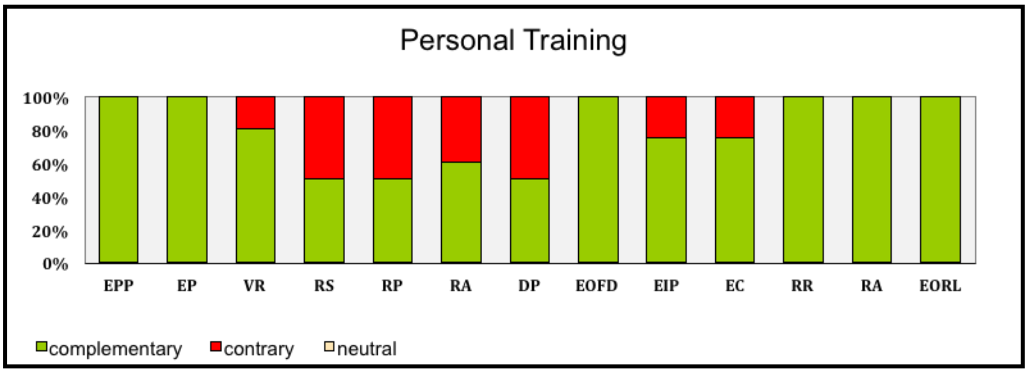


*Figure 2: Relation of Personal Training with ecologic Targets*

The relation between the economic purpose of the enterprise profitability and ecologic targets of the environment-oriented finance and development, risk reduction and environment-oriented rights and laws is 80% contrary and 20% neutral. Moreover, this purpose has a conflict relation with risk avoidance up to 100%. There are negative economic results with environment protection measures which shown in figure 3.

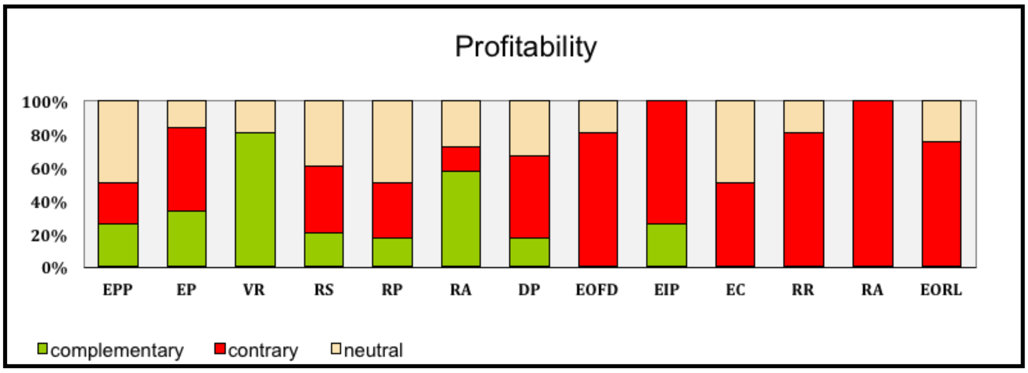


*Figure 3: Relation of Profitability with ecologic Targets*

In figure 4 it is shown the economic purpose of the competitive potentials with the purpose of the eco-improvement proposals is up to 20% complementary and to 80% contrary. On one hand, the relation is complementary if the sustainably development plays a role for the competition of the enterprise with others in the long term. On the other hand, it is contrary if high environmental costs because of the eco-improvement proposals are caused. This raises the product expenditure and simultaneously reduces the enterprise competitiveness of the. Differently with the purpose of the environmental production processes, the relation is complementary to 50%, neutral to 35% and contrary to 15%. For instance, application of a modern arrangement for reduction of $CO_2$ issues in a process leads to a sustainable existence of the enterprise. Alternatively, some environment protection measures with the production processes rise economic costs.

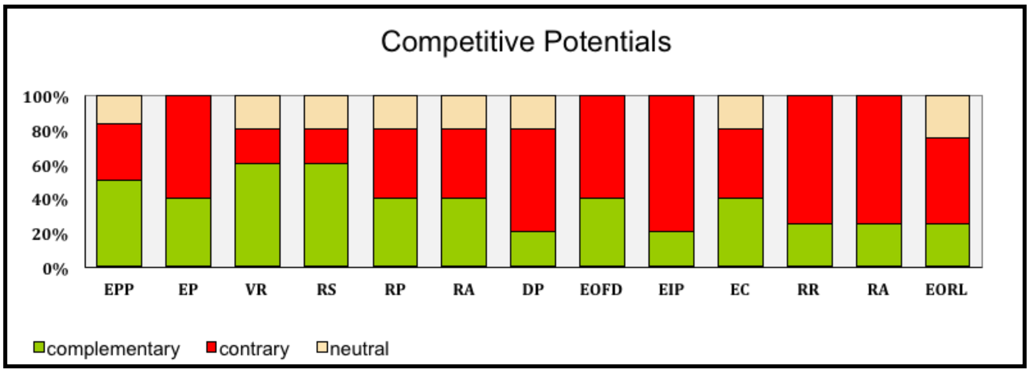


*Figure 4: Relation of Competitive Potentials with ecologic Targets*

The connection between value-enhancement and ecologic targets (risk reduction and risk avoidance) behaves complementary up to 80% and neutral up to 20%. This refers to the enterprise policy that is relevant for requirements of the enterprise guidance as well as for the conversion of the production-integrated environment protection strategies. An alternative ecologic purpose such as the disposal potentials to value-enhancement behaves 80% contrary. Here, the reduction of waste raises the economic costs as can be seen in figure 5.

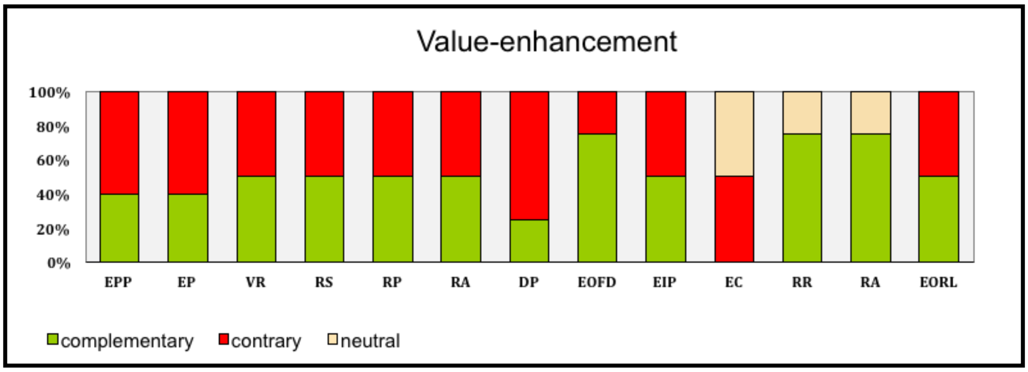


*Figure 5: Relation of Value-enhancement with ecologic Targets*

In figure 6 it is represented the personal productivity which is related with the ecologic targets (environmental production processes, environmental performance and resource protection) through 100% conflict. Other ecologic targets such as risk avoidance and risk reduction have to 50% complementary, 25% contrary and 25% neutral relation with the personal productivity. Because of the environment-related purposes the economic costs on the one hand are reduced and on the other hand are raised.

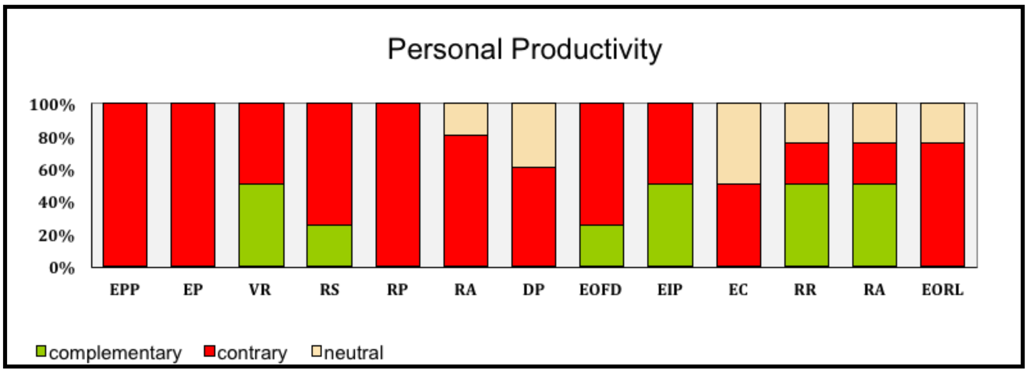


*Figure 6: Relation of Personal Productivity with ecologic Targets*

In figure 7 the economic purpose of resources cost reduction is related to ecologic targets of environmental production processes and vitality of resources through 100% complementary. The reason for that is the reduction of resources cost requires ecologic vitality of resources and ecologic productivity of production processes. Moreover, the relation between resources cost reduction and ecologic purpose of resource supply is to 75% complementary and to 25% contrary. This means that storage cost on the one hand raises resources cost but on the other hand it saves resources. Other ecologic targets (disposal potentials, environment-oriented finance and development) are related to resources cost reduction through 50% complementary and 50% contrary. Thus, the realization of these purposes enables to reduce on the one hand the resources application and to increase on the other hand the environmental costs.

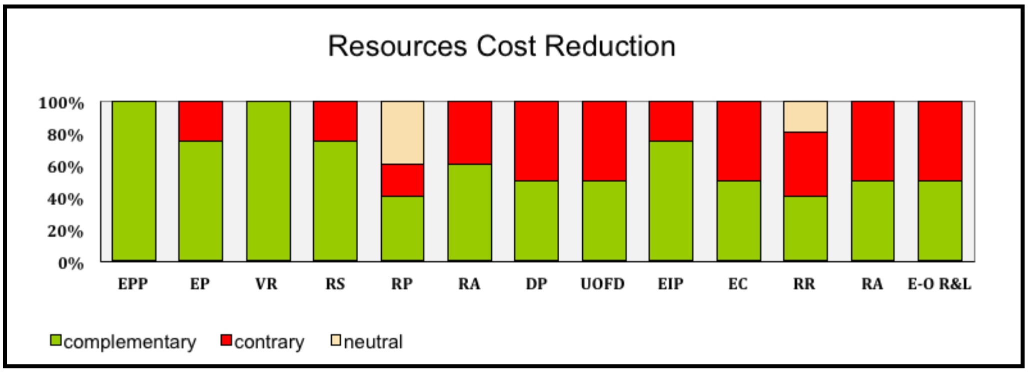


*Figure 7: Relation of Resources Cost Reduction with ecologic Targets*

As can be seen in figure 8, the market-related Goals and the ecologic targets of environmental performance and eco-improvement proposals are to 100% contrary. Generally, the market-related purposes are connected with the strengthening of the competition ability of the enterprise. Thus, the environment protection measures raise the product costs and hence reduce the competition of the enterprise. Interestingly, the ecologic purpose of the emission control with the market-related goals is to 75% complementary. Most compelling evidence, the protection of the climate is a political-social demand which imposes issue restrictions on the enterprises.

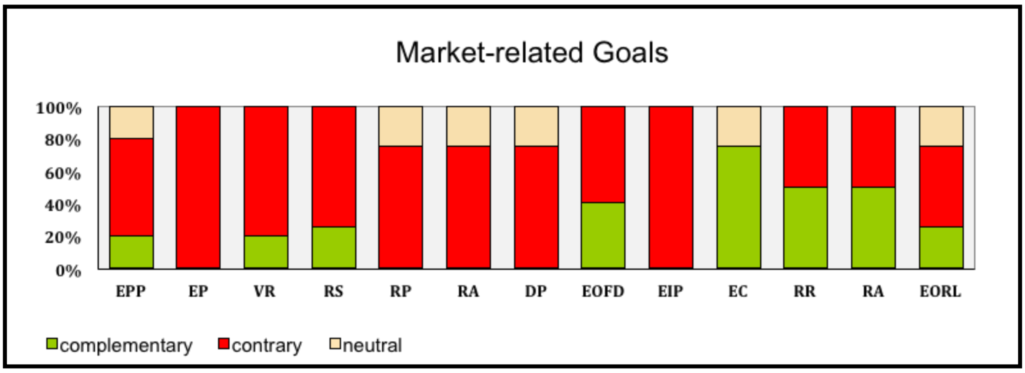


*Figure 8: Relation of market-related goals with ecologic Targets*

As a result, the enterprise guidance has to help the environment protection from passive to an active role to provide a target system for sustainability production processes. On this situation, the relation of ecologic and economic targets should be harmonized together. Afterwards, because of the complementary character has high priority in the enterprise management, a practical implementation of a target system of sustainable-oriented production becomes better in concrete environment protection strategies. Accordingly, in cases of contrary relations the ecologic and economic targets each other should be qualified. It is not necessary to aim at the optimum of the purpose reaching, but it is enough if the discrete targets only in an adequate field are pursued.

## 4. Conclusion

To sum up, the connection between both targets is elaborated. Generally, both targets evolved from strategic environmental protection to securing of the enterprise existence as well as the observance of qualified demands of society. Furthermore the establishment of a concrete target system within the sustainability-oriented design of production provides the enterprise with strategic clarity. Compared to the different stakeholder’s demands, it is necessary to word clear and verifiable targets that can be realised by strategic instruments of Eco-controlling. Hence, an active environment protection could be reached by harmonized relation of ecologic and economic targets. Moreover, a concrete target system in the strategic Eco-controlling gets strategic clarity. Then, the requirements of the stakeholder must be formulated to clear and checkable purposes in order to be realized furthermore by strategic Eco-controlling instruments.

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# Four-Dimensional Sustainable E-Services

Maryam Razavian, Giuseppe Procaccianti, Damian Andrew Tamburri[1]

## Abstract

E-services are not sustainable, unless specifically designed for sustainability along four dimensions (4D): economical, technical, environmental, and social. Designing 4D-sustainable e-services is very complex, mainly due to the many challenges in communicating and assessing sustainability. This paper proposes a conceptual model that identifies the core elements of 4D-sustainable e-services. Our goal is to enhance the shared understanding amongst sustainability stakeholders, while easing sustainability assessment and negotiation. We illustrate the value of the conceptual model using a real-life case study featuring an airport baggage handling system[2].

## 1. Introduction

We live in a society that increasingly depends on e-services—*services* that are provisioned via IT technologies, and involving multiple parties that exchange something of value. Examples are Internet banking, disaster management, and electronic health record. As e-services become more integral to the life of people, enterprises, and governments, it becomes more critical that they last, i.e. that they are *sustainable*. We need e-services that are economically, technically, environmentally, and socially sustainable: *economic sustainability* to ensure that e-services create economic value; *technical sustainability* so that their technical assets actually enable the e-services to cope with changes; *environmental sustainability* to avoid that e-services harm the environment they operate in; *social sustainability* to ensure e-services provide fair exchange of information between parties. From now on, we call such e-services, four-dimensional sustainable, in short, "4D-sustainable".

Consider for example the *baggage handling* e-service in airports. Provided services center around transporting the travelers' baggage. To provide this e-service a group of parties (traveler, airline, airport, baggage handlers) work together and exchange something of value ("money", "services for baggage transportation", "right to check security"). From economic perspective, the baggage handling e-services can only be sustainable if each party can gain profit. From a technical perspective, the e-service is sustainable if the IT technology behind it can deal with changes (e.g., changes in security regulations). From environmental perspective, the e-service is sustainable when it minimizes its environmental impact, for example in terms of energy consumption (e.g., through energy efficient baggage routing). Finally, from the social perspective, the e-service is sustainable if it ensures that all actors are treated fairly in terms of their rights (e.g., protecting sensible information about baggage location).

Despite their integral role in the society, current e-services are not designed for sustainability. To create sustainable e-services, it is best to design for sustainability upfront. This paper aims at taking the first step towards such a design. E-services will not be sustainable, unless we specifically design them to be; however, designing 4D-sustainable e-services is vastly complex [1]. So far, service engineering research has left dealing with such complexity unassisted—which can be attributed to the many initial technical challenges that needed to be overcome.

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Our goal is to fill this gap: we propose a conceptual model for representing 4D-sustainability. Our conceptual model takes a value modeling perspective to sustainability of e-services, where the e-service is viewed as a set of value exchanges between actors (for example, the baggage handling service). We attribute the sustainability of an e-service to a positive value exchange between actors. Our goal is to enhance the common understanding amongst stakeholders, but also to allow for assessments and negotiation. The conceptual model has clearly defined modeling constructs to design and to reach common understanding about the sustainability of the e-services.

## 2. Related Work

The concept of sustainability derives from the report of the Brundtland commission [2] where the expression “sustainable development” was coined as “the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Although current literature emphasizes the need of a multi-dimensional approach on sustainability, existing research focuses on the individual dimensions; the social dimension [3], the environmental dimension [4], economic dimension [5], or the technical dimension [6]. To date, little research [7] has been performed to further develop a multi-dimensional approach. A recent example is the work in [8] where the authors define sustainability as a software quality attribute categorized in four dimensions.

## 3. Running Example

Our running example is extracted from a baggage handling system. A SOA solution provider company has designed a service inventory for a baggage handling system that is adoptable in different types of airports (e.g. hub, domestic, international, low-cost) and can be used by different types of airlines (e.g. legacy, domestic, international and intercontinental). From a bird's-eye view, baggage handling is quite simple. The traveler arrives at check-in desk, and her/his baggage is tagged by the Airline. Airport plans and governs the baggage handling process. Ground handlers do the real baggage management. They can optimize the routes taken by the carts to get the most urgently needed bags to their destinations faster. They also track-and-trace the baggage. Finally, the security provider supports the screening of the baggage. Consequently, baggage handling relies on five different actors: traveler, airline, airport, ground handlers, and security provider.

## 4. 4D-Sustainability Conceptual Model

To represent 4D-sustainability, we propose a conceptual model embracing the fundamental elements that represent the 4D-sustainable e-services. To do so, we carried out a literature review on 4D-sustainability followed by focus groups [9], putting together our expertise in services engineering and (at least) one of the sustainability dimensions. As a result we: (a) defined what a 4D-Sustainable e-Service entails; (b) created the 4D-Sustainable Conceptual Model. Finally, we discussed the model with the aid of a real-world case study in the area of baggage handling systems.

The conceptual model is fully approached from the value proposition point of view; in all of these dimensions, we identify a concept of value, i.e. something that expresses the degree of utility, or benefit, created by a service in a specific dimension. Subsequently, we define each of the four sustainability dimensions as positive value exchange specifically for that dimension.

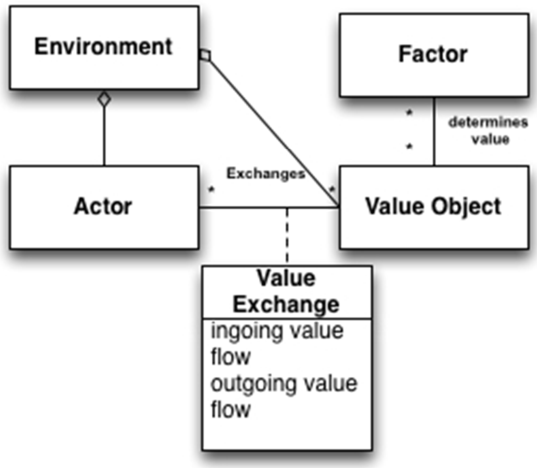


*Figure 1: The 4D-Sustainability Conceptual Model*

The 4D-Sustainable Conceptual Model, shown in Figure 1, entails interrelated core elements that are prevalent in all the four sustainability dimensions. These core elements are instantiated for each of the sustainability dimensions.

### 4.1. Core Elements

In this section we present the each of the core elements shown in Figure 1.

**Environment.** Environment is the context that entails actors and a *finite* amount of resources and is constrained by a set of rules (e.g., of physics, society, economy).

**Actor.** An actor is an entity that has the goal of achieving a positive net value by exchanging value objects.

**Value Object.** A value object is a resource that has economic, technical, social, and/or environmental value. For instance, from economic perspective, a value object is a service, product or even an experience that has economic value. The important point here is that a value object is *of value* for one or more actors.

**Value Exchange.** A value exchange is the exchange of value objects between actors. The net value of the exchange is the difference in value of the exchanged objects.

**Factor.** A factor is a property of the environment that determines or influences the value of a value object. Factors are *drivers of change:* they are the only possible element that triggers unforeseen changes in the environment.

### 4.2. Variations for the sustainability dimensions

Between the four dimensions, the notion of sustainability varies significantly, therefore the core elements have very different semantics. In this section, we apply the 4D-Sustainable conceptual model to each dimension: we first define the concept of sustainability with respect to the specific dimension, and then we represent the specific semantics of the core elements.

#### 4.2.1. Economic Sustainability

*Economic sustainability* is about creating **a positive economic value exchange** between all the actors participating in the e-service. In the economic dimension, all actors are legal entities that are profit-and-loss responsible. Such actor exchange a service, experience, money or in general anything of economic value. To be sustainable, all these actors should make *profit*, i.e., they should make a positive net economic value exchange. In Table 1 we present the semantics for the core elements of economic sustainability.

*Example: Baggage handler, security provider, airport and airline are all legal entities that are profit-and-loss responsible. To be economically sustainable, it is essential that each of these actors makes profit and the whole ecosystem creates a positive cash flow.*

| | |
|---|---|
| **Environment** | The context where the *partners or competitors* work together to create a service. The environment possesses various *economic value objects* (investments, services and goods of economic value) |
| **Actor** | *Legal entities* that are profit-and-loss responsible, i.e., they are able to be profitable after a reasonable period of time (in case of an enterprise), or to increase value for itself (in case of an individual). Examples are enterprises such as 'airport', 'airlines', or individuals such as 'travelers'. |
| **Value Object** | Something of economic value that satisfies a particular need, or is used to produce other value objects. Examples are 'baggage transformation service' or 'money' which are both of value for traveler and airport. |
| **Value Exchange** | What an actor offers to (an outgoing offering) or requests from (an ingoing offering). For example, 'money' is transferred from the 'traveler' to the 'airline company', in return to `transferred baggage' |
| **Factor** | Something that determines the economic value of the value object in terms of monetary units. According to [10] of such factors include the valuation of:<br>● *What the service offers*, e.g. the capability that allows the customer to reach certain goals. For example, baggage handling is valued because it can help the customer to pay his/her bills<br>● *The perceived quality of the service* (secure vs. non-secure payment)<br>● *Beauty of the service* (travelers may appreciate the design of a the track-and-trace user interface, apart from its function and quality) . |

*Table 1: Core aspects of Economical Sustainability*

### 4.2.2. Technical Sustainability

*Technical Sustainability* is the ability of a software service network to **cope with change and evolution**, while providing the requested features and capabilities. In the technical dimension, the *actors* are not only legal entities and individuals, but also systems that are either providers or consumers of a software service. This creates a *software ecosystem [11]* that represents the *environment* for technical sustainability. In this context, a *value exchange* is represented by the combination of requesting and providing a service, in terms of granting an actor the requested feature/capability that represents the *value object* for the service. Thus, the *value* of a feature is represented by its degree of fulfilling a specific need, hence a *fitness* (as an example see [12]). Of course, the fitness is determined by a number of *factors:* two obvious factors are the *customer needs* [10] of the actors, and the level of *quality* with which each service is offered to the consumer. In Table 2 we present the semantics for the core aspects of technical sustainability.

*Example: Consider the baggage-screening service provided by the security provider to the airport. To be technically sustainable, this service should be able adapt to changes (e.g., changes in screening technology), while fulfilling the airport needs.*

| | |
|---|---|
| **Environment** | The context is a software ecosystem (system of systems) composed of prosumers that provide/consume services according to their needs and with some degree of quality. |
| **Actor** | Individuals, enterprises, systems that either provide or consume an IT service. |
| **Value Object** | The technical implementation of a feature/capability via an IT service. The technical value of functionality is its ability to fulfill a need. This ability can be measured in terms of fitness to a specific (goal/requirement/need). |
| **Value Exchange** | The combination of the request and provision of a service. A positive value exchange happens when the provided service not only fulfils the current need of the consumer, but also anticipates its implicit and/or future potential needs (e.g., additional features/capabilities, higher quality than what required) |
| **Factor** | The factors are what determine the fitness between a need and a provision of a service. These factors include:<br>• Need: an actor needs certain functionality.<br>• Service Quality: The functionality is provided with some quality of service. |

*Table 2: Core aspects of Technical Sustainability*

### 4.2.3. Environmental Sustainability

*Environmental sustainability* revolves around the concept of natural resources and how e-Services make use of them. Due to the pervasive nature of ICT technologies and the worldwide scale at which they operate, e-Services are more and more interacting with the *natural ecosystem* of our planet. The ecosystem represents the *environment* in the environmental perspective of our conceptual model. This interaction translates into a *service network* composed by e-Services and *ecosystem services* [13], i.e. the benefits people obtain from ecosystems. In particular, for the purpose of this work we focus on *provisioning* services, i.e. goods and resources provided by our ecosystem such as food, water, energy, and *regulating* services, i.e. benefits obtained from the regulation of ecosystem processes such as waste treatment and climate. Those represent our *value objects* for environmental sustainability.

*Example: The carts used by the baggage handling company consume fuel for each trip. Fuel is a form of energy provided by the ecosystem, hence it is a value object for environmental sustainability.*

The *value* assessment of natural resources has been extensively investigated by researchers in economics and environmental sciences [14]–[16] and it is a controversial issue. Indeed, valuation is a necessary process if we aim at balancing between the different sustainability dimensions [17]. To represent environmental value, we use the concept of *natural capital [16]*, defined as "the stock of capital derived from natural resources such as biological diversity and ecosystems, in addition to geological resources such as fossil fuels and mineral deposits". Hence, the service network is *sustainable* if the global natural capital of the value network is preserved, hence all value exchanges should have a *positive* net value. In Table 3 we present the semantics for the core aspects of environmental sustainability.

| | |
|---|---|
| **Environment** | The Natural Ecosystem, i.e. "a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit." [13] Humans are an integral part of ecosystems. |
| **Actor** | Entities that make use of ecosystem services. For example, the Baggage Handling company uses an energy provisioning service to power the carts. The Airport company uses regulating services to regulate temperature and climate inside the airport. |
| **Value Object** | Objects that hold natural capital and environmental value. e.g. Fuel. |
| **Value Exchange** | A consumption or usage of ecosystem services from the environment, e.g. Fuel Consumption. |
| **Factors** | Factors are drivers of change in ecosystems and ecosystem services that alter the environmental value or the natural capital of a value exchange. For example, Climate change affects the weather conditions, hence the weather regulation services. Technological factors such as bio-fuels or solar-powered carts affect the energy provisioning services. |

*Table 3: Core aspects of Environmental Sustainability*

#### 4.2.4. Social Sustainability

*Social sustainability* entails the resilience by which e-Services uphold the fair exchange of information and social status among the actors involved in service exchanges. Actors in this case are considered as the people or organizations that assume a relevant role for the purpose of the service exchange. For example, a service owner is an *actor* during a service exchange. Also, *service providers and consumers are actors* during the exchange required for contractual agreements to take place. Social sustainability in this case is assured only if both parties can be guaranteed a fair and reciprocal information exchange.

Similarly, *their information exchange* during contractual agreements is considered *a value exchange*, since the contract itself can be seen as the social *value object* by which a social and organizational relation is established and maintained (based on trust and contractual restriction). The scenario in which the said information exchange takes place, is defined as the social *environment* of the information exchange. For example, a platform for e-Service sharing takes place to be a social environment through which the information exchanges above can take place. Said social environment should allow equal opportunities for organization, collaboration and profit to all actors involved in the information exchange in order to be sustainable.

Finally, the environment, actors, value objects and value exchanges can be influenced by a number of *social (or organizational) factors*. Said factors are contingencies dictated by any of the above elements and assume a fundamental role to regulate value exchanges and their fairness. For example, using an electronic platform for e-Service sharing offers constraints on the value exchanges possible since no direct way for informal face-to-face interaction is possible, in general. Factors are contingencies constraining the resilience of a social value exchange and, therefore, must be accounted and measured as mediators for social sustainability, in order not to incur in social debt regarding the e-service solution [18].

*Example: travelers through an airport must trust on the reputation of airline companies for their baggage's location, safety and security. Airline reputation as well as traveler rights, as established by governmental rules and regulations, represent social value objects.*

| | |
|---|---|
| **Environment** | The organizational and social structure underlying service exchanges, that is, the set of organizations and social entities involved in service exchanges, together with the social (e.g., mutual trust) and organizational (e.g., contractual) relations that bind them [19]. For example, the baggage handling company, the airport management corporation, the human operator subcontractors, the security subcontractors are all part of the organizational-social structure involved in the baggage handling e-service, so are the social and socio-technical services part of such a structure. |
| **Actor** | Humans or organizations that play a role during service exchanges. For example, the Baggage Handling company uses security subcontractors for the safety and security of baggage. The airport uses monitoring and inquiry services to make sure that security is applied to all baggage and, also, that security personnel may only interact with said baggage in a purposefully governed way. |
| **Value Object** | Objects that hold social capital value or may yield social debt, e.g. trust and reputation among actors involved in a service network. |
| **Value Exchange** | A fair and reciprocal consumption, usage or exchange/agreement between social value objects, e.g. Security Scans from security personnel to baggage handling subcontractors involves an exchange of trust and validation which are both value objects in the overall organizational and social structure for the airport management organization. |
| **Factors** | Factors are social and organizational characteristics that determine the value exchange. For example, reputation affects the degree of trust that actors share in a value exchange. Other examples may be openness, laws, norms, beliefs and organizational culture. |

*Table 4: Core aspects of Social Sustainability*

## 5. Discussion

Even with our simple running example, our conceptual model highlights various insights on how to assess sustainability aspects of a service network. First, by reducing sustainability assessment into a value modeling problem the conceptual model facilitates making comparisons and trade-offs. For instance, a service could be profitable from an economic perspective (hence economically sustainable) for its provider, but it might consume too many resources from the environment, hence in the long run it won't be able to operate anymore. While, in [20] we enlist a number of trade-offs between economic- and technical dimensions, further research is needed to identify trade-offs across all the four dimensions.

Second, by focusing on valuation of sustainability in all 4 dimensions our approach takes a step towards assessment of sustainability, although quantitative valuation methods for each sustainability dimension are still needed.

A current limit of our approach is that, for the sake of simplicity, we do not consider the dynamic evolution of the service network: we currently evaluate “snapshots” of the network. Future work will address the development of *dynamic views* on sustainability, to show the evolution over time and on the different dimensions. These dynamic views will model how factors change over time, and consequently the value assigned to the value object varies. These views will support stakeholders in constantly monitoring the sustainability of their services and react to changes in the environment.

## 6. Conclusions

Sustainability of e-services must be approached from all four dimensions (economic, technical, environmental and social) In this contribution, we addressed 4D-sustainability as a value modeling problem. Our approach offers a number of interrelated core elements (common among the four sustainability dimensions) as well as dimension-specific elements, variable elements. Our approach uniquely addresses the multi-dimensional aspect of sustainability as a first class element. Also, by focusing on 4D core elements, we enable describing the essence of sustainable e-services in a unified manner. By focusing on variable elements we provide means to identify conflicts or trade-offs between dimensions. We also showed how to apply the conceptual model using a real-life case study featuring an airport baggage handling system. Our future research efforts will use this model as a basis to create a modeling notation and technique for 4D-sustainability of e-Services.

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# Exploring Environmental Sustainability Performance in the Cellular Telecommunication Industry in Egypt

Shahira El Alfy[1], Wael Kortam[2]

## Abstract

The paper explores environmental sustainability performance of the cellular telecommunication companies in Egypt and examines its drivers. A conceptual model linking institutional environment, market orientation, financial resources, attitude towards natural environment, pro-environmental behavioural intentions and environmental sustainability performance together is developed and tested in order to investigate and verify the relationships among these variables. The result provides insights on the nature of the relationship among these variables for finding effective means towards the improvement of environmental sustainability performance.

## 1. Introduction

With the Egyptian economy on its way for recovering from a slope, policy makers, business firms, and consumers might falsely think that environmental sustainability is to come at the bottom of the development list. A closer look to the EU definition of sustainability might explain why sustainability earns more consideration and lead to revisiting areas of attention. European commission defines sustainable development as “progress that integrates immediate and longer-term needs, local and global needs, and regards social, economic and environmental needs as inseparable and interdependent components of human progress” [5]. Accordingly, this definition would lend environmental sustainability a great importance in addressing several issues both at the micro and macro levels which are inseparable from human progress and well-being worldwide including Egypt. How sustainability is driven in Egypt, what is the current sustainability performance and would a firm market orientation affect its environmental sustainability performance, are three unanswered questions. The current study attempts to find answers for these questions in the cellular telecommunications industry which is a subsector of the broader sector of Information and Communications Technology sector (ICT).

The purpose of the current paper is to develop a framework that presents suggested relationships between the institution environment, managers’ attitudes, behavioral intentions and their influence on firm environmental sustainability IT performance (eSITP) in the cellular telecommunications subsector in Egypt. The current study aims at examining the nature and magnitude of the relationships among study variables and their influence on eSITP.

## 2. Theoretical Background and hypothesis

### 2.1. Cellular Telecommunication in Egypt

According to a study conducted by the Ministry of Communication and Information technology (MCIT) in Egypt, Information and Communication Technology (ICT) sector has a relatively high demand multiplier of 1.23. This reflects the contribution of the ICT sector to the Egyptian economy and hence its importance where each unit of ICT output results in 1.23 units increase in the Egyptian Gross Domestic Product (GDP). Based on Ministry of investment report the ICT sector in Egypt is divided based on activities into communication, Information Technology (IT) and IT sys-

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tems services. The cellular telecommunication market comprises three operators with market shares divided among them as 41: 35:24 %. There is a growing market size and a relatively low penetration rates of which would translate into potential opportunities for further growth. MCIT has reported a high leap in mobile revenues from EGP 2.12 billion in 2000, to EGP 24.8 billion in 2009 constituting 72% of telecommunications revenue. Growth of business activities may result into either environmental benefits or environmental burdens and thereby the importance of exploring current environmental sustainability practices is amplified.

### 2.2. Conceptual Model and Hypothesis

As shown in figure (1), the main study variables and relationships among them are depicted. Hypothesis 1(H1) is based on the open systems theory in which organizations are strongly influenced by their environment. The environment consists of other organizations that exert various forces of an economic, political, or social nature [37]. National institutions are a strong determinant of environmental practices at the firm level [30]. Such institutions can exert regulatory, economic and social impact. Previous research has proved the influence of regulatory, economic and social variables on firm's adoption of environmental management practices [2], [33]. Pro-environmental behaviors can either be facilitated or limited by external conditions relating to factors such as social norms or availability of regulatory incentives [20]
*H1: An institutional environment conducive to environmental sustainability is associated with a positive environmental IT sustainability performance (eSITP*).

Some firms have limited options as they are governed by industry regulations to be environmentally conscious [15]. Institutional and environmental factors such as regulatory support for sustainability might drive IT firms to develop Green IT [6], [8].
H1a: A regulatory environment conducive to sustainability is associated with a positive eSITP
H1b: A normative environment conducive to sustainability is associated with a positive eSITP
H1c: A cognitive environment conducive to sustainability is associated with a positive eSITP
Market orientation (MO) is conceptualized in the literature in terms of a cultural and a behavioral perspective. The cultural perspective where firm market orientation is perceived as an organizational culture develops the behaviors necessary for continuity of a firm's superior performance [27]. Since environmental sustainability (ES) is addressed as part of a firm's overall performance, thereby it can be deduced that market orientation has a role in a firm's sustainability performance and practices. Market orientation is operationalized in terms of three main dimensions, which are market intelligence, inter-functional coordination and response to market. Market orientated firms develop a belief system in which organizational behavior with respect to customers, competitors, and internal functional coordination activities become an overriding priority [17].
*H2: Market orientation positively affects firm eSITP*.
H2a: Market intelligence positively influence firm eSITP
H2b: Inter-functional coordination positively influence eSITP
H2c: Response to market positively influences eSITP.

A focus on natural environment requires high costs and long payback period just like any other strategic initiative introduced [25]. The adoption and implementation of natural environment practices need financial resources and insufficient resources hinder the adoption of pro-environmental sustainability measures [4], [11]
*H3: Firm financial resources affect eSITP*

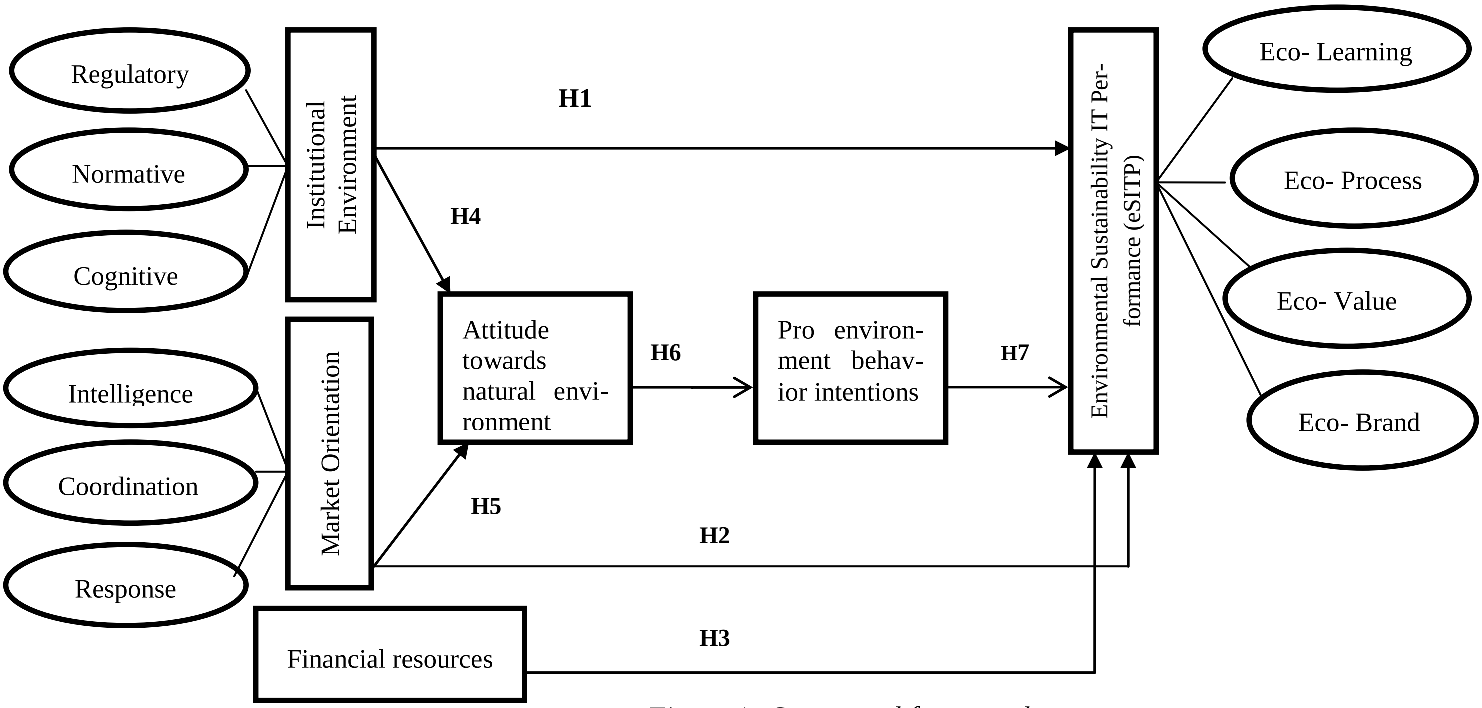


*Figure 1: Conceptual framework*

Managers' perception of the normative, regulatory and cognitive elements of the institution environment is considered as the beliefs component of the theory of reasoned action (TRA) which would affect the formation of the attitude. Similarly, it can be argued that if managers have a positive perception, held positive beliefs and sensed support from the institutional environment with regard to the natural environment then they are more likely to develop a positive attitude towards natural environment (ANE). Attitude is the degree to which one has a positive or a negative evaluation of certain behaviors [1].Such an evaluation is expected to be a function of managers' beliefs and perceptions of the institution environment influence. Based on the theory of planned action beliefs and evaluations underlie and determine attitudes. Therefore, the following hypothesis is examined

*H4: Institution environment affects managers' attitude towards environmental sustainability*
H4a: A regulatory institutional environment conducive to ES positively affects managers' ANE
H4b: A normative institutional environment conducive to ES positively affects managers' ANE
H4c: A cognitive institutional environment conducive to ES positively affects managers' ANE

Market orientation entails integration of cross functional efforts, market sensing and responding. The rising global concerns for environmental protection [40] and escalating societal expectations for better environmental performance are among the environmental trends that a market oriented firm would scan, detect and respond to and disseminate across the entire organization. In response to environmental mandates, market oriented firms are likely to adopt a more positive attitude towards the natural environment in its efforts.

*H5: Market orientation affects managers' attitude towards environmental sustainability (ANE)*

H5a: Market intelligence positively influence managers' ANE

H5b Inter-functional coordination positively influence managers' ANE

H5c: Response to market positively influences managers' ANE

Attitudes are a key predictor of pro-environmental behavior [7]. Accordingly, more focus is provided to natural environmental issues when managers hold strong environmental attitudes [31]. According to TRA theory, attitude influences the intentions towards performing a certain behavior.

*H6: Managers' attitude affects their pro environmental behavior intentions*.

Overt behavior is a function of behavior intentions or willingness to perform the behavior. Therefore managers are likely to implement environmental sustainability practices if they have positive behavioural intentions.

*H7: Managers' pro environmental behavior intentions affect eSITP*

## 3. Methodology

### 3.1. Measurement

Two research questionnaires were developed. One was directed to managers at the cellular companies and the other was given to environmental experts working in the telecommunication regulatory entity. Constructs in the current study have been previously operationalized.

| Construct | Description of Concept | Source |
|---|---|---|
| Institutional Environment-InsEnv | An organizational field with interdependent social, legal and political organizations operating in a specific arena | [12],[41] |
| Market Orientation-MO | A cross functional responsibility that sets meeting customers' needs as a top priority. | [41] |
| Attitude towards natural Environment-ANE | An individual's learnt tendency to respond consistently either favorably or unfavorably with respect to the natural environment. | [23, p. 6] |
| Pro-Environmental behavior intentions-ProEbi | "Intention to perform a particular behavior, a plan to put behavior into effect". | [47, p.92] |
| Financial Resources (FR) | Firms' ability to finance its core business operations and the financial capacity to support extra activities | [33], [49] |
| Environmentally sustainable IT performance-eSITP | IT firm's ability to develop and implement an eco-sustainability culture while applying eco sustainability criteria across the entire processes | [39][19],[56] |
| Eco-learning | IT firms' ability to nurture sustainability behavior and knowledge among employees and management. | [19],[39] |
| Eco- process | The existence of a process that implements criteria for the design, and delivery of IT products &services. | [19], [56],[39] |
| Eco- brand | A firm's ability to create & propose a green value to its target customers | [[39] |
| Eco- value governance | Firm's ability to measure tangible and intangible Green IT benefits. | [39] |

*Table 1: Construct operational definitions and measurement*

The internal consistency reliability of the scale directed to managers and experts are relatively high ($\alpha$= 0.96) and ($\alpha$= 0. 89) respectively. All construct reliabilities are > 0.8.

### 3.2. Data Collection

It is well noted in the literature that managers' attitudes, beliefs and values would ultimately affect firms' practices [14].Therefore, respondents were managers from different departments, around 75% from IT and 26% from other departments. Additionally, data was collected from experts in the regulatory body in an attempt to identify potential perceptual gaps between managers and experts.

## 4. Data Analysis

### 4.1. Descriptive Statistics

From table (2), there is low relative dispersion in responses expressed in terms of coefficient of variation (CV) which is less than 1 for all study variables. Company managers tend to have a neutral perception of the extent to which institutional environment is constructive with total weighted mean ($\bar{x}$ = 3.30) Firms' market orientation is relatively high ($\bar{x}$= 3.86). Similar results are found for managers' ANE, pro-environmental behavioural intentions and financial resources

| Constructs | Respondent | Mean | SD | CV | t | sig | MD | RMD |
|---|---|---|---|---|---|---|---|---|
| Institutional Environment | Managers | **3.30** | **.56** | **.18** | .055 | .96 | .01 | .40 |
| | Experts | 3.29 | .44 | .13 | | | | |
| Environmental Sustainability of IT performance (eSITP) | Managers | **3.17** | **.68** | .21 | .71 | .48 | .20 | 6.53 |
| | Experts | 2.97 | .53 | .18 | | | | |
| Eco-Learning | Managers | 3.07 | .83 | .27 | .55 | .58 | .19 | 6.44 |
| | Experts | 2.88 | .79 | .27 | | | | |
| Eco- process | Managers | 3.37 | .72 | .21 | .34 | .73 | .10 | 3.10 |
| | Experts | 3.27 | .66 | .20 | | | | |
| Eco-brand | Managers | 3.11 | .82 | .26 | 1.78 | .08 | .61 | 21.81 |
| | Experts | 2.50 | .82 | .33 | | | | |
| Eco-Value | Managers | 3.15 | .81 | .26 | -.31 | .76 | -.16 | -3.27 |
| | Expert | 3.25 | .71 | .22 | | | | |

*Relative Mean difference (RMD) = Mean difference/ Average Means

*Table 2: Descriptive statistics*

Responses consistently indicate a moderate level of eSITP ($\bar{x}$= 3.17) explained by a low moderate performance Eco-learning ($\bar{x}$= 3.07), Eco-brand ($\bar{x}$=3.11)and Eco-value governance ($\bar{x}$=3.15) that is slightly raised by the Eco-process mean value of ($\bar{x}$= 3.37).There is difference between managers' and environmental experts evaluation, that is statistically significant ($p< .05$) and with 95% confidence level in terms of regulatory and normative dimensions and managers' ANE with a relative mean differences of (RMD= 17.25, -18.17, 26.32%) respectively. Environmental experts' evaluation of ANE ($\bar{x}$= 3.02) is less than manager's perception of their own attitude ($\bar{x}$= 3.94) by 26%, possibility due to social desirability bias that led to manager's overestimation of their ANE.

## 4.2. Hypothesis Testing

The main research objective is to explore the drivers for eSITP thereby multiple regression is used to determine how variables in the conceptual framework can predict eSITP. Based on table (3), all hypotheses are supported except for three research hypothesis that are not supported. The normative dimension has the highest explanatory power ($\beta = .55; r^2= .30; p< .000$).H4 is supported, institutional environment affects ANE ($\beta= .23; p<.05; r^2=.05$). Institutional environment has a relatively low explanatory power for the variance in managers' ANE.H4b, H4c are not supported. Further investigation shows that managers reported a very positive attitude towards natural environment ($\bar{x}$= 3.94) which could possibly be attributed to social desirability bias rather than an actual inclination towards natural environmental issues. This explanation is confirmed with the discrepancy between the managers' responses about their own attitude and environmental experts' perception of managers' ANE ($\bar{x}$= 3.02; RSD=26%; $p< .01$). H5a, H5b, H5c are supported. Market Intelligence has strongest contribution to explaining managers' ANE and the highest predictive power ($\beta = .44; r^2 =.19$), followed by response to market and inter-functional coordination ($\beta = .42; r^2 =.17; \beta = .32; r^2 =.10$). When all three variables entered into the same regression equation, the overall model has ($p< .001$), and results for market intelligence and response to market are statistically significant ($p <0.1; \beta=.33; p< .05; \beta =.28$). Inter-functional coordination result shows a statistically insignificant effect on managers' ANE. H6 is supported ($p< .001; \beta= .53; r^2 = .28$).

| Hypothesis | β | $r^2$ | Conclusion |
|---|---|---|---|
| H1a: Regulatory environment and eSITP | .49*** | .25 | Supported |
| H1b: Normative environment and eSITP | .55*** | .30 | Supported |
| H1c: Cognitive environment and eSITP | .28** | .08 | Supported |
| H2a: Market Intelligence and eSITP | .33** | .11 | Supported |
| H2b: Inter-functional coordination and eSITP | .45*** | .21 | Supported |
| H2c: Response to Market and eSITP | .24* | .06 | Supported |
| H3: Financial resources and eSITP | .41*** | .17 | Supported |
| H4a: Regulatory environment and ANE | .27** | .07 | Supported |
| H4b: Normative environment and ANE | .10 | .01 | Not supported |
| H4c: Cognitive environment and ANE | .17 | .02 | Not supported |
| H5a: Market intelligence and ANE | .44*** | .19 | Supported |
| H5b: Inter-functional coordination and ANE | .32** | .10 | Supported |
| H5c: Response to market and ANE | .42*** | .17 | Supported |
| H6: ANE and pro-environmental behavioral intentions | .53*** | .28 | Supported |
| H7: Pro-environmental behavioral intention and eSITP | .13 | .02 | Not supported |

***p< 0.05; **p< 0.01; ***p< 0.001*** *Table (3): Summary of hypothesis testing*

The relationship between attitudes and behavioural intentions is consistent with theory of planned behaviour (TPB) which suggests that attitudes, subjective norms and perceived behaviour control predict behavioural intentions.H7 is not supported ( $p< .05$). There is evidence in the literature of the existence of a gap between behavioural intentions and actual behaviour. Managers' willingness to act in a certain way does not guarantee a consistent behaviour [38]. Several limiting factors can widen the gap between behaviour intentions and actual behavior called resistant and driving factors such as inadequate institutional infrastructure, poor eco-literacy, limited business support or economic barriers [39]. In order to partially fill the gap, a possible driver related to study variables is introduced to moderate the relationship between pro-environmental behavioural intentions and eSITP. Inter-functional coordination is the variable considered most relevant to the driving and limiting factors stated in the literature. Additionally, as shown in table (3), market orientation elements have the greatest explanatory power for mangers' ANE, market orientation is positively associated with ProEbi ($\beta= .36$, $t (102) = 3.17$ , $p< .01$) and a strong relationship between ANE and ProEbi ($\beta= .53$, $t (102)= 5.2$, $p < .001$) is observed this calls for testing ANE for a mediation role. Mediation analyses were tested using the bootstrapping method with bias-corrected confidence estimates [24]. In the present study, the 95% confidence interval of the indirect effects was obtained with 5000 bootstrap re-samples. Results of mediation analysis confirmed the mediating role of ANE in the relation between market orientation and ProEbi (B = .27; CI = .11 to .48). Results indicated the direct effect of market orientation became non-significant (B = .09, $t (102) = .81$, $p = .42$) when controlling for ANE, thus suggesting full mediation. Putting all variables together after being statistically centred to overcome possible correlations that might weaken the effect of the independent variables on eSITP, several iterations of regression analysis were conducted, the following model proved to achieve the highest predictive power for eSITP:

$$eSITP= 3.16+ 0.33Reg+ 0.36Norm+ 0.26FR+ 0.15(ProEbi\_InterfunCo)$$

$$(P < .001);\ r^2=.37;\ r^2 =.37;\ r^{2\,=}\ .35;\ r^{2\,=}\ .33$$

Where: eSITP= Environmental sustainability IT performance; Reg= Regulatory institutional environment; Norm= Normative institutional environment; FR= Financial resources, ProEbi_InterfunCo= a moderating variable where inter-functional coordination has a moderating positive effect on the relationship between Pro-environmental behavior intentions and eSITP.

The model fit measures indicate a relatively high predictive power ($r^2$ = .47; p< .001). Therefore 47% of environmental sustainability IT performance variability is explained by the above variables in the model. Dimensions of the eSITP are explained**.**

***Eco-Learning =*** *3.30+0.25Reg+0.32Nor+0.25FR+0.26ProEbi_InterFunCo*
***Eco- Process =*** *3.35+.31Reg+0.21Nor+0.33FR+0.16ProEbi_InterfunCo*
***Eco-Brand****=3.11+0.11Reg+0.10Nor*
***Eco-Value governance****=3.13+0.29Reg+0.29Nor+0.23FR*

To identify other possible relationships, structural equation modeling (SEM) is used to estimate a series of interrelated relationships. The following table reflects the linkages of the tested model.

| Path | Initial Model | | Revised Model | |
|---|---|---|---|---|
| | Standardized Coefficient | Standardized Error | Standardized Coefficient | Standardized Error |
| Reg => ANE | .24* | .11 | .13 | .09 |
| Reg =>EcoP | .26* | .29 | .16 | .08 |
| Reg =>EcoV | .41*** | .11 | .26* | .11 |
| Nor =>EcoL | .38*** | .38 | .19 | .18 |
| Nor =>EcoP | .21* | .21 | .03 | .08 |
| Nor =>EcoB | .43*** | .43 | .28* | .11 |
| Nor =>EcoV | .34*** | .34 | .16 | .08 |
| FR =>ProEbi | .33*** | .08 | .33*** | .08 |
| FR =>EcoL | .27* | .11 | .27** | .10 |
| FR =>EcoV | .26* | .11 | .17 | .09 |
| FR => ANE | | | .21* | .08 |
| EcoL =>EcoP | .41*** .07 | | | |
| EcoV =>EcoP | .20* .08 | | | |
| ECoV =>EcoB | .54*** .15 | | | |

**p< .05; **p< .01; ***p<.001 Table (4): Tested model linkages*

A summary of the path analysis reflects the drivers for each element in eSITP. Eco process is driven by normative, regulatory environment, Eco learning and Eco value. Eco value governance is driven by regulatory and normative environments and financial resources. Eco brand is driven by Eco value and normative environment. Eco learning is driven by normative environment and financial resources. As shown below revised model meets the fit criteria

| Model Fit | Chi Sq. | Chi Sq/df | CFI | GFI | NFI | RAMSEA | RMR |
|---|---|---|---|---|---|---|---|
| | **≥ 0.05** | **≤ 5** | **≥ 0.9** | **≥ 0.9** | **≥ 0.9** | **≤ 0.08** | **≤ 0.05** |
| Initial | 150.88 | 7.5 | .78 | .80 | .77 | .25 | .06 |
| Revised | 47.86 | 1.37 | .978 | .938 | .929 | .059 | .03 |

*Table (5): Model fit measures*

## 5. Discussion and Conclusion

The current study has two main objectives; one is to explore the eSITP landscape and its current status in the cellular telecommunication in Egypt, second is to investigate performance drivers and their effect on eSITP. Based on the extent to which cellular companies carry out environmental sustainability practices, it is found that there is an average performance and still a wide scope for improvement exists. Both corporate managers and environmental experts have that similar perception on most of eSITP dimensions with the exception of Eco brand where experts evaluation on that dimension is less than managers' by 20%. Eco process is the dimension with the highest scoring ($\overline{x}$=3.37).A relatively low Eco brand scoring ($\overline{x}$=3.11) can be due to three possible reasons including managers retreatment from providing and promoting a green value to target customers who find " green " as an unimportant element of their value equation this might be further attributed to a normative and cognitive environment with a low moderate scoring as these two dimensions affect managers and the customers' belief systems and social expectations as well. Additionally a relatively low Eco value governance, would also lead to a low Eco brand where the relationship between the two variables is tested and proved significant ($p < .001$; $\beta= .54$). Eco process is the dimension with the highest scoring possibly due to the ownership structure of the cellular companies who are internationally owned or jointly owned and therefore execution of certain process becomes a must for being part of a companies' global strategy in addition to a relatively effective regulatory environment which proved to significantly affect eSITP. Furthermore, Eco value affects Eco process ($p< .05$; $\beta=.20$) since a company that manages green IT benefits and adopts investment techniques to manage Green IT is probably expected to design its processes accordingly. Eco learning has the lowest mean value ($\overline{x}= 3.07$) due to limited company-wide awareness of the IT role in environmental sustainability ($\overline{x}= 3.07$) and limited sponsorship of sustainability training ($\overline{x}= 3.09$), and not having a strategy with clear targets for moving to carbon neutral operations ($\overline{x}= 2.95$). Therefore, out of the four eSITP dimensions, Eco process has the highest score followed by Eco value, Eco brand and finally Eco learning.

Based on this study, factors affecting eSITP are normative dimension, regulatory dimension, financial resources, moderating effects of inter-functional coordination and pro environmental behaviour intentions.There is sufficient evidence supporting the effect of institutional environment on environmental sustainability performance yet which factors of institutional environment has the greatest impact is still a point of inconsistency. Oorganizations' orientation is shaped in their quest of legitimacy [28]. For business firms to earn legitimacy that enhances performance and boosts the likelihood of economic survival, they must conform to rules, norms, routines, authoritative guidelines in the external environment [36]. The current research indicates that the normative dimension has the largest impact on institutional environment ($p< .05$; $\beta=.20$). Regulatory framework is the primary driver of firms' top management environmental attitudes and behaviors [33], [29].A recent research reported that regulatory dimension has the lowest impact [32]. Such inconsistency might remain that way due to differences in economic, educational, political and legislative development. The indirect and direct role of inter-functional coordination ($\beta = 0.45$; $r^2 = .21$) on eSITP is among the original contributions of this current research. The result is aligned with the strategic nature of eSITP and reflects the necessity of orchestrating the firms' departmental efforts to improve sustainability performance and developing a sustainability culture across the organization. Financial resources have a direct and an indirect effect on eSITP ($\beta= .41$; $r^2=.17$). There is sufficient evidence in the literature that posits a positive relationship between financial resources and environmental sustainability performance along several years [4], [35], [25]. Among the reasons why this relation holds is attributed to the initial investment costs required for green initiatives, development and implementation of environmental measures and revisiting current organizational processes for alignment with improved natural environmental sustainability practices. Besides its, direct effect, financial resources has a positive relationship with managers' ANE, Eco learning, and Eco value are all previously untracked relationships. Additionally, the new paths of the revised model provide statistical evidence of other direct and indirect relationships. One of the findings is the strong relationship among elements of eSITP Eco Learning, Eco brand, Eco process and Eco value governance. The strong relationship among these elements is explained with the theoretical foundation of eSITP which utilizes the balance scorecard to manage and evaluate firm performance based on four perspectives, learning and growth/ Eco learning; customer perspective/Eco brand; internal business process/ Eco process, financial measurement/Eco governance [26],[22]

Descriptive statistics of other study variables affecting eSITP shows a perceptual gap between managers and experts regarding the normative institutional environment (RMD= 18%), though seen as least effective yet there is statistical evidence of having the largest magnitude of influence on eSITP. A wider gap exists for ANE (RMD= 26%) with a very high evaluation from the managers' side and an average evaluation from the experts' which indicates the existence of social desirability bias for the responses of managers. Twelve out of fifteen hypothesized relationships are statistically supported with a high significance level. The relationship between cognitive environment and ANE, between normative and ANE and pro environmental behaviour intentions and eSITP were not supported. Mangers ANE is more shaped by regulatory environment which in a way might hold true for a culture with a high power distance (PDI= 80) and coercive power is commonly used. The later hypothesis is not supported probably due to the existence of a gap between intentions and actual practices.

## 6. Theoretical and Managerial Implications

The study has drawn into attention the identification and measurement of potential gaps in perception between two important stakeholders. The research uncovered new relationships among variables and measured its magnitude of influence on the overall eSITP. The moderating role of inter functional coordination and its magnitude of influence on performance and the relationships among variables of eSITP can open a path for other models and frameworks that is more internally oriented and would effectively guide managers to enhance eSITP.

There is an overemphasis in the literature on factors external to the organization as being the main drivers for the adoption of environmental sustainability. The organization itself, however, has been largely treated as a ‘‘black box’’ [18]. The current research addressed some internal factors that have a major influence on eSITP directly or indirectly through managers' ANE. Examples of the internal factors identified are financial resources, firm market orientation, attitudes and practices.

The relatively low influence of the cognitive institutional environment would draw educators' attention and policy makers towards the importance of actively promoting, supporting and integrating environmental sustainability education so that the whole community's belief system would be shaped accordingly in order to adopt a positive attitude towards natural environmental and the most appropriate practices or at least to recognize and appreciate the value at the individual level in order to develop and reinforce a positive driver for companies to further institutionalize environmental practices since it would be aligned with customers' value.

The new paths generated in the revised model using path analysis reflect how the interaction between elements of the dependent variable ( Eco learning, Eco brand, Eco process, Eco value ) have a relationship through which managers can utilize as tools to enhance the overall eSITP.

Based on the descriptive analysis and the factors that significantly affect eSITP, managers in the cellular telecommunication in Egypt need to focus on enhancing the Eco value governance ($\beta = .54$; $p < .001$), ($\beta = .20$, $p < .05$) as it has a significant effect on Eco brand and Eco process and thereby the overall eSITP. Accordingly, several initiatives and improvements are recommended including the measuring, tracking and managing green IT benefits for both internal employees and external customers to communicate and clarify the "green" value. This step would allow for a green positioning or at least including "Greenness" in the organization's value proposition and marketing strategy (Eco branding).Employing investment analysis techniques to analyze Green IT performance this in turn will encourage managers to design environmentally sustainable processes (Eco process) that enhance environmental performance (EP) since EP will be measured and tracked. To facilitate Eco process, Eco learning becomes essential and a need for sponsoring staff to acquire sustainability training, designing customer and employee sustainability education and training while spreading a sustainability culture across the organization becomes evident. Environmental sustainability is a strategic issue therefore, the alignment and inter-functional coordination becomes crucial and the current research has provided statistical evidence of the direct and indirect effect of inter-functional coordination on eSITP. Firm market orientation proved to have a major influence on managers' ANE, ProEbi, and eSITP. Managers' recognition of this link is important for directing firm's market orientation towards improved ES. Managers need to collaborate with all stakeholders to ensure alignment of efforts instead of having perceptual gaps as in some dimensions in the current study. According to organizational theory, organizations are dependent on various entities and should seek to collaborate with them to seek higher performance gains in the long run instead of pursuing short-term benefits [34]

## 7. Limitations and Future Research Directions

The nature of the study constructs such as market orientation and firm performance are long term endeavours in which outcomes might be already taking place but results might not be evident in the short run therefore a longitudinal study would be more adequate. A cross sectional data is collected for time constraints and given the limitation and difficulty of longitudinal data.

The research context is limited to cellular telecommunications domain which is considered a sub-sector of a large telecommunication sector. The research addressed only the ecological aspect of environmental sustainability while a broader view of the term would encompass the social and economic elements of environmental sustainability**.**

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# Sustainable target cube A Synthesis of Sustainability and Information System

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## Abstract

The businesses have a critical role in moving the society toward sustainability. The fast changing and dynamic global business environment requires firms to be more flexible to quickly adapt and respond to market changes. Among the forces that drive changes, requirements for corporate responsibility and sustainability are getting more urgent. During such difficult time as this economic downturn, companies are faced with hard choices to survive. Research has acknowledged that addressing sustainability issues is critical to the long-term existence and thriving of companies [4]. The concept of sustainability make it necessary that besides the economic categories and the operational environment protection, it should be considered the social effects of company in management actions. Sustainability business oriented can be realized through developing a corporate target cube in enterprise. Such cube will help organizations to shape their targets in accepting social, environmental and economic responsibilities.

The current research tries to review the research background done till now and depict a perspective of an integrated target cube for both scholars and managers. Furthermore, this paper has a holistic look toward the concept of sustainable information system.

## 1. Introduction and research background

Sustainability should be seen as a concrete, integrated and comprehensive concept, that despite consisting three different dimensions but it represent a unified notion. The question is how companies can integrate sustainability in their daily business operation. Schaltegger [14] stated that four sustainability challenges arise in the companies regarding sustainable development. Ecological challenge which improve the eco efficiency, Social challenge which deal with improving the Socio-effectiveness, Economic challenge regarding environmental and social management which improve the eco-efficiency and / or socio-efficiency and finally integration challenge bringing together the three aforementioned challenges and integration of environmental and social management in the conventional economically oriented management. Hall [8] noted the emerging research associated with sustainable development and entrepreneurship. Entrepreneurship is one of the major efforts for sustainable products and processes, play important role for many social and environmental problems. Hall overviewed of sustainable development and the role of entrepreneurship and outline recent contributions exploring this role. Seuring and Müller [15] investigated a comprehensive review on conceptual framework for sustainable supply chain management. Byggeth [2] stated a method for sustainable product development based on a modular system of guiding questions. . Erek et al. (2009) elaborate on all three sustainability aspects in relation to IS organizations, although the data collection and analysis are primarily focused on the environmental aspect. He counted some advantages of sustainable information system such as

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achieve transparency of the suppliers' products and services, minimize the consumption of resources while maximizing the output, meet internal and external (stakeholder) demands, and recycle and reuse materials. Some scholars discuss what contributes to a more sustainable future, e.g., in terms of the social aspects brought forward by Web 2.0, but the overall theme is yet again the environmental aspect [1]. Long [11] has developed a target system shown how ecologically and economically targets can be integrated in in –house logistic. In another study, Wittstruck and Teuteberg [16] refers to reduce material and energy consumption, use renewable energy sources and create save and healthy working environments as the main objectives of sustainable information system. While limited academic research has investigated the relationship between sustainability and information system, practitioners' literature has been increasingly paying more attention to the role of information system in enhancing and maintaining sustainability in business processes. Caldelli and Parmigiani [3] tried to evaluate the degree to which companies' information systems correspond to needs determined by the objectives of sustainability the company imposes on itself, and did it through a case study in Italy. Chen [4] considered a question about how information systems can help organizations develop ecological sustainability. Their findings from applying institutional theory indicated that information system can be leveraged to achieve eco-efficiency, eco-equity and eco-effectiveness through automating, informating, and transforming organizations. Upward informating system is often associated with enhanced organizational control, as it informs management in almost all aspects of business operations.

While authors of the mentioned studies in the research background were tried to discuss the role of information system in sustainability, there is still a gap in some areas. First, the social dimension of sustainability is not studied well in the literature, and the social sustainability is a vague construct in this way. The literatures often concentrated on the environmental aspect of sustainability and neglect to study the social concerns and the inter-linkage between social dimension with environmental and economical aspects of sustainability. Regarding this issue, the first question that must be addressed in assessing the social sustainability of a corporation is which social impacts or indicators should be considered? In response to the above question, companies should be evaluated in terms of their social impacts for example on their stakeholders including owners, investors, employees, suppliers, customers and even a society. This paper intends to investigate corporate social and ecological targets in 3 levels of management and embed these targets group in daily operation of organization.

Second, integration between targets in each dimension of the sustainability was not studied in the previous researches. Integration of the sustainability dimensions is a critical issue in sustainability literature. So, the integration concept and process is not as obvious as the other issues in sustainability literature. Integration in sustainability assessment become to a great concerns, because such assessments must bring together a wide variety of issues and topics. An integrated assessment for sustainability involves a comprehensive consideration of the economic, social, environmental, and other relevant aspects of the entity, including the relationships between all these factors. S claimed that integrative approach helps to identify win-win-win solutions that integrate all three dimensions of sustainability. While lack of integration resulted to misunderstanding of sustainability and resulted to confusing assessment report of sustainability; integration allows better identification and documentation of indirect and synergistic effects which result from linkages between environmental, economical and social impacts which otherwise might be overlooked in separate, more specialized assessments [12].

Third authors did not provide empirical evidence about the influence of information system on sustainability; therefore the question about how information system could support sustainability would be an interactive research question. The attempts of the scholars to discuss sustainable information systems didn't led to a sustainable information system from social dimension and there is a gap in knowledge from the socio-cultural aspect.

In the proposed research, it is tried to fill these gaps, and to provide implication for both of scholars and managers.

## 2. Research Question and Objectives

The relationship between sustainability and information system will be investigated. The focal point of study is about the relationship between information system and sustainability into a concept which it called Sustainable Information System (SIS). So, the main question of the research would be stated as follow:

*How information system could support sustainability?*

To answer this question, in the first phase, a target cube will be developed which could be used to evaluate the concept of sustainability (Environmental, Social & Economical), regarding the different level of analysis (Strategic, Tactical & Operational)(Lang, 2007) and information system functions and attributes (Information Transfer, Information Processing, Information Storage) [13, 7]. This cube enables the researcher to identify the targets for main functions of information system that could support each dimension of sustainability in different level of analysis. Also, this cube helps the researcher to compare targets in each dimension of sustainability, and integrate them in a framework which could be applied to the information system context. The integration could enlighten the internal relationship between sustainability dimensions and describe that whether their relationships are complementary, conflicting, or neutral. On the other hand, integration will help researcher to develop a target cube which contains coordinated criteria for formulating the framework of sustainable information system. So, such cube led to identify the main attributes of the information system that support sustainability, and could be regarded as the primary answer to the main research question. In addition, this cube will clarify the theoretical attributes of sustainable information system (SIS) as a kind of information system that is compatible with sustainability concept. Then, in the second phase of the research, this cube will be applied to a specific case, and it will be tested from the viewpoints of comprehensiveness, innovation, feasibility, accuracy, rationality, and applicability. The main question of the research is quite effective as it will mainly help in identifying that how information system would support sustainability; how it integrated with social, environmental and economical dimensions of sustainability; and what is the optimum architecture of sustainable information system. Investigation about the main question of the research resulted to find answer about the below secondary purpose:

- What are the social attributes of sustainability, regarding the information system field of study?
- In how far is it possible to integrate these attributes?
- What are the main attributes of sustainable information system?

Finding an answer for the mentioned question could complete the results of the research, fill the gap of the current theory, and provide directions for future research on sustainable information system from the theoretical perspective.

## 3. Proposed study

Target cube plays a main role as an operational planning, management and control tool, therefore it is necessary that the objectives are structured, ordered, fully known to all stakeholders in the company, and be transparent and there exist no spaces, contradictions and uncertainties among the targets [9].

Sustainable target cube can be realized throughout developing the organization enablers including leadership, stakeholder, policy, organizational resources and processes in terms of economic, social and environmental results. It will help organizations to measure their integrated capabilities in accepting social, environmental and economic responsibilities. It will form with the aim of improving and integrating all of the organizational criteria and tries to assess the four mentioned criteria and consequently enhance the environmental, social and economic results. (Fig. 1)

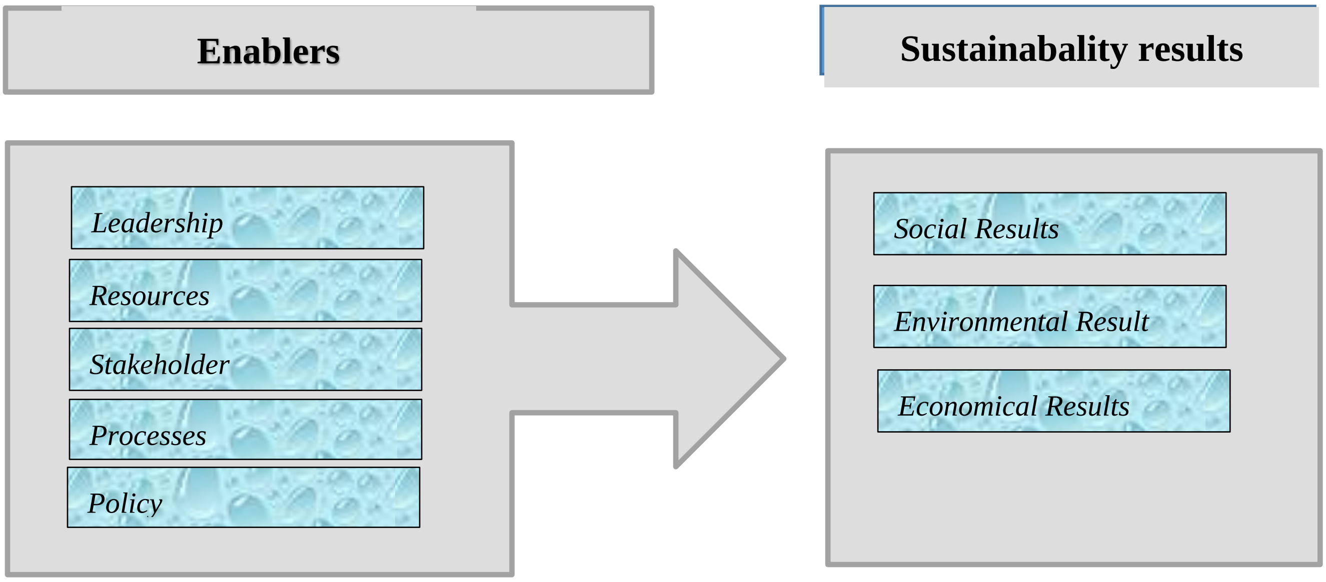


*Figure 1: Criteria relationship*

Since in current research, developing the target system is groundwork of realization of sustainability concept, the next part would be allocated to discussing target system and its component.

## 4. Targets and targets system

Targets describe the emerging states of reality, which can be achieved by certain measures or solutions". The formulation of corporate goals and their concretizations taking into account different stakeholders are an important task in management since goals are key command variables, "on which future action can be measured and optimal decisions can be taken". Basically by developing a target systems have to solve the important targets conflicts [11].

A target system consist of a group of targets that targets situated in a particular area and functionally related. Such targets are so related that their destruction will produce some particular effect desired by the attacker.

To develop a target cube sustainability-oriented, it is necessary first to order the targets in a meaningful manner and define the upper Targets for ecological and economic dimensions as well as social dimension separately. Subsequently, the middle targets (tactical) and sub targets (operative) are derived from top targets (Strategic). The top targets are increasingly operationalized with the help of sub-targets [11].

The development of a target cube in practice requires the following steps:

- To build target catalog
- To build the target system
- To operationalize the target system

- Weighting System [10].

## 5. Methodology

Finding and selection of company relevant objectives constitutes the main problem in developing a consistent target system. This research conduct based on deductive approach. A deductive research process has its starting point in the theory. The researcher continues with formulation of hypotheses, which are supposed to be tested with the collected data and finally confirmed or not. A deductive approach starts out from a general idea and results in more specific concept. The literatures on concept of sustainability are theoretical foundations which current research is based on, and researcher will use them to answer the main question of the research and to develop a framework for sustainable target cube. It is notable that while this research is deductive one, the scientific norm of logical reasoning provides a two-way bridge between theory and research. In practice, this typically involves alternating between deduction and induction approaches as well as necessary. Current research has two phases. The first phase is the development of target cube which is the basis of sustainable information system framework, and the second be devoted to the information system concept. The research method for development of target cube is chosen to be Delphi method. This method is an expert survey that has proven a popular tool in information systems research for identifying and prioritizing complex issues for managerial decision-making.

## 6. Research Supposed Results

As mentioned in the research objectives, current research led to find an answer for the question of "How information system could support sustainability?". Finding an answer for this question resulted to determine the criteria of sustainable information system which could be used as a pattern for comparing information systems regarding with the concept of sustainability. Another considerable result of this research is about the integrated target cube that will be the basis of formulation and development of sustainable information system. The integration could enlighten the internal relationship between sustainability dimensions and describe that whether their relationships are complementary, conflicting, or neutral. In addition, this integration provides a valuable insight about the ties between dimensions of sustainability and strategic, tactical or operative level of analyses. Discussing the integration is an important part of this study since that the development of sustainable information system needs a set of coordinated and integrated targets which don't have conflict in nature and have synergy to build a sustainable framework.

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# Time Series Scenario Composition Framework in Supporting Environmental Simulation Tasks

Chi-Yu Li[1], Frank Molkenthin[2]

## Abstract

To answer the impacts under specific what-if scenarios together with simulation tools has been demanding in different environmental problems. In this contribution, a general software framework for time series scenario composition is proposed to deal with this issue. It is done through providing an interface to process available raw time series data and to compose scenarios of interest. These composed scenarios can be further converted to a set of time series data, e.g. boundary conditions, for simulation tasks in order to investigate the impacts. This software framework contains four modules: data pre-processing, event identification, process identification, and scenario composition. These modules mainly involve Time Series Knowledge Ming (TSKM), fuzzy logic and Multivariate Adaptive Regression Splines (MARS) to extract features from the raw time series data and then interconnect them. These extracted features together with other statistical information form the most basic elements, MetaEvents, for the semi-automatic scenario composition. Besides, a software prototype with two application examples containing measured hydrological and hydrodynamic data are used to demonstrate the benefit of the concept. The results present the capability of reproducing similar time series patterns from specific scenarios comparing to the original ones as well as the capability of generating new artificial time series data from composed scenarios based on the interest of users for simulation tasks. Overall, the framework provides an approach to fill the gap between raw data and simulation tools in engineering suitable manner.

## 1. Introduction

Due to the rapid development of different computer and sensor technologies, scientists and engineers nowadays are able to collect, access, handle, etc. huge amount of data more easily than before. Moreover, there also exist a number of simulation tools focusing on different aspects of different environmental problems with different time and space scales. However, one tool, which fills the gap between available mass raw data and simulation tools, is still not commonly seen, especially in investigating the impacts from certain what-if scenarios for further decision-making.

Some tools and studies also try to fill the gap between mass raw data and simulation tools in answering the impacts from certain scenarios. For instance, the National Groundwater Modelling System (NGMS) [1] contains several predefined scenarios for groundwater problems together with MODFLOW as the simulation tool. Some studies, such as in [2], use Monte Carlo based approaches to generate reasonable inputs for further simulation tools for flood risk assessment. In this contribution, a different approach is proposed by providing a flexible interface for users to create the scenarios of their interest. The entire process is semi-automatic and comprises different modules from data pre-processing to scenario composition. One purpose of this framework is to form the most basic elements, MetaEvents, which represent specific features of a set of independent collected time series data and also contain corresponding statistical information. The information, which MetaEvents contain, is not isolated but complementary. They know the "natural

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order" of the phenomena through the processing of the available data. With such information, MetaEvents can be used as LEGO® bricks to compose or build scenarios of interest in engineering suitable manner. Afterwards, these scenarios can be converted into a set of corresponding time series data for further simulation tasks, e.g. boundary conditions.

## 2. Framework Concept

To fill the gap between available mass raw time series data from different sources with different space and time scales and the simulation tools, a software framework, as shown in Fig. 1, is proposed to resolve this issue. As shown in Fig.1, this framework contains four modules: data pre-processing, event identification, process identification, and scenario composition.

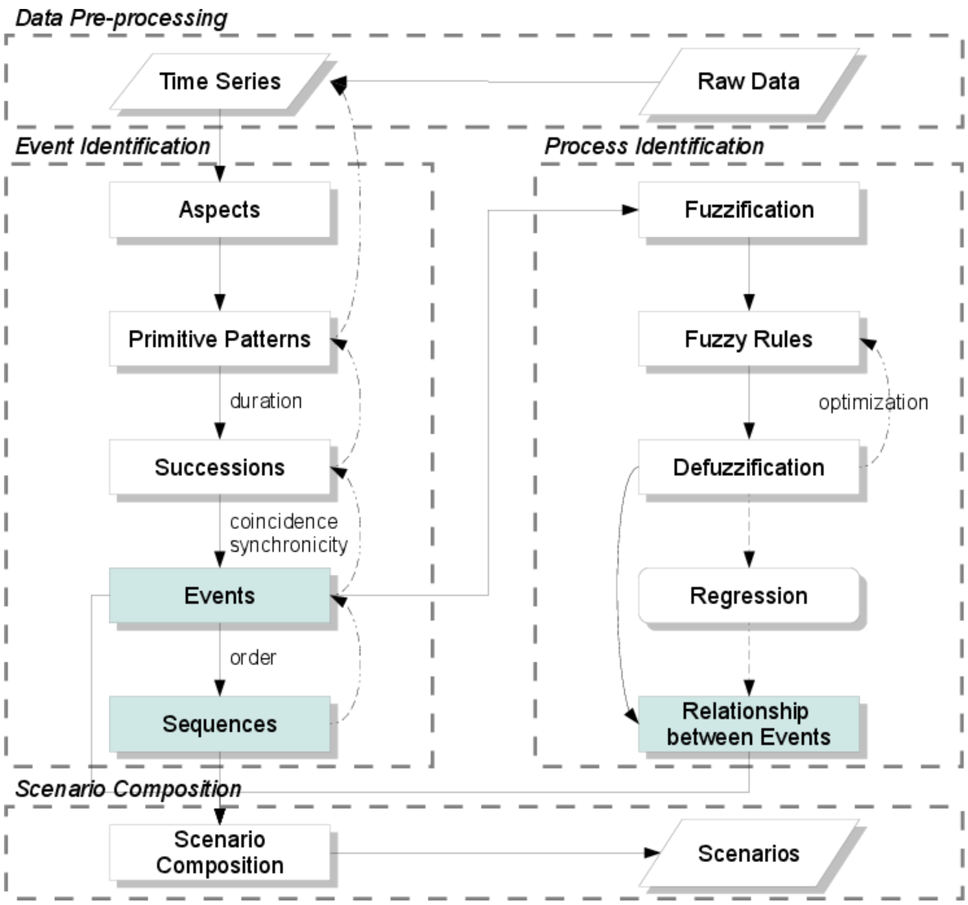


*Figure 1: Framework of Scenario Composition*

### 2.1. Data Pre-processing

Data pre-processing is a crucial step in any data-driven approach and so is in this framework, since it is also data-driven based. It prepares the raw data into the necessary time series sets, Aspects, for the subsequent steps in this framework. It is also problem- and domain-specific and can contain different techniques, such as gap-filling, noise-removing, etc. At the end of the data pre-processing, a set of time series data are grouped into different Aspects with different semantics, e.g. different physical state variables, different time series patterns, etc. For instance, a collection of air temperature and soil moisture time series data can be regarded as two Aspects due to the reason of different physical state variables; two precipitation time series data sets collected from different meteorological stations, e.g. in a plain and on a hill, can be considered two Aspects if they have different patterns.

### 2.2. Event Identification

The purpose of event identification is to extract features, Events, within a certain time interval among the entire time series data set based on the Time Series Knowledge Mining (TSKM) proposed by Mörchen [3]. These extracted Events will be in human-readable format. For instance, a hydrological data set containing the information of air temperature, soil moisture and precipitation can be identified an Event as *aridity* when the air temperature is *high*, the soil moisture is *low* and the precipitation is *low* if dry season occurs.

Event identification contains a sequence of steps, as shown in Fig. 1, and different techniques, such as the methods of clustering, segmentation, rule generation, etc., to extract Events as it is based on TSKM. These techniques are also problem- and domain-specific. The sequence of steps is semi-automatic and the knowledge and experiences of domain experts can be also taken into consideration while extracting Events.

### 2.3. Process Identification

What process identification does is to provide a way to identify and describe physical relationships among different state variables since the Events derived from event identification are descriptive and loosely-connected. This process identification is built upon Mamdani-type fuzzy inference system with Multivariate Adaptive Regression Splines (MARS) for better interpretation [4], and the later serves as a second mapping function to ensure better descriptions of the phenomena of interest.

### 2.4. Scenario Composition

As shown in Fig. 1, the information from both event identification and process identification will be merged in the module of scenario composition. Such information will form the basic component, MetaEvent, in scenario composition. The MetaEvent is the Event together with its metadata derived from the collected data, e.g. statistical information, describing the characteristics of the extracted features. A scenario is composed by a sequence of MetaEvents and it describes a situation which could possibly happen.

The object of scenario composition is to provide a manner to compose synthetic scenarios of interest and, then, to generate the corresponding time series data based on these user-defined scenarios. To achieve this object of scenario composition, the framework has to offer users the necessary information of each MetaEvent, e.g. duration, mean values, next possible MetaEvents, etc., and an interface, e.g. Graphical User Interface (GUI), to compose the scenarios of interest.

## 3. Prototype and Application Examples

### 3.1. Prototype Design and Implementation

In order to demonstrate the concept of this framework, a prototype is designed and implemented in R and Java software technologies, and the information between R and Java environment is implemented with the help of Java Native Interface (JNI). Due to the reasons that lots of techniques involved in the framework is problem- and domain-specific, only the general algorithms are implemented in this prototype and the following examples is also carried out with this generalized prototype. Apart from being a data management/generation tool, it also keeps track of the related metadata to ensure its traceability. Besides, this implementation of prototype can work as a standalone application as well as serve as an add-on to other simulation tools.

### 3.2. BinghamTrib Data Set

Since the framework offers an interface for users to compose any scenario of interest, it also implies that it is difficult to "validate" the results with the traditional sense of validation. However, it demonstrates the capability of this framework to reproduce similar time series patterns comparing to the original ones from a specific scenario in this application example.

In this application example, the hydrological data BinghamTrib data set from the R package `hydromad` [5] is used for this demonstration. This data set contains three physical state variables: rainfall (mm/day), temperature (°C), and streamflow (mm/day). Among them, rainfall and streamflow data are collected for the Bingham River Trib at Ernies Catchment (2.68 km$^2$) by Department of Water, Water Information Provision section, Perth Western Australia. Temperature data are collected by Bureau of Meteorology, Australia. The collected time series data are on a daily basis and from 1974-05-18 to 2008-11-02 as shown in Fig. 2.

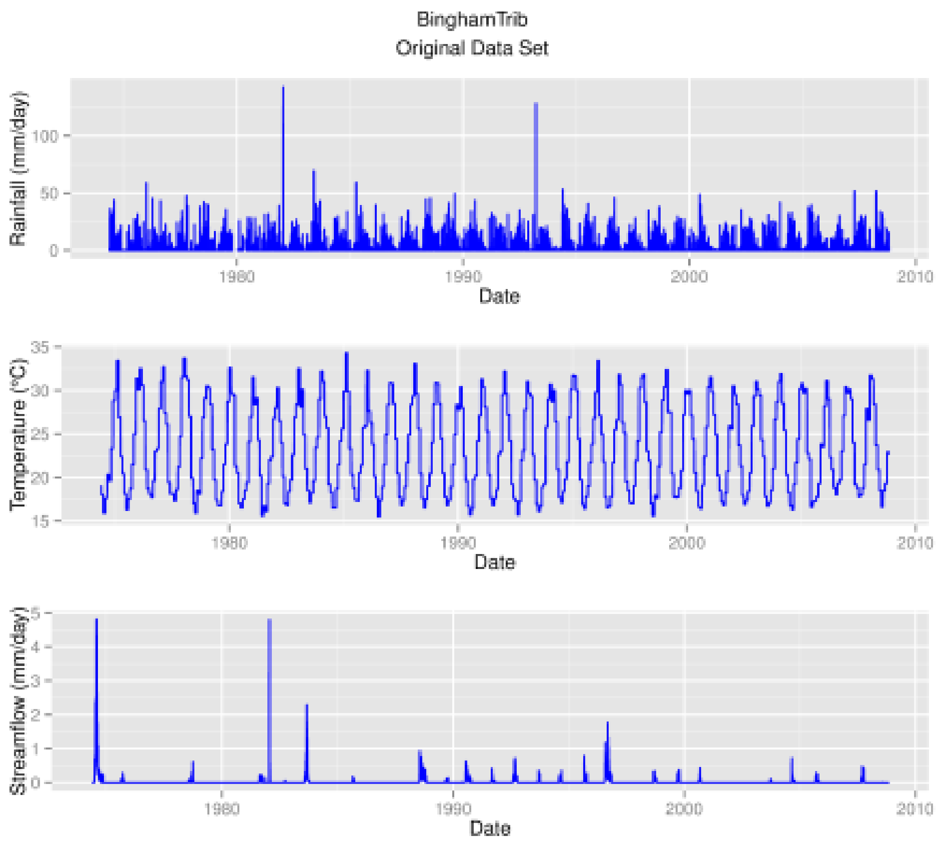


*Figure 2: Original BinghamTrib Data Set from R package* `hydromad`

This data set is almost complete, and only some rainfall records are missing. Through inspecting the history of rainfall and the neighboring values of the gaps, these gaps are filled with the value of zero. Moreover, to derive MetaEvents, the time series set has to be grouped into meaningful categories according to the concept of TSKM. This can be done manually with the help of expert's knowledge, regulations, or through different possible techniques, e.g. clustering. Here, for the demonstration purpose, the general purpose *k*-means clustering is applied on this data set. Depending on the type of data and through trial and error, these rainfall, temperature and streamflow data are grouped into five, five and three categories. These grouping together with the default settings of the prototype, there are total 42 MetaEvents derived. With these derived 42 MetaEvents as basis, a specific scenario is composed to reproduce the original data and the comparison between the original time series data and the scenario-converted ones in the range of

10 years from 1990 to 2000 is shown in Fig. 3. As shown in Fig. 3, with the specific scenario, it is possible to reproduce original time series patterns. Two derived MetaEvents used to compose this scenario, MetaEvent 21 and MetaEvent 41, are also indicated in Fig. 3, and MetaEvent 41 is able to capture the rainfall peak value in year 1993. While looking into the generated time series data, stepwise patterns can be observed due to the reason that the current prototype implementation uses the mean value of each physical state variable within each MetaEvent as a default value for time series data generation. This reason also leads to the fact that these generated default values are not able to catch extreme values.

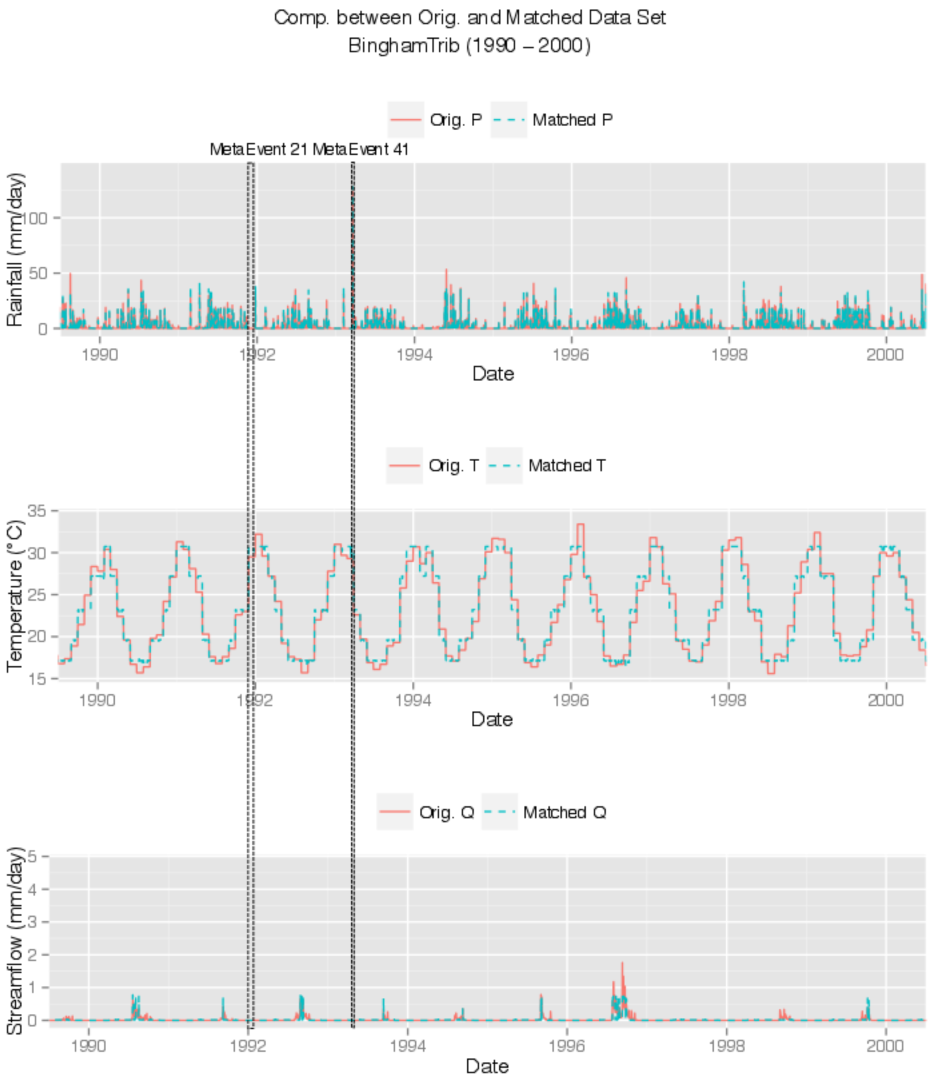


*Figure 3: 10-year Comparison of Original BinghamTrib Data Set with the Matched MetaEvent Default Values (BinghamTrib Data Set 1990 – 2000)*

### 3.3. Oder River Data

In this application example, the data set describing the 1997 Oder Flood in Germany [6] is chosen to demonstrate how the framework can be used with other simulation tools. For this purpose, the focus of this application example is to generate time series data from a specific user-defined scenario, and then to apply these data as boundary conditions in the selected simulation tool. The study area of this application example focuses on the part of the Oder river, starting from the town of Eisenhüttenstadt to the city of Frankfurt (Oder), on the border between Germany and Poland, and the distance of this river section is about 30 km long.

For the purpose of the demonstration, this simulation is simplified and only the flow condition of the river from the town of Eisenhüttenstadt to the city of Frankfurt (Oder) without dam breach is considered. With this simplification, DHI Mike 11 is chosen as the 1-D simulation tool for this demonstration and time series data collected for this application with different resolution and time span are as follows:

- discharge data ($m^3$ /s) at daily intervals from 1996-01-11 to 1997-11-01 at Eisenhüttenstadt
- water level data (m) at 15-minute intervals from 1996-11-01 to 1997-11-02 at Eisenhüttenstadt
- water level (m) at 15-minute intervals from 1996-11-01 to 1997-11-02 at Frankfurt (Oder)

Before this demonstration, a simple pre-processing is carried out to keep all time series data have the same time span and resolution. This is done by reducing the time span from 1996-11-01 12:00:00 to 1997-11-01 12:00 and converting the daily discharge data at Eisenhüttenstadt to the ones at 15-minute intervals with the help of spline interpolation as shown in Fig. 4.

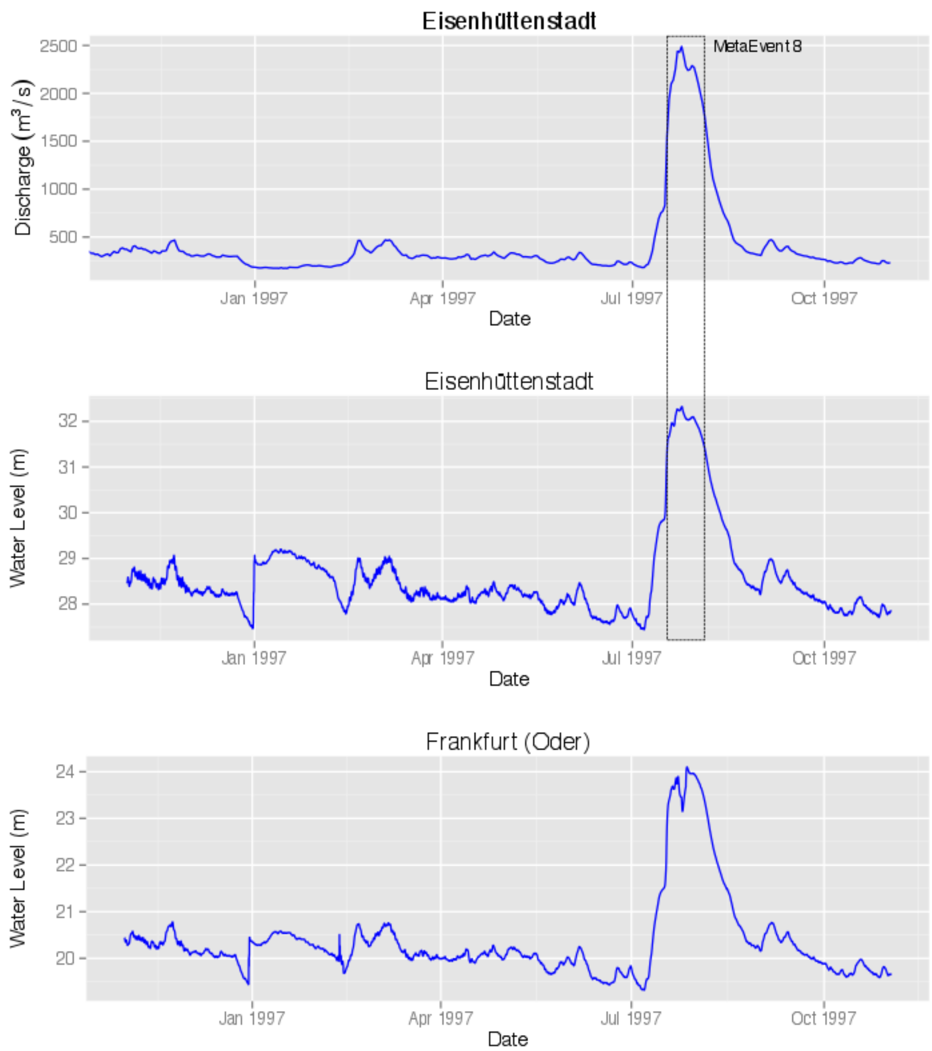


*Figure 4: Measured Time Series Data at Eisenhüttenstadt (1996-11-01 to 1997-11-02) and a derived MetaEvent describing the "peak"*

As the steps in the previous example, the discharge data at Eisenhüttenstadt and the water level data at Frankfurt (Oder) are grouped into five and three categories respectively, and total numbers of nine MetaEvents are derived. For instance, a derived MetaEvent 8 describing the "peak" is also shown in Fig. 4. This MetaEvent 8 contains some basic information, for instance: mean discharge value of 2239.40 $m^3/s$ at Eisenhüttenstadt, mean water level of 23.72 m at Frankfurt (Oder), 4% of the event frequency, etc. Based on these derived MetaEvents, a scenario containing two peaks instead of the original one-peak scenario is composed to demonstrate the capability of composing scenarios of interest and the usage of the framework together with other simulation tools. The generated time series data for discharge at Eisenhüttenstadt and the water level at Frankfurt (Oder) based on this two-peaks scenario are as shown in Fig. 5. The first peak is composed by MetaEvent 6, MetaEvent 7 and MetaEvent 9, and the second peak is composed by MetaEvent 7, MetaEvent 8 and MetaEvent 7 as shown in Fig. 6. These generated discharge and water level time series data are served as upper and lower boundary conditions individually for a calibrated and validated 1-D Mike 11 model. As mentioned earlier, the default generated time series data appear stepwise patterns due to the settings of current prototype implementation. The water level at downstream based on this two-peaks scenario is simulated as shown in Fig. 6.

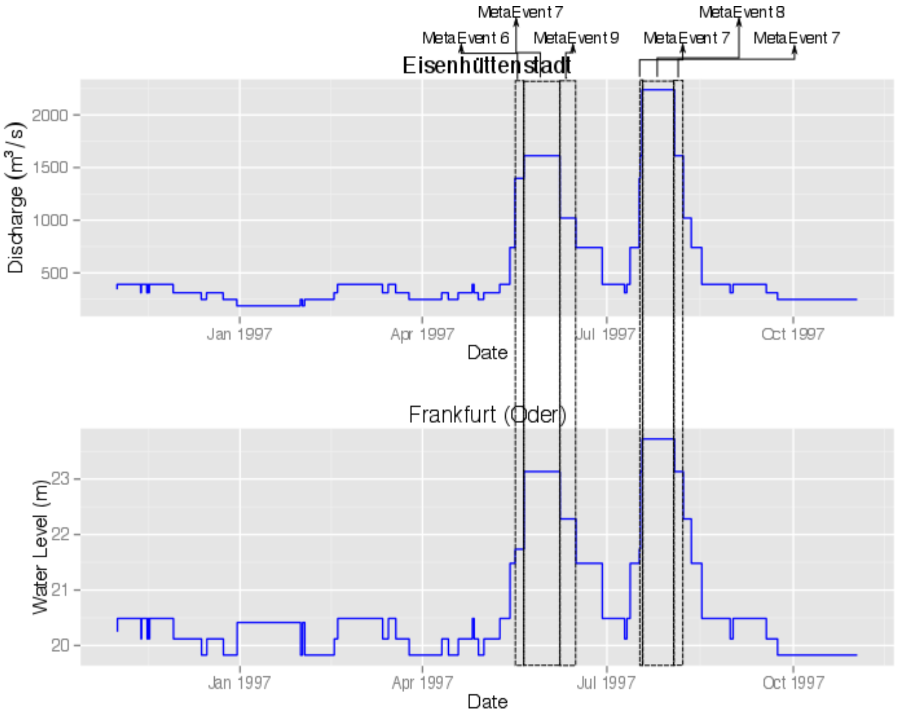


*Figure 5: Generated Two-Peaks Time Series Data*

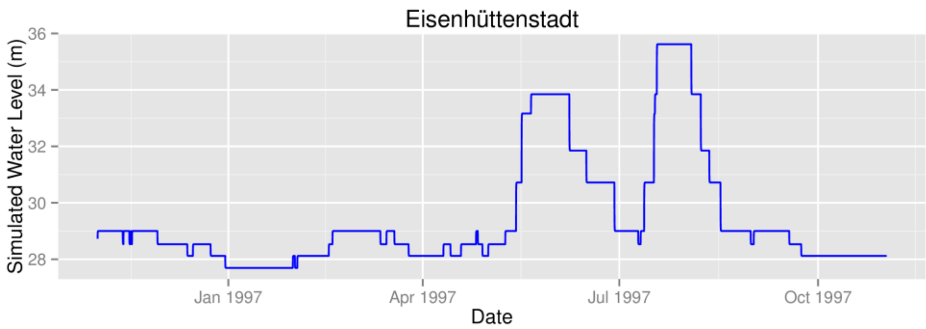


*Figure 6: Simulated Water Level at Eisenhüttenstadt*

## 4. Conclusions

In order to fill the gap between mass raw data and simulation tools, a framework of time series composition is proposed here to resolve this issue. With this framework, features of a set of time series data are extracted and form the most basic elements, MetaEvents, for scenario composition. With these MetaEvents, which contain not only features but also corresponding statistical information, users can compose the scenarios of interest with the help of information offered from the framework. The process to break a set of time series and to form MetaEvents is semi-automatic and the techniques required are problem- and domain-specific. In this contribution, a generalized prototype is introduced and this prototype with two different application examples also demonstrate the concept and the capability of the framework. Due to the generalization of the prototype, it still shows the room for improvement, especially in the generated time series data. Overall, it provides a general tool for users to be able to compose scenarios of their own interest and to convert the data for further simulation tasks to answer the impacts under such scenarios in engineering suitable manner.

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# A method for the constrained interpolation of RLE-compressible chemical weather heatmaps

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## Abstract

Chemical Weather (CW) and other geospatial environmental information produced by numerical models are often published on-line in the form of heatmaps which have undergone several lossy processing and transformation steps, resulting in a relatively low visualization and recoverable data, compared to the model data which generated them,. In this paper, a method which is fine-tuned to the partial reconstruction of such chemical weather data starting from discrete-level heatmaps is presented, which relies on the augmentation of ordinary interpolation methods through the use of peak-limiting functions and other constraining methods.


## 1. Introduction

In recent years, there has been a noticeable increase in the amount of Chemical Weather (CW) and other geospatial environmental forecasting information published on-line in various forms, with the most important form being visualized pollution (Chemical Weather) forecasts maps in the form of heatmaps [1]. However, despite this availability of forecasts, which require large amount of data to generate, access the high-quality, numerical data behind them, for either research or service-creation purposes, is still relatively restricted.

Methods to recreate numerical data from heatmaps have been proposed and applied in [3] and [7], but they are limited by the lossy process used to create the heatmaps themselves, where a significant part of the initial information ends up being discarded. The data used to produce these heatmaps are commonly the outputs of numerical dispersion models simulating the variation of pollutant concentrations in time and space, such as the SILAM [6] integrated modelling for atmospheric composition, created and managed by the Finnish Meteorological Institute.

In this paper, a method which is fine-tuned to the partial reconstruction of chemical weather data in the form of discrete-level heatmaps is presented. This method relies on the augmentation of ordinary interpolation methods through the use of peak-limiting functions and other constraining methods which ensure that the interpolation's results will adhere to specific context-dependent boundaries and value distributions.

## 2. Materials and methods

In general, chemical weather data as produced by air quality (AQ) models, henceforth referred to forecasts, can be viewed as 2D signals extending into geographical space (longitude-latitude), when referred to a particular time instance. The amplitudes of these signals express the concentration for a given pollutant, usually in $\mu g/m^3$, $_{ppm}$ or ppb units. Forecasts often also have a time and an altitude

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dimension, effectively making them 3D or even 4D signals, but they can be treated as purely 2D signals for the purpose of data analysis, if a specific time instance and altitude are considered. The most typical heatmap type encountered in the domain of Chemical Weather Air Quality Forecasting [4] uses colour-coded coverages to represent the concentration value ranges of air pollutants such as CO, NO, $NO_2$, $SO_2$, $O_3$, $PM_{10}$ and $PM_{25}$.

In this paper, AQ forecast datasets provided by the Finnish Meteorological Institute and generated by the SILAM model [6] were used, covering the region of Europe between the bounding coordinates of (25° W, 30° N) and (45° E, 72° N), approximately, with an orthogonally projected 352 (lon.) x 220 (lat.) data grid.

For the constructive training of the interpolator functions, a dataset of model data from the SILAM model, spanning the entirety of 2013 was used, and including over 8000 forecasts . As a control set for performance evaluation, a set of 100 randomly chosen forecasts was used from those available.

For the visualization of heatmaps, other than those directly taken from AQ forecasting services, ad-hoc visualization software was developed, written in Java and Matlab.

### 2.1. AQ heatmaps

Due to the nature of the quantization process applied to AQ forecasts, the resulting heatmaps can be regarded as a particular class of non-uniformly sampled signals [2,5]. In addition, due to the specifics of CW forecasting itself, it is possible to make certain assumptions regarding the distribution of values in a CW forecast heatmap [3,7], if the quantization process and the value ranges of the quantization levels employed in the heatmap itself are known. An example of a CW forecast heatmap and its colour scale is given in Figure 1.

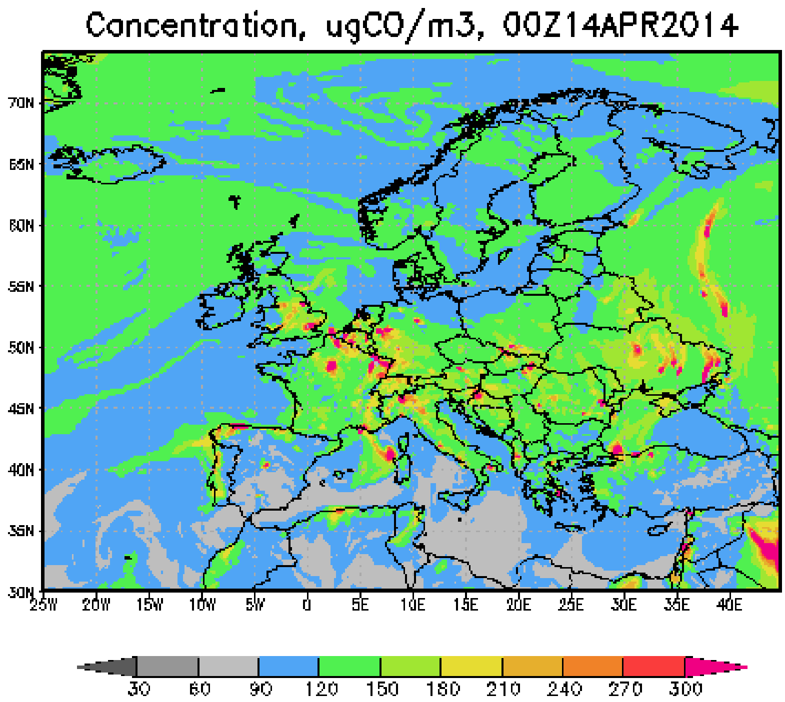


*Figure 1: A sample forecast heatmap, representing CO concentrations over Europe with its colour scale at the bottom (courtesy of FMI),*

Quantizing a CW forecast produces more or less continuous connected contoured regions of local maxima and minima in a quantized signal domain. It can be shown that the transition boundaries (isolines) between such regions coincide with points where the uncertainty of the true value of a signal is minimized [3], thus they can be used as known threshold crossings or interpolation keypoints, regardless of the interpolation method used. In addition, even if the quantization process classifies ranges of continuous values into discrete bins or levels, using a many-to-one irreversible mapping, this means that the true values of points in the 2D space belonging to a particular classification bin, can only vary between a specific floor and ceiling value, with the values at the borders between different contours being known very precisely or even exactly, due to their transitory nature. This is generally true for most contour points, though small-scale inaccuracies might be introduced by the contouring algorithm, which might cause permanent loss or misclassification of certain small-scale details.

By using these elements, as well as knowledge about the value distributions inside the contours themselves, it is possible to produce an interpolation of higher quality and reliability for the reconstruction of CW data from heatmaps.

### 2.2. Numerical method and interpolation

The method presented in this paper uses a set of pre-trained constraining functions, with their domain defined in the longitude and latitude dimensions of a 2D signal representing CW data on a geographical regions (the base unit may also simply be grid points), and their co-domain defined on the pollutant's concentration value. The functions are produced in sets of triplets representing the maximum, mean and minimum values encountered within a longitudinal or latitudinal section of a contour.

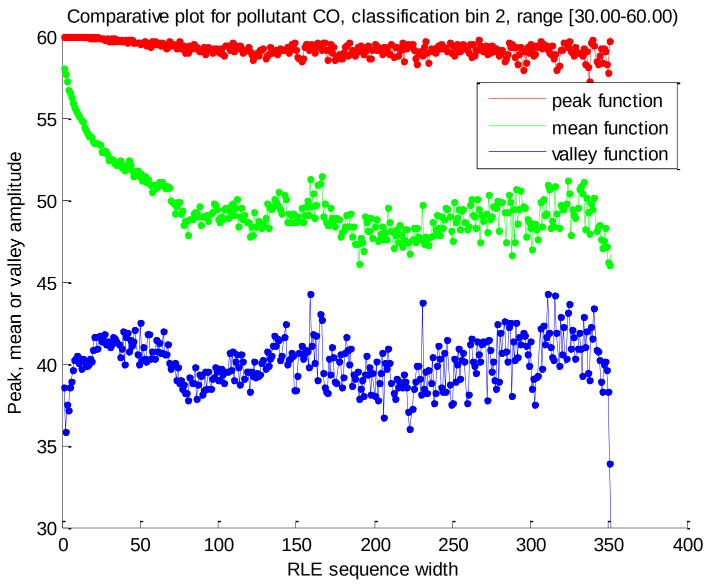


*Figure 2: The structure of constraining function for a specific pollutant (CO) and a particular classification bin (range of 30 to 60 $\mu g/m^3$) trained on the longitudinal dimension, width expressed in grid units.*

Each quantization level employed in the heatmap has its own function triplet, as shown in Figure 2. These functions allow for the explicit exposure of any relationships that might exist between the spatial dimensions of a quantized contour and the peak, average or minimum value that it might contain. The functions are constructed by statistically analysing several CW datasets (for the time being, of a single dataset provider), and expose that a non-trivial relationship often exists. With this knowledge, it's possible to construct a contour width-dependent interpolator function.

The quantized heatmap is converted to a Run-Length Encoding (RLE) compressed representation, which segments the image in horizontal and vertical scan lines, each containing several RLE sequences, as shown in Table 1. RLE sequences themselves are classed into the following categories, depending on their position and relationship with other RLE sequences: 1) initial/ending maxima or minima 2) local minima or maxima 3) transitional ascending or descending.

The endpoints $P_{start}$ and $P_{end}$ of each RLE sequence are used as constrained interpolation keypoints (any interpolation method used must cross them), as their value is known with the best possible (for a heatmap) accuracy, a property which derives from their construction as part of isolines. An example of how a 1D section of a 2D curve is quantized is shown in Figure 3 and Table 1.

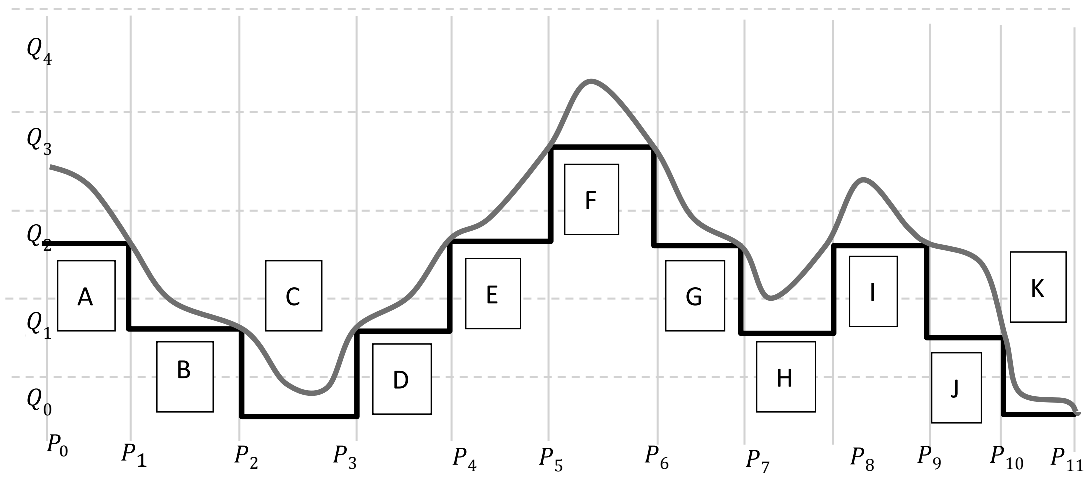


*Figure 3: An example of how a curve is quantized into a finite number of levels and split into RLE sequences, each labelled from A to K.*

| RLE Sequence ID | $P_{start}$ | $P_{end}$ | Quantization level | Classification |
|---|---|---|---|---|
| A | $P_0$ | $P_1$ | $Q_2$ | Initial Maximum |
| B | $P_1$ | $P_2$ | $Q_1$ | Descending |
| C | $P_2$ | $P_3$ | $Q_0$ | Local Minimum |
| D | $P_3$ | $P_4$ | $Q_1$ | Ascending |
| E | $P_4$ | $P_5$ | $Q_2$ | Ascending |
| F | $P_5$ | $P_6$ | $Q_3$ | Local Maximum |
| G | $P_6$ | $P_7$ | $Q_2$ | Descending |
| H | $P_7$ | $P_8$ | $Q_1$ | Local Minimum |
| I | $P_8$ | $P_9$ | $Q_2$ | Local Maximum |
| J | $P_9$ | $P_{10}$ | $Q_1$ | Descending |
| K | $P_{10}$ | $P_{11}$ | $Q_0$ | Ending Minimum |

*Table 1: The RLE Sequences generated by the curve in Figure 3 and their properties.*

Each RLE sequence $k$ is used to compute the amplitude and standard deviation of a Gaussian (normal distribution) interpolation kernel with a general formula of:

$$G_k(x) = A(Q_k, w_k)e^{-\frac{(x-\mu_k)}{\sigma_k{}^2}}, \text{ with } x \in [P_{start}(k), P_{end}(k)] \quad (1)$$

where $A(k, w_k)$ is the peak amplitude that corresponds to a RLE sequence of a given width $w_k = P_{end}(k) - P_{start}(k)$ and quantization level $Q_k$, according to the computed constraining functions, and $\mu_k$ is the k$^{th}$ RLE sequence's midpoint. The value of $\sigma_k{}^2$ is computed as:

$$\sigma_k{}^2 = -\frac{\left(\frac{w_k}{2}\right)^2}{2\ln\left(\frac{y_{cross}(Q_k)}{A(Q_k,w)}\right)} \quad (2)$$

where $y_{cross}(Q_k)$ is a function which returns the amplitude at the crossing point for a given quantization level (for the example of Figure 3, that would be 30). This way, keypoint crossing by each RLE sequence's interpolation kernel is guaranteed, a property which is retained even when combining vertical and horizontal interpolation passes. Local minima, transitional and initial/ending sequences use a variation of formula (1), which computes inverted Gaussian distributions or only a portion of a Gaussian distribution's curve, as appropriate, but always respecting the constrained crossing and floor/ceiling conditions. The various sequences and their interpolated values thus computed, are subsequently spliced together to form a continuous reconstruction for a given scanline, as is shown in Figure 4.

This interpolation procedure is applied on both the horizontal and vertical dimensions of the quantized heatmap and then the two separate 2D interpolations obtained from each pass are averaged, yielding the final 2D interpolation. It has been determined experimentally, that averaging one horizontal and one vertical interpolation pass gives the best results. It's possible to use additional passes e.g. in reverse for each direction, but those don't always bring benefits, while wasting computational time.

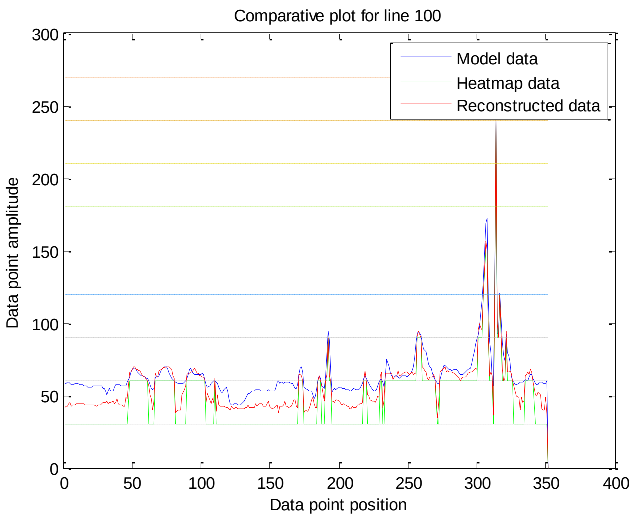


*Figure 4: Comparison between model data, heatmap data (quantized) and reconstructed data for a specific latitudinal line (line 100) of a reference CO forecast.*

## 3. Results

In the conducted tests, it was determined that for sufficient training of the constraining functions, it was enough to use at most 150 to 200 forecasts, spread out over several months of the year and covering diverse enough conditions in order to avoid overfitting particular seasonal phenomena. Using more forecasts resulted only in marginal interpolation improvements, as can be seen in Table 2 for the PSNR metric, expressed in dB.

Depending on the specific pollutant considered, the Root Mean Squared Error (RMSE) metric between the original forecast numerical data and the reconstructed/interpolated data, was on average reduced by a factor of up to one half compared to the RMSE between the original forecast data and the untreated heatmap data. Similarly, the Peak Signal-to-Noise Ratio (PSNR) metric showed improvements ranging from about 2.0 to 6.0 dB, depending on the pollutant and forecast considered.

| N | **CO** | **$SO_2$** | **$NO_2$** | **$O_3$** | **$PM_{10}$** | **$PM_{25}$** |
|---|---|---|---|---|---|---|
| 10 | 5.968 | 1.987 | 2.628 | 4.731 | 2.933 | 2.740 |
| 25 | 6.124 | 2.051 | 2.594 | 4.586 | 2.972 | 2.781 |
| 50 | 6.162 | 2.029 | 2.548 | 4.605 | 2.928 | 2.768 |
| 75 | 6.185 | 2.116 | 2.580 | 4.614 | 2.947 | 2.777 |
| 100 | 6.240 | 2.108 | 2.592 | 4.625 | 2.949 | 2.794 |
| 150 | 6.224 | 2.089 | 2.575 | 4.623 | 2.962 | 2.797 |
| 200 | 6.231 | 2.083 | 2.577 | 4.632 | 2.968 | 2.784 |
| 400 | 6.233 | 2.102 | 2.579 | 4.628 | 2.974 | 2.799 |

*Table 2: Improvement of the PSNR metric (in dB) for interpolating different pollutant types depending on the number N of forecast datasets used for training the constraining functions*

In Table 3, the average improvement yielded by the application of the interpolation, on a control set of 100 forecasts of each kind are shown. On average, the PSNR metric is improved (larger values are better); the ΔRMSE metric (difference between RMSE values) also improves (negative values are better). ΔRMSE (%) indicates the percentage of the RMSE reduction between the RMSE of heatmaps (RMSE-f) and of their reconstruction (RMSE-r), versus the unmodified model data, used as a reference. RMSE values of different pollutants are not directly comparable.

| | **CO** | **$SO_2$** | **$NO_2$** | **$O_3$** | **$PM_{10}$** | **$PM_{25}$** |
|---|---|---|---|---|---|---|
| **PSNR [dB]** | 6.171 | 2.071 | 2.584 | 4.630 | 2.071 | 2.780 |
| **RMSE-f** | 19.415 | 0.582 | 0.664 | 11.407 | 1.629 | 1.256 |
| **RMSE-r** | 9.680 | 0.468 | 0.494 | 6.704 | 1.162 | 0.915 |
| **ΔRMSE** | -9.736 | -0.114 | -0.171 | 4.630 | -0.467 | -0.341 |
| **ΔRMSE (%)** | -50.144 | -19.650 | -25.673 | -41.229 | -28.668 | -27.167 |

*Table 3: Average improvement yielded by the proposed algorithm by reconstruction a control set of 100 forecast heatmaps, for each pollutant type. RMSE metrics are expressed in $\mu g/m^3$.*

In general, training was most successful for heatmaps created from linearly spaced quantization scales and with an even distribution of values across their quantization scales (like the ones of the $O_3$ and CO pollutants), which helped avoid phenomena like having too little data points available for higher-class bins. The particular monthly and seasonal periods of the datasets used for training and for control didn't result in appreciable variations in the final results.

In Figures 6c and 6d, the absolute RMSE maps of the model data versus their lossy heatmap and of the model data versus their heatmap-based reconstruction (for a reference forecast) are shown, in terms of CO concentration units (μg/m$^3$). The original model data are shown in Figure 6a, their lossy heatmap in Figure 6b and their reconstruction in Figure 6e. The reconstructed version appears smoother than the untreated heatmap, and preserves features like hills and valleys present in the model data, while resulting in a noticeably less noisy RMSE map.

In Figure 6f, the 2D FFT spectrum of the reference CO forecast of Figure 6a is shown, revealing that model data is not, in general, a band limited signal. While most energy is concentrated on lower bands and there is a noticeable DC bias (shown as a horizontal line), the forecast is obviously not sufficiently band limited for inverse spectrum reconstruction conditions to apply [2,5,8]. In such conditions, interpolation methods that operate in the spatial (rather than in the frequency) domain, may be preferable, as there are less problems with finding sufficient quantities of spectrally significant threshold-crossing points, and generally less corner cases to handle.

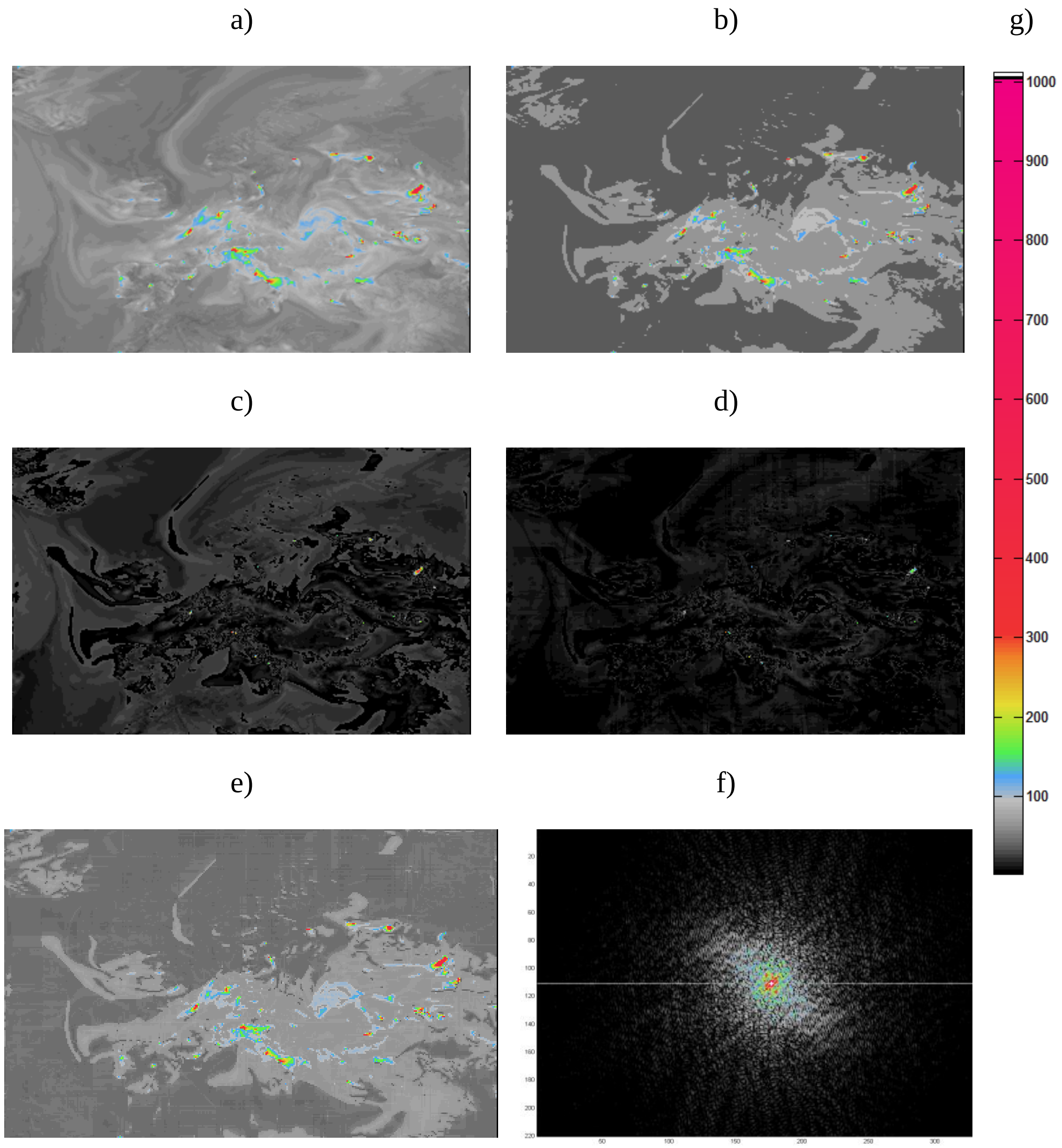


*Figure 6: a) the reference CO forecast b) its quantized version c) the difference map of the model data versus their heatmap version d) the difference map of the model data versus their heatmap-*

*based reconstruction e) reconstructed version with the proposed algorithm f) The 2D FFT spectrum of the reference forecast g) the common colour scale, expressing CO concentration in $\mu g/m^3$. The same color scale is used in all images.*

## 4. Discussion and conclusion

In this paper, a method for the domain-specific interpolation of air quality heatmaps is presented.

The method proved particularly effective at interpolating chemical weather data, providing consistent improvements in the Peak SNR (PSNR) and reductions in the Root MSE (RMSE) metrics for several types of air pollutant heatmaps. In this way, the method can be used to recover a closer representation of the original models' data, by using significantly less data and bandwidth and in a way which is transparent to the model publishers themselves, making it ideal for streaming detailed Chemical Weather coverage information on the internet.

The method was fine-tuned to a specific application domain and using datasets from a specific provider, but it is expected to be adaptable to other domains where heatmaps representing 2D signals with similar spectral and spatial characteristics are employed, as long as a way for constructing or training constraining functions suited to the specific domain is provided.

Ideally, it is expected that when the constraining functions are constructed based on dataset training or by using analytic formulas and models which are close enough to an acceptable ground truth for a particular domain, they will exhibit wider applicability beyond their originating datasets.

For example, training functions trained on the SILAM dataset could be used in different AQ datasets, after accounting for the different spatial and quantization domains. This can be the object of future work, as access to more reference datasets in the same (AQ) or other environmental science domains is gained.

## 5. Acknowledgements

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# Implementation of a Semantic Language for Environmental Phenomena Processing in Time Series

Gerhard Dünnebeil[1], Bojan Božić

## Abstract

This paper describes our implementation of a semantic language for environmental phenomena processing in time series. Our contribution consists of the dedicated time series processing language Formula3, which can be used in a dynamic environment by expert users and time series analysts, and is based on a novel pipe-oriented architecture. In addition to the language description, we also present our approaches for key-value-pair time series processing and semantic enrichment of time series expressions. The concepts are validated by the implementation of Forumla3 as a processing and query language and the time series are visualized in the graphical time series editor. We conclude the paper with references to related work and an outlook to future extensions for our language.

## 1. Introduction

In current time series processing there is a need for a dedicated language with a novel architecture to deal with the enormous amount of time series data. Expert users require a solution which provides efficient and fast time series processing together with a modern, service oriented architecture which supports dynamic and context-aware functionality for time series analysts and expert users from different domains. Therefore, our paper presents such a language together with the implementation of a pipe architecture as well as the definition and suggestion of a key-value-approach and semantic time series concept.

The rest of the paper is organized as follows. Section 2 describes the system architecture in detail, including the building blocks of our software and the pipe-oriented architecture. Section 3 introduces the Formula3 time series processing language, its implementation, and some examples for time series processing expressions, as they are defined in the language's syntax. The key-value-pair approach is presented in section 4, where we also illustrate the concept in a table by defining which parts are provided by time series, datahandler, and property provider. Our ideas for semantic time series processing with the use of Formula3 are introduced in section 5. Here, we describe direct and indirect semantic value injection as well as the selection of an algorithm which supports data processing in semantic time series. In section 6 we show the results of our work on the example of a graphical time series editor. Finally, section 7 and 8 provide an overview about related work in the area and an outlook to further work which we plan in order to offer a fully-fledged implementation of our language covering the consideration of context via semantic extensions.

## 2. System Architecture

OpenUwedat is a set of utilities and libraries. They are dedicated to rapidly creating and assembling time series applications. The basic concept is to keep a unified view on every possible source and

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sink of time series data including meta data. For this task building blocks are defined that use a small set of unified interfaces to interact with each other.

The TSAPI core is implemented using JAVA but there are client libraries available for python and VBA which allow accessing data from non-JAVA applications. Other client implementations are possible.

### 2.1. The building blocks

An object type called “Time Series” is used to exchange measurement data throughout the system. Individual measurement data can be addressed by a string (“value key”) and a time stamp. Value keys are not predefined or limited by the framework. Measurement data is not limited to numbers. Thus it is possible to model arbitrary data models.

Time Series objects are transient and only used during communication between other building blocks.

The endpoint of such a communication is always a “datapoint”. Datapoints are grouped together by logical or physical criteria. Such a group is called a “datahandler”. Typical datahandlers act as drivers around physical devices. Other datahandlers act as inline elements in communications and are then called “processors”. Note, that data stores like databases are also treated like “devices” which leads to a vast independence of data storage brands. This also allows encapsulating legacy systems or build “interface adapters” to existing devices.

Datahandlers and processors are “plugins” and can be injected into the framework by configuration files. Thus the framework can be adapted for new applications and needs.

Communication channels are defined by the application and are called “pipes”.

Time Series and Datapoints can describe themselves by providing “meta”-information. This allows downstream elements to adapt their behaviour depending on the nature of the time series currently processed.

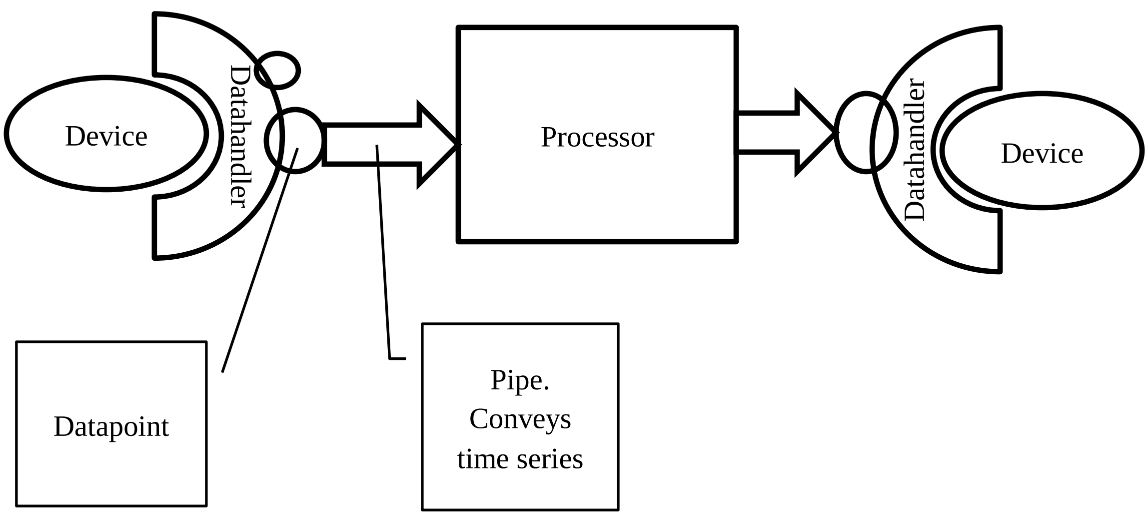


*Figure 1: Pipe Architecture*

## 3. Formula3

One way to define processors in the system is a special implementation which defines a generic processor. At runtime this processor is configured by using a time series processing language called "Formula3".

Formula3 can process data by applying operations to each individual point in time or by building aggregates.

Formula3 itself is implemented in python using a compiler created with PLY[2]. The compiler creates an abstract syntax tree which is then interpreted in a second step. Operators which perform recurring tasks are thus typically compiled only once. F3 is embedded into the Java core by the use of Jython[3].

Possible operations include all basic arithmetical operations as well as calls to subroutines. All commonly used mathematical routines like exp, sqrt, etc. are available.

Formula3 operates fully recursively meaning all operations can be nested.

Additionally Formula3 can be extended by custom made subroutines.

Examples:

| | |
|---|---|
| @A << A[i]*3 >> | Multiply all values by three. |
| @A <<mean( A ]t-15min..t]) >> every 15 mins | Calculate the average over the values in 15minute steps using a Window of 15 minutes with its end aligned at the current result's time stamp. |
| @A @B << A[i]+B[i] >> | Sum up two time series. |

## 4. The Key-Value-Pair Approach

OpenUwedat has the approach to be agnostic to the application which is currently built. Thus we decided not to restrict the framework to any special method of retrieving and creating semantic values. Instead we chose a "flat" interface which provides semantic information in form of key-value pairs (KVP). KVPs can be provided by different means such as fixed dictionaries but also by other means. The interface definition does not provide any limitations here.

Each time series should hold a small set of KVPs. The existence of these KVPs is the basic self-description of the time series and, therefore strongly recommended. Other KVPs augment the meta data and are of relevance for only certain applications. These KVPs are usually injected from the outside on a project-by-project manner.

[2] See http://www.dabeaz.com/ply/

[3] See http://www.jython.org/

### 4.1. Property Retrieval, The Chain of Command

A time series can be asked for any semantic property. However, it makes no sense for a time series to store every possible property. Thus we implemented a chain-of-command like structure. If a time series does not know about a property currently queried, it will ask its origin datapoint. This will, in turn, query its datahandler. Data handlers that are specialized to work with one system or device or at least a small family of devices usually have intrinsic knowledge about their counterpart. They can provide this knowledge as time series properties. The most common use case for this is the description of the time series structure. But if the external system provides more semantic information, it can be provided as well.

If a data handler does not know about the property it was asked about it has to ask the system property provider.

System property providers are also modelled in form of a plugin which can be injected.

System property providers can be chained so that a previous provider can delegate to a subordinate one in case it does not want to handle a query.

We have implemented system property provider which can provide properties as constants, by simple conditional list lookups, using SQL queries and by using SPARQL-Queries. Other possible implementations depend on the application at hand.

| Key | Value | Source |
|---|---|---|
| Keys | “Value”, “Checklevel”, Validity” | Provided by the Time Series |
| DefaultKey | “Value” | |
| Scalar | True | |
| DeviceType | “HORIBA 4711” | Provided by the Datahandler |
| Class | Meteorology | Provided by the System via Property Provider |
| Location | 14.56/48.37 | |
| NUTS-Code | NUTS:AT:122 | |

*Table 1: Example set of KVPs for a time series*

## 5. Semantic time series processing using Formula3

As Formula3 deals with the time series it has access to their related semantic information. This can be used to influence the way Formula3 processes the time series values.

### 5.1. Direct Semantic Value Injection

Often a processing algorithm needs further information about the environment of the measurement site. In many cases, this is just a constant value like the height above sea level or some empirical correlation factor that varies with the type of station.

Formula3 allows accessing this kind of value directly and incorporating it into the algorithm.

e.g. @A << A[i]*$A.HSL >>(assuming the “Height above Sea Level” can be queried by the key HSL.)

This technique assumes that the semantic value is used similar to a literal. The internal processing replaces the semantic value by a constant value during the calculation process for an individual time series.

### 5.2. Indirect Semantic Value Injection

In many use cases a related value used in a formula is *not* a constant but is itself a time series.

The TSAPI framework allows defining “links” aka “pointers” to other time series to be in the semantic context of a time series. This allows to make queries like “give me the air pressure at the nearest meteorological station” This can be used within Formula3 to combine related time series.

E.g. @A << A[i]*$A.AP[i] >>

### 5.3. Algorithm selection

In many cases processing details should be hidden from the average user. A typical use case for this is a user who knows that he wants to calculate mean values for certain time series but does not want to deal with the details. The process of calculating an average is e.g. different for a scalar compared to a vector.

This process is typically done in a subroutine in Formula3:

E.g. @A <<mean( A ]t-15min..t]) >> every 15 mins

The subroutine hidden behind the symbol “mean” can change its behavior depending on the semantic context of “A”. Thus it is possible to hide the calculating details from the average user.

## 6. Result presentation

A collection of client programs exists that allows tapping into the system and inspecting results.

Beneath querying pure values from the system all tools also accept F3 expressions which allow querying modified data.

The “Graphical Time Series Editor” (GTE) allows inspecting and modifying data interactively in several forms of presentation. Besides graphical and tabular presentations it allows to also display data in form of geographic maps.

The GTE evaluates time series properties and offers different interface options to the user depending on several property values.

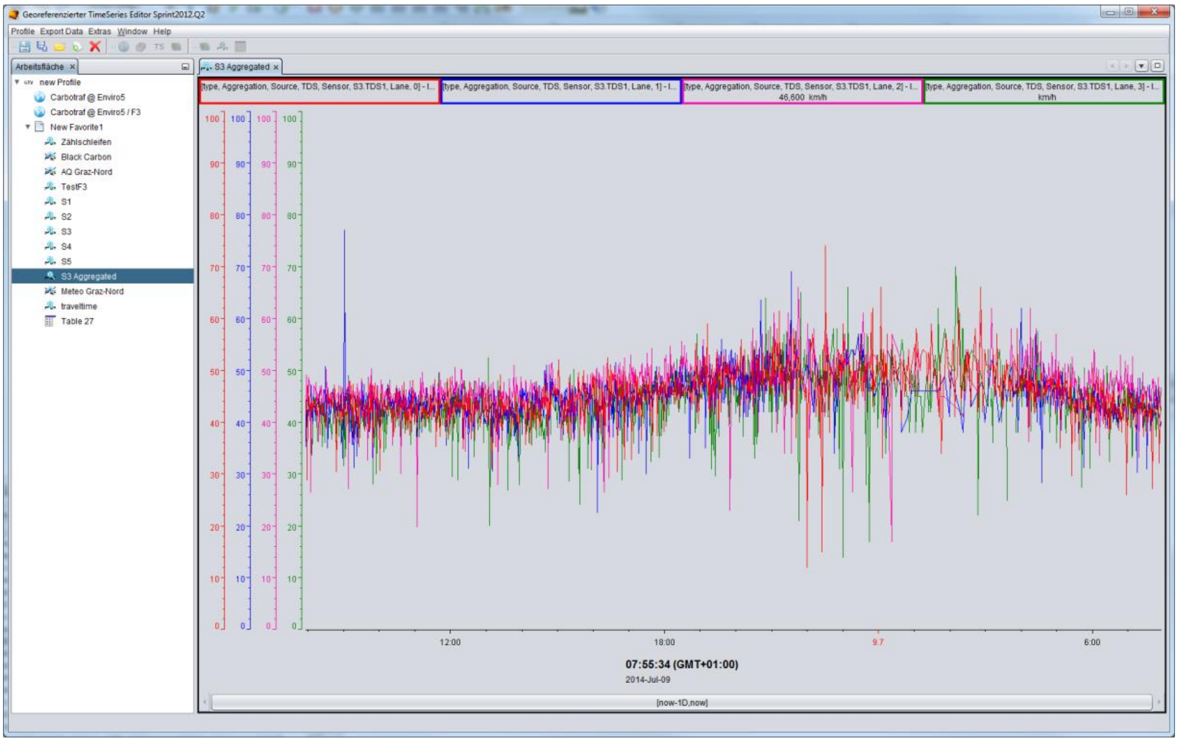

*Figure 2: Sceenshot of the GTE tool*

For users leaning more to the MS Office world an interface exists that connects to VBA. This can be used to insert time series into MSWord or MSExcel.

An encapsulation of gnuplot exists which can be used to script automated diagram creation.

It is also planned to add an interface that allows querying data in JSON-format which will allow easy integration of the result presentation with web browser based tools like D3.js[4]

## 7. Related Work

General concepts in Semantic Time Series Processing have been published by the authors in [1]. In [2], [3] and [4] simulation and modeling, community building and filtering of semantically enriched time series are described. Contributions for the research fields of ontology mapping and reasoning are presented in [5]. [6] describes the whole idea of a community building and tagging framework based on semantic time series.

Further related research field are: Time Series Processing, Semantic Web Technologies, but also applied research in Semantic Sensor Web, Crisis and Disaster Management, and Environmental Monitoring.

A current state of the art in time series analysis is provided in [7]. Somewhat related to our implementations are existing solutions for numeric computations (e.g. Octave in [8] and MATLAB in [9]).

In the area of Semantic Web there is always much interest for the integration of new data sources and services, such as Semantic Web Services which are described in [10]. Furthermore the community looks for the application of their technologies in various fields. Social media platforms (described in [11] and information retrieval systems [12]) are only two of the many examples.

[4] http://d3js.org/

Another relevant field of research from the Semantic Web area is Knowledge Management which can be subdivided into Knowledge Representation and Reasoning and is the subject of matter in [13].

Finally, [14] describes the idea of Semantic Sensor Web which is a very interesting application for our language. Also decision support systems, as introduced in [15], can be used in crisis and disaster management frameworks as well as in environmental monitoring (in [16]).

## 8. Conclusion / Summary / Outlook

We have designed and implemented a language that allows to process time series. We have created a simple concept that allows controlling the way this language processes data by using semantic information. We have created a concept, how this semantic information can be retrieved in a flexible way.

The approach of letting the algorithms being controlled by semantic values promises to shift the focus of the average user. Instead of concentrating on the “how” of the processing task the user can more focus on the “what” leaving the fine details of the processing algorithm to the system. This is an added value as the user can still write algorithms the “old fashioned way” without using semantics.

The chosen approach for retrieving semantic information definitely has the advantage of its universality. There is no a-priori assumption about how a system must work. We can adapt to virtually every existing system design. One disadvantage is that currently all semantic queries must be predefined at the server. Another disadvantage is that this approach is not ad-hoc compatible with standard interfaces which deal with semantic.

Related work in this field is very rare. Most of the used solutions use general solutions for numeric calculation such as the already mentioned GNU Octave and MATLAB. Another language, which is frequently used for time series processing tasks, is R. An overview of the language including usage for time series processing can be found in [17]. The only similar approach we could find until now, is the graphical models toolkit described in [18]. However, the approach is rather outdated and concentrates on the field of speech processing and the usage of time series combined with techniques of speech recognition. Therefore, the solution could not be used in order to solve our specific tasks.

We have already implemented F3 to work without semantic information. We also have implemented the retrieval of semantic information as this is also used elsewhere in the system. The next steps will be to implement the use of semantic information within F3.

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# The Analysis and Design of a Sustainable E-learning System for Business Intelligence Development

B Scholtz[1], M Esterhuyse[2]

## Abstract

The process of developing Business Intelligence (BI) dashboards is a complex task and has a steep learning curve. The complexity of the process stems from the need to integrate several disparate applications, each with their own learning curves. Traditional paper-based learning environments do not accommodate the differing learning paces of students in higher education. An e-learning system can be used to improve the flexibility and the sustainability of the learning system due to its adaptive nature. This study reports on a heuristics evaluation and a cognitive walkthrough of the process of the development of a BI dashboard at a South African university. The study also reports on an extant systems evaluation of e-learning systems supporting the development of BI applications and dashboards. The evaluation results are used to analyse and design a sustainable e-learning system.

*Key words: current learning process; e-learning; extant system evaluation; sustainability.*

## 1. Introduction

The gaps in the education level of South Africa is partly due to the country's social and political history [1]. There is therefore a need to improve the learning system in South Africa by moving from a traditional face-to-face teaching approach to an e-learning approach [3-7], which has been the focus of a paradigm shift in education [2]. An e-learning system can assist in improving a traditional learning system by providing advantages such as knowledge enrichment with functionality like blogs, wikis and forums; increased flexibility, accessibility and convenience; improved infrastructure; cross-platform access; enhanced study environments for students; low delivery costs; ease of updating content; collaborative learning and scalability [3,7].

Students studying Information Systems (IS) related fields such as Enterprise Resource Planning (ERP), extended ERP and Business Intelligence (BI) can also benefit from the use of e-learning approaches. BI is defined as a process of capturing, accessing, understanding, analysing and transforming raw data into actionable information in order to aid quality decision making and to improve performance [7]. Extended ERP is a business strategy that supports businesses in their utilisation of industry-specific sets of applications which may include BI as a component [8]. BI consists of various tools and technologies such as digital dashboards which is a visual tool aiding strategic decision-making [9]. The learning curve of developing BI dashboards is steep and students require a significant amount of programming experience [10]. An e-learning system can therefore assist with improving the flexibility of the learning process [22]. An e-learning system for BI development is therefore required, but designers of e-learning systems should strategically consider the long-term nature of an e-learning system as well as the quality of the system, so that institutions can be assured of the sustainability of these e-learning systems [12,13].

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Whilst several studies have investigated e-learning systems [14,15], research related to the learning process of BI development is limited, particularly with regards to the development environment and the components required for a sustainable e-learning system. This study provides a valuable contribution towards reducing the gap in the literature since it provides empirical evidence of suitable features of e-learning tools for BI that can be implemented in Higher Education Institutions (HEIs). The following section discusses literature related to e-learning and the sustainability thereof, in the context of BI development. This is then followed by a discussion of the research methodology and then by an analysis of the results. The recommendations and conclusions for the study complete the paper in the last section.

## 2. Sustainable e-learning systems for BI development

IS students are often required to enrol in BI courses as this is a crucial skill for IS graduates [15]. BI is a process involving the conversion of data into information and information into knowledge [16], and enables managers to better understand business contexts by providing access to real-time data that enables valuable insight into the business [17]. BI consists of various tools and technologies such as digital dashboards which allow managers to see meaningful patterns within the data that would otherwise be meaningless due to the abundance of data that is usually presented to the manager [9]. A dashboard acts like a “magnifying glass” of the organisation because of the ability it gives the users to focus on highlighted areas of a business in various forms which may also be drilled-down to allow the user to see more information [18]. Developing BI tools and technologies such as BI dashboards can be a complex task and studies have shown that only 24% of BI projects were considered successful [19]. The process of developing dashboards requires the developer to have substantial programming skills and experience within many application software environments to create even the most basic visualisations [11,20]. Therefore, students may find that it is quite a challenge to integrate a variety of data sources and scattered systems, each with their own business rules and learning curves [20].

A recent trend in the field of education is e-learning which has changed learning and teaching methods drastically [22]. E-learning is the convergence of learning processes and Internet technology which has become a favourable alternative learning method in education [23]. E-learning is an umbrella term used to describe all of the technologies and tools that have been introduced into the process of teaching and learning to create an improved learning process [24]. The two main components of an e-learning system are a course management system (CMS) and an assessment management system (AMS) [25]. The CMS handles learning content such as text, video, sound and pictures. In addition to this, the AMS evaluates the student’s knowledge capability based on what was learnt from the CMS.

In order to prevent the implementation of an e-learning system becoming a tool that just sits alongside institutional practices, it is necessary for a change in the culture of the implementing institution [11]. The sustainability of the e-learning system should be strategically considered by the institution with regards to the long-term nature and quality of the system [12,13]. According to Gunn [11], an e-learning system is considered sustainable when the following three conditions are met:

- **Proof-of-concept:** The e-learning system has been through a proof-of-concept stage and has been proved to be beneficial to teaching and learning in the long-term after having been implemented within a course;
- **Potential for adoption:** The e-learning system has proven potential to be adopted, and even adapted, for use beyond the original development environment, and;

- **Sustainable maintenance:** Maintenance, the use of and further development of the e-learning system does not stay dependent on the individuals that created it so that if their future contribution ceased, the future of the e-learning initiative would not be compromised.

A sustainably developed e-learning system aims to transform the current methods of teaching and learning, and the way in which HEIs function [12,13]. In the same way that e-learning systems should be sustainable, they should also promote sustainability. Sustainability is achieved by using e-learning systems to distribute learning material electronically, thereby eliminating the need to print learning material which is prevalent in the traditional learning environment [22]. E-learning can promote sustainability by enabling students to access the system from any location, thereby saving transportation costs [15,22]. Therefore, it can be deduced that e-learning systems should be both sustainable and promote sustainability.

The increase in demand at HEIs for e-learning initiatives has warranted the need to evaluate existing learning processes in order to ensure that an e-learning system is sustainably implemented to ensure its longevity [14], and the benefits associated with the e-learning system [26]. Three factors for designing effective and sustainable e-learning systems have been identified, namely the learners' self-efficacy, multimedia formats and interaction environments [27]. Learner characteristics such as self-efficacy needs to be identified and accounted for because it is necessary to understand the targeted users of the system. Multimedia formats can facilitate the creation of complex cognitive skills such as reasoning and inference. The ability for e-learning systems to adapt according to the individual user's needs is an important consideration.

A recent trend in learning approaches is gamification, which is described as the usage of game design elements in non-gaming contexts such as education [27,28]. Gamification incorporates game elements into a non-gaming software application to increase user experience and engagement [29]. It can be used to improve the participation and motivation of students to complete activities that may not previously have been attractive [27,28]. Game design elements may include the ability to rate activities, posing activities to students in the form of challenges and providing rewards or incentives for the students that complete the tasks and on the contrary, penalties or additional tasks for those who do not complete the tasks [27,29]. Learning is enhanced with gamification because the interaction time between the student and the content of the e-learning system increases substantially, the speed of browsing through courses increases and results are improved [30]. Instant feedback is an important aspect that gamification provides for students where they can observe the level of knowledge gained at the end of certain milestones, which can motivate them to improve [30]. It can be deduced therefore that gamification can support the factors of multimedia formats and interaction environments which are recommended for a sustainable e-learning system. The development of BI dashboards in educational environments can be supported with the implementation of a sustainable e-learning system that can help students resolve the problems that they may experience in the learning process [31].

## 3. Research Methodology

The purpose of this paper is to investigate and report on the design of a sustainable e-learning system which can support the process of developing BI dashboards. The main research question of this paper is *"How can a sustainable e-learning system be designed to support the current learning process of developing a BI dashboard?"*. In order to address the main research question, two research objectives need to be realised, namely:

RO1: Analyse the problems of existing BI learning processes; and

RO2: Determine the suitable components of a sustainable e-learning system for BI development.

In order to answer the research question, a case study approach was adopted and the current learning process of developing dashboards at a South African HEI was analysed. The process was investigated and described by means of a cognitive walkthrough. A cognitive walkthrough is a usability evaluation method in which evaluators work through a series of tasks in order to accomplish a greater task and ask a set of questions from the perspective of the user [32].

Requirements for a software system such as an e-learning system can be analysed and determined by observing and evaluating the current processes within an organisation by conducting a heuristics evaluation [28]. A heuristics evaluation is a method that aims to find usability problems that are identified as issues for the user by providing a set of guidelines with which the user compares the interface or process with in order to find the usability problems [34]. Heuristics evaluations can be used in both the design and evaluation phases of software development and can also be used to evaluate paper-based designs before creating functional prototypes. Human-computer interaction (HCI) studies show that using three to five evaluators are sufficient in determining usability problems [34]. Therefore once the cognitive walkthrough was completed, a heuristic evaluation took place in order to derive the design for the proposed e-learning system. The evaluation of the current learning process of developing BI dashboards was conducted using three participants, all of which are postgraduate students in the department of Computing Sciences (CS) at the Nelson Mandela Metropolitan University (NMMU). The ERP system used in order to develop the BI dashboard is SYSPRO which is a popular ERP vendor in South Africa [35].

The procedure of heuristically evaluating the current processes may be supplemented with the comparative evaluation of extant systems [36]. An extant systems evaluation can be used to identify suitable features for the “to-be” processes, automated by the proposed system [32,36]. From this it can be deduced that heuristics evaluations of existing processes and e-learning systems can be used for requirements analysis and design of new e-learning systems. An extant systems’ evaluation of e-learning systems was also undertaken. The insights gained from the evaluations of these systems are used to identify best practices and to determine which features would be suitable for incorporation into the design of a sustainable e-learning system for BI dashboard development [32,36].

## 4. Results of the analysis of the current learning process

The results of the cognitive walkthrough revealed that the process of developing BI dashboards for BI students involves five high-level processes which are executed in several disparate systems (Figure 1). Participant 1 was inexperienced with regards to the development of BI dashboards, Participant 2 had some experience with developing BI dashboards and Participant 3 had substantial experience with developing BI dashboards. By using participants with varying experience levels, it is possible to discover a full range of potential problems that BI students may discover.

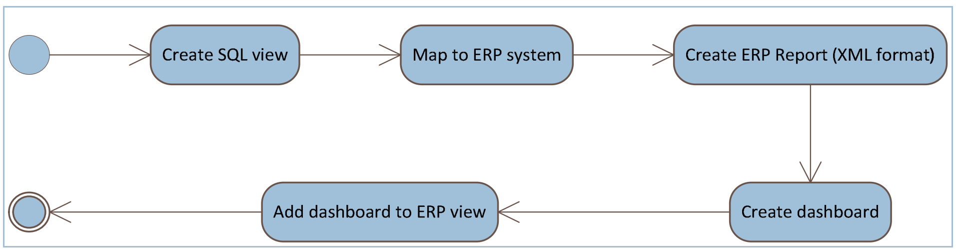


*Figure 1: Activity diagram of the current process of developing a BI dashboard*

At the beginning of the evaluation, the participants were provided with task instructions and a questionnaire. The participants were required to complete this questionnaire whilst developing the dashboards. The questionnaire used in the evaluation consisted of both open-ended and closed-ended questions. The questionnaire comprised of a severity scale where participants had to identify and rate the problems that they faced in the development process. The severity scale ranged from a severity rating of 1 to 4, with 1 being a cosmetic problem; 2 being a minor problem; 3 being a major problem and 4 being a usability catastrophe. Participants were encouraged to consider Nielsen's heuristics [38] when identifying problems with the development process.

It is clear that some participants found problems with the same tasks such as the problem of *"Adding the developer tab in Xcelcius was an issue"* as discovered by Participant 1 and Participant 2 (Table 1). All three participants identified the same issue, which was *"Not enough detail when converting the report to export in XML format"* and gave it a rating of 3. None of the problems identified were rated "Cosmetic" (rating 1). There was, however, a rating of 4 allocated to one of the problems identified by Participant 1, indicating that there was a "usability catastrophe". The overall theme of the problems identified was the *"Insufficient task instructions"*. Participants struggled to complete tasks within the process due to the lack of detail in the instructions given to them.

| Problem Number | Description | Task | Severity Rating | | |
|---|---|---|---|---|---|
| | | | P1 | P2 | P3 |
| 1 | Task instructions do not properly explain all of the steps in creating the SQL view | 1 (Creating a SQL view) | 3 | | 2 |
| 2 | Instructions are confusing because where it refers to "length", it is meant to refer to "edit pattern" | 2 (Adding the data dictionary in SYSPRO and editing columns) | 2 | 2 | |
| 3 | Need tasks to be more broken down to make it clearer for the user | 3 (Whole SYSPRO component) | | | 2 |
| **4** | **Not enough detail when converting the report to export in XML format** | **3 (Converting report to an XML file)** | **3** | **3** | **3** |
| 5 | Adding the developer tab in Xcelcius was an issue | 4 (Enabling the Developer tab) | 4 | 3 | |
| 6 | Image is not clear for creating indicators for the variance column | 4 (Indicators for variance column) | | | 2 |
| 7 | Could not find the data manager and needed assistance | 4 (Adding a map connection with usage refresh) | | 2 | |

*Table 1: Problems discovered by participants in heuristics evaluation*

A post-task questionnaire was given to the participants which was based on the NASA-Task Load Index (TLX) developed by Hart and Staveland [39]. The TLX evaluation determines the workload required by a certain process or system. Participants were required to rate the frustration level, effort, performance, temporal demand, physical demand and mental demand on a 5-point Likert scale with 1 being either very low or very poor and 5 being either very high or very good.[3]

The analysis of the results of the TLX evaluation (Figure 2) indicates that two of the three participants rated Effort positively with a score of 4 (80%). From this it can be deduced that the process of developing a dashboard requires a high amount of effort. The average score of the frustration level experienced by the participants ($\mu$ = 2.67) is neutral. Participant 1 rated the mental demand of the task positively, with a score of 4 out of a possible 5. It can be inferred that the task of developing a BI dashboard can be mentally demanding. One of the participants stated that it was challenging to work with new software but the instructions were vague.

[3] The following statistical ranges were applied: negative [1 to 2.6), neutral [2.6 to 3.4] and positive (3.4 to 5].

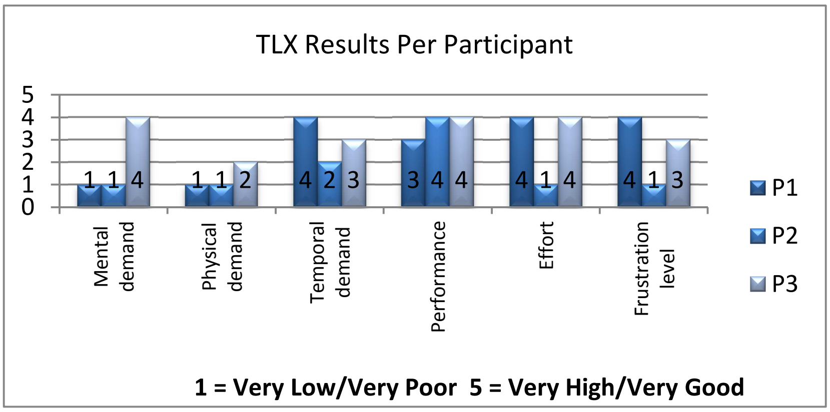


*Figure 2: TLX results per participant*

## 5. Design of sustainable e-learning system

The cognitive walkthrough revealed several problems with the existing learning process of the NMMU. In order to identify best practices for e-learning systems, an evaluation of an extant system took place. The system evaluated was the Obami platform, which has features such as: blogs, media galleries, resource repositories to newsfeeds, online chat, messages, portals, assignments, events and widgets. Obami also has a Flash Games portal where assessments test users' logic, memory, maths, language and typing skills [39]. Obami is an e-learning web-based platform that uses a gamification approach and connects users in a virtual learning environment (VLE) and is considered a social learning platform because it encourages collaboration and uses gaming aspects [40].

The literature review, usability evaluations and extant systems evaluation revealed several components required for the design of a sustainable e-learning system which can be used for the development of BI dashboards (Figure 3). The system's functionality must promote long-term benefits, be adaptive and flexible and have maintenance requirements that are not dependent on an individual [11]. The basis of the e-learning model consists of two components, namely the course management system (CMS) and an assessment management system (AMS) [25]. The features that the sustainable e-learning system must support are demonstrations, games, assessment and incentives based on gaming performance.

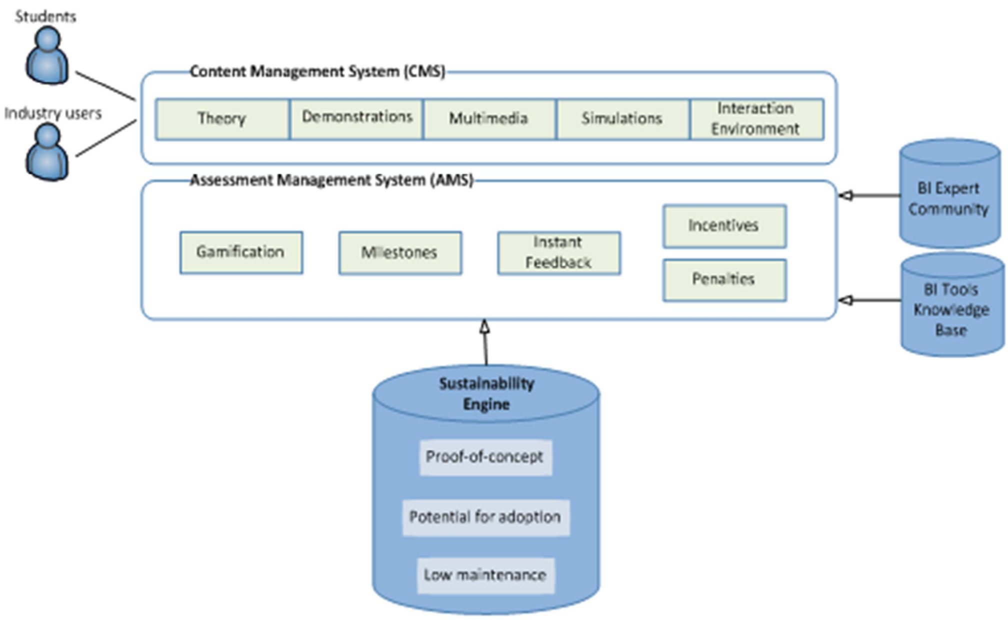


*Figure 3: Sustainable e-learning model for BI development*

## 6. Conclusions and recommendations

This study primarily aimed to report on the analysis and design of a sustainable e-learning system for BI development. A heuristics evaluation of the current learning process and an extant systems evaluation of e-learning systems supporting the development of BI applications and dashboards is reported on. Whilst the heuristics study was undertaken with a seemingly small sample of students at NMMU, the results are still very useful in identifying and understanding the problems with the current process of developing dashboards.

The results obtained from the study show that there are problems that exist with the current learning process that can be improved with the implementation of a sustainable e-learning system using gamification elements. The study provides a valuable contribution to improving the education of BI dashboard development and improves e-learning implementations in a sustainable and long-term way. However, further research needs to be conducted on the implementation of the model for sustainable e-learning as well as suitable development tools. Additional empirical research also needs to be conducted regarding the usefulness and usability of the proposed model after implementation.

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# A Tool for Simulating the Spread of Invasive Mosquitoes

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## Abstract

There are many concerns about the spread and establishment of exotic mosquito species in Europe, some of which are highly competent to transmit pathogens. The fast spread of some invasive mosquito species, e.g. the Asian bush mosquito, might be explained by a combination of natural dispersal and human transport. Therefore, the aim of this study was the development of a software tool that is capable to model the local spatial-temporal spread of invasive mosquitoes through natural dispersal and their transportation through human transport via cars. The evaluation of the tool shows that it is capable to simulate the spread but also reveals the need for more biological data about invasive mosquito species.

## 1. Introduction

Mosquitoes can cause significant nuisance and are important vectors of several pathogens [8]. Therefore, this group of insects was and is subject of research all over the world, but especially in areas with health concerns due to mosquito-borne diseases, e.g. Africa [5]. Nevertheless, in view of the worldwide range expansion of several mosquito species, some of which are highly competent to transmit pathogens, the interest in this research topic is also increasing in other geographical areas [2]. Especially climate change and globalisation are considered to facilitate the spread and establishment of these species [2,27].

There are many concerns about the introduction and establishment of exotic mosquito species in Europe, some of which are highly competent to transmit pathogens [16]. The worldwide most important invasive mosquito species is the Asian tiger mosquito (*Aedes albopictus*). The species is known to be a highly competent vector of several pathogens and is considered to be the vector, which caused the autochthonous transmission of Chikungunya virus [6,19] and Dengue virus [4,14,20] in Southern Europe. Surveillance studies at potential introduction sites in Germany identified motorway service stations as important gateways [1,10,18,26]. Individuals of the Asian tiger mosquito are considered to enter cars or trucks in Southern Europe, where the species is established since several years and transported by transit traffic.

The fast spread of another invasive mosquito species in Germany, the Asian bush mosquito (*Ochlerotatus japonicus*), highlighted the necessity of dispersal analyses and the demand for modelling tools to predict the spread of invasive mosquito species. The species was firstly detected in the year 2008 in Southern Germany at the border to Switzerland. During the following years, the species was found to spread fast in Southern Germany and additional populations were detected in Northern Germany (reviewed by [11]). The fast spread of the Asian bush mosquito might be explained by a combination of natural dispersal and human transport [25]. The distribution and habitat preference of invasive mosquitoes were analysed in several studies in Europe. At least for the Asian tiger mosquito there are several habitat models on the basis of climate data and landscape parameters, which give information on the actual and potential distribution in Europe [3]. However, there are only few studies on the spatial-temporal spread of invasive mosquito species via traffic

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[23]. This applies in particular to the small scaled, regional spread through natural dispersal and human transport (e.g. cars). Information on the potential spread of invasive species especially can help to develop an adequate surveillance program and control strategies.

Therefore, the aim of this study was the development of a software tool that is capable to model the local spatial-temporal spread of invasive mosquitoes through natural dispersal and their transportation through human transport via cars.

## 2. Mosquito Tool

A software tool for predicting a possible exposure of mosquitoes has to take the passive transport by vehicles as well as the active dispersal of mosquitoes into account. These two processes take place on different scales in time and space. Such multi-scale modelling is often used to model physical phenomena [24]. Hoekstra et al. [7] studied the modelling of complex automata by coupling cellular automata with different temporal and spatial scales. A framework for modelling ecological systems as multi-scale models has already been proposed [21,22]. The theoretical background of this framework models complex spatial processes on different scales by so-called hierarchical asymmetric cellular automata, which allow the coupling of cellular automata (layers) with different spatial and time scales as well as restricted interactions between layers. The *Mosquito Simulation Tool* (*MoSiTo*) presented here follows this approach. It consists of two automata: the *MosquitoCA* on a spatial fine-scale layer and the Tool *VASim*, which models the dissemination of mosquitos by traffic on a coarse spatial level.

Both components of *MoSiTo* have been prototypically implemented in Python as a Plugin for the geographic information system QGIS (version 1.8 and 2.x, resp.) and can also be used independently from each other.

### 2.1. Traffic network Tool *VASim*

Tourist traffic from regions with established mosquito populations are considered as a potential reason for mosquito dispersal. The traffic network tool *VASim* ( [17]) models this transport.

The transport can be viewed as a generalized (asymmetric) cellular automaton [21] where the cells represent *starting points*, *stops* (at resting places, motorway stations), and *destinations of vehicles*. The neighbourhood relation is determined by a traffic route from the starting point to the destination with stops in between.

The movement of cars on a traffic route and the release of mosquitos at stops is modelled by the cells' state: The cell at the starting point of the route is initialized with a *vehicle object*. Each *vehicle object* (*VO*) represents a set of cars, which traverse the same route. It is characterized by parameters to describe its behaviour:

- The minimal distance between *stops* ($d_{min}$) and its *mileage* determine where the *vehicle object* will *stop* and possibly release mosquitoes.
- The distribution of the number of mosquitoes inside the *VO* at the start of the simulation and the probability for *mosquitoes leaving* the vehicle at every single *stop* determine how many mosquitos will be initially in the *VO* and leave it at a *stop*.

Beside the information about the *VO*, the cell stores the distance to the prior cell (attribute *length*) and the number of mosquitoes, which have been released (attribute *mosquitoes*). The behaviour is modelled as transfer step and update step:

- The transfer step moves the *VO* information to the next cell:

```
cell[i+1].VO = cell[i].VO
```

- The update step describes the release of mosquitos inside a cell:

```
cell[i].VO.mileage += cell[i].length
If cell[i].VO.mileage > random_km(cell[i].VO.d_min):
     mosquitos_out = random_Mosquitos(cell[i].VO.inside)
     cell[i].mosquitos +=mosquitos_out
     cell[i].VO.inside -= mosquitos_out
     cell[i].VO.mileage = 0
```

The `random-functions` allow random deviations from the minimal distance between stops of a vehicle and from average number of mosquitos released.

Hence, a traffic route defines a one-dimensional cellular automaton. As it is possible to assign an arbitrary number of routes to one simulation scenario, a more complex neighbourhood relation is possible.

For initialization of *VASim* at least one traffic route between arbitrary starting points and destinations and a list of possible *stops* along the route (rest areas, service stations) must be specified as xml-documents. *VASim* extracts the cell attributes and topology from these inputs. The documents can be generated by the web services OpenRouteService (http://openrouteservice.org) and the Overpass API (http://www.overpass-api.de/), which are based on OSM XML OpenStreetMap data. The vehicle objects at the starting position of each route are initialized according to user-specified probability distributions for the initial number of mosquitos inside and the release of mosquitoes.

So far *VASim* does not model time explicitly. In one simulations step the *VO* is transferred from one cell to the following - the real time, which corresponds to this transition, depend on the distance between the *stops*, i.e. *length* of the cells.

## 2.2. MosquitoCA

The *MosquitoCA* [13] models the autonomous dispersal and the possibility of establishing a population as a fine-scale 2-dimensional cellular automaton with a regular grid of cells. The dynamic is based on the static data about the area using the Corine landcover information (http://www.eea.europa.eu/) and integrates climatic information about the regional temperature.

Each cell is characterized by its habitat quality factor ($hab \in [0,1]$), the number of its adult mosquitoes (*adults*) and mosquito larvae (*larvae*), which vary during the simulation. The maximum mosquito or larvae capacity of cells depends on the habitat quality. Hence the optimal capacities of adult mosquitos ($A_{max}$) or larvae ($L_{max}$) are reduced by the habitat quality factor. The size of the cells depends on the flying range of the mosquito species in the given time step.

The dynamics of the number mosquitoes per cell depends on the mortality rate ($m$), reproduction rate ($r$), the length of a gonotrophic cycle ($u$), i.e. the time span of alternate feeding and laying of eggs, and the larvae's development rate $d$. $u$ and $d$ depend on climatic factors (temperature) and are defined as in [15]. The variable $P$ describes the length of a time step in the simulation and corresponds to one day.

The default dynamic of the cellular automaton is based on rules for reproduction, mortality, and dispersion based on the MALCAM model published by [15] with some minor improvements concerning the different habitat qualities. The dynamic of adults and larvae inside each cell is determined by

$$larvae(t) += P \cdot (adults(t-1)\frac{r}{u} - d \cdot larvae(t-1)) \cdot hab \cdot (\, 1 - \frac{larvae(t-1)}{L_{max} * hab})$$

$$adults(t) \mathrel{+}= P \cdot (d\ larvae(t-1) - m\ adults(t-1)) \cdot hab \cdot \left(1 - \frac{adults(t-1)}{A_{max} * hab}\right)$$

Alternatively to this predefined dynamics inside each cell, user specified rules can be specified and used in *MosquitoCA*.

For each cell the number of leaving mosquitos is computed as in [15] by

$$leaving(t) = adults(t) \cdot \frac{P}{u}.$$

We simplified the MALCAM model for the entering of cells: the flow of mosquitos from cell[i] to cell[j] is computed by cell[i].leaving(t) weighted by the normalized habitat quality factor of cell[j]:

$$cell[j].entering(t) = cell[i].leaving(t) \cdot \frac{cell[j].hab}{\sum_{k\ neighbor\ of\ i} cell[k].hab}$$

The simulation of *MosquitoCA* results in a map, which shows the distribution and abundance of mosquitoes in the cellular automaton.

## 2.3. Coupling

*MosquitoCA* and *VASim* are only loosely coupled: In a first step, *VASim* computes the *initial occurrences of mosquitos* at the *stops* along the routes for a given set of routes and *vehicle objects*. These *stops* comply with cells of the *MosquitoCA*. This allows to check, whether the suspected traffic flows are able to transport mosquitos that far. Starting from these *stops* as initial places, *MosquitoCA* computes the *dispersal* of mosquitoes.

In the next version of *MoSiTo*, we plan to integrate a refined time concept: as the survival rate of transported mosquitos and the behaviour of the mosquitos depend on the time of the day, in future version *VASim* cells will transfer mosquitos numbers tagged with a time stamp information.

### Evaluation scenarios

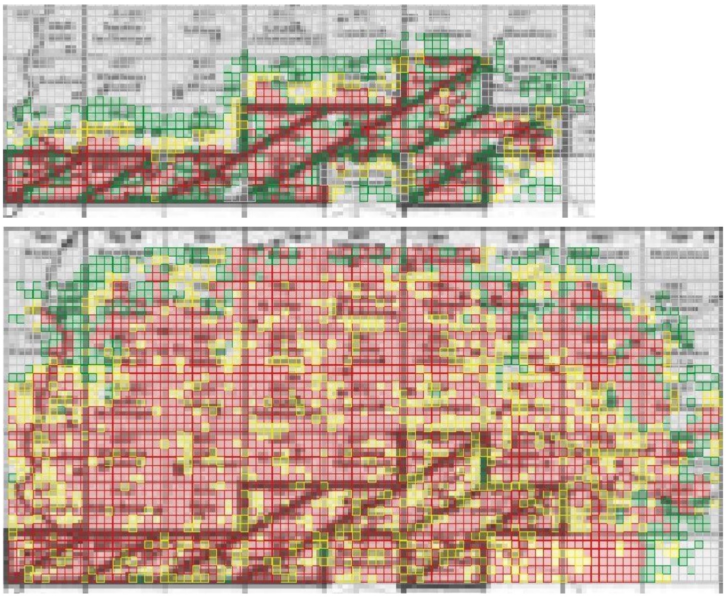
For ensuring the correct implementation of the underlying models, the *MoSiTo* layers *MosquitoCA* and *VASim* have been successfully tested separately with virtual scenarios. Due to the limited availability of data about the detailed behaviour of neozoa and their spread, we based our real world evaluation on existing publications.

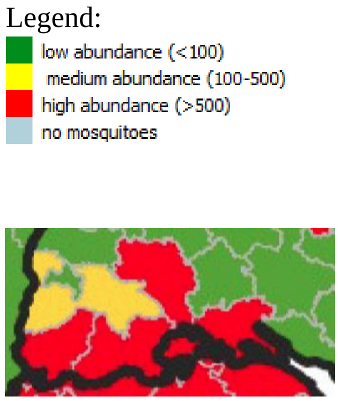
## 2.4. Scenario 1: Spread of Mosquitos

The fast spread of the invasive Asian bush mosquito (*Ochlerotatus japonicus*) in Germany highlights the necessity of dispersal analyses and the demand for modelling tools to predict the spread of invasive mosquito species. The species was firstly detected in the year 2008 in Southern Germany at the border to Switzerland. During the following years, the species was found to spread fast in Southern Germany (reviewed by [11]). This spread is probably due to natural dispersal and, therefore, is a good case study to evaluate the *MosquitoCA* tool.

Huber et al. [9] presented a map where the Asian bush mosquito has been found in 2011. Their study only included punctually data. Therefore, raster grids cells in a resolution of a topographic map (1:25.000, 18km×10km) were defined as colonized, if at least one positive point lay in the respective grid cell. As this scale is much to coarse for a detailed simulation, we initialized the automaton with 135×55 cells of size approx. 0.01×0.01 square degree (1.1km×1.1km) and focused to the infested area in the south of Baden-Württemberg, using a daily rates of 0.1 (mortality *m*) and 1.0 (reproduction rate *r*), and a constant temperature of 20°C. The habitat qualities of the cells were derived from the Corine landcover data 2006 on a 250m×250m grid. Based on expert knowledge the landcover types were classified as “not suitable”, “medium suitable” and “very suitable” and each cell was assigned a habitat quality of 0.01, 0.5 or 10, resp. As the cell size of *MosquitoCA* and the Corine grid differed, the landcover in the centre of the cell determined its habitat quality.

In order to start *MosquitoCA* with the map of 2011, about 20 cells in the infested area were initialized with 1000 mosquitoes and 5000 larvae and (pre-)simulated for 25 time steps (days). Figure 1 shows the occurrence of mosquitoes and after the pre-simulation phase with 2011 distribution data [9]. The infected areas from 2011 show a medium to high occurrence of mosquitoes. Below the simulated occurrence after about 120 time steps can be seen with a map section of the 2014 distribution.






*Oc. japonicus* distribution 2014, source: http://www.ecdc.europa.e

*Figure 1: Simulated mosquito occurrences after pre-simulation (left, upper) and after 120 timesteps (left, lower). Positive Ochlerotatus japonicus raster grids in 2011 [9] in a resolution of a topographic map (1:25.000, 18km×10km) are edged dark gray (left, upper). Small sketch in the right show the observation from Ochlerotatus japonicus in this region from 2014.*

Our modelling results showed a much faster spread of *Ochlerotatus japonicus* compared to the observed spread in the real-world. This might be explained by different reasons: 1) the input data do not have a very good quality and are only based on a very broad meshed mosquito survey. Colonized areas with very low *Ochlerotatus japonicus* might be not detected. Therefore, the currently published distribution maps might not reflect the actual distribution of the species. 2) Furthermore, our model use several assumptions and simplifications, e.g. each cell have the same, relatively high temperature (20°C) and there are no temperature variations in space and time, which significantly accelerate the spread in our model. Therefore, the incorporation of upper and lower development temperature thresholds might give a more realistic picture.

## 2.5. Scenario 2: Transport and Spread

Further *Ochlerotatus japonicus* foci were detected in Northern Germany (reviewed by [11]), which appeared to be too far away to be explained by natural dispersal, but might be explained by human transport via car traffic [25]. Therefore, this scenario 2 was used to evaluate the *VASim* tool in the first place. Beyond that, subsequent simulation of the spread with the tool *MosquitoCA*, starting from service stations might explain findings of the main traffic routes.

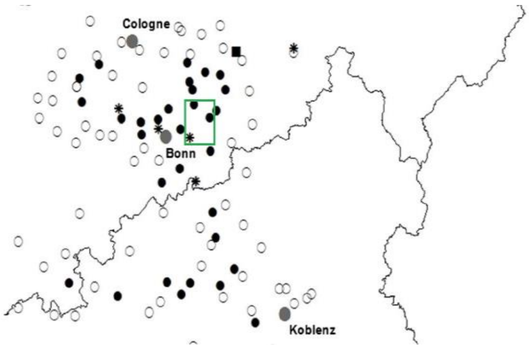



*Figure 2: Mosquito findings in [12], dark points: presence of Ochlerotatus japonicus. Green frame: location of scenario 2*

In scenario 2, the object of investigation was the possibility of an introduction of mosquitoes from southern Germany by traffic which is passing the motorway junction Weilheim (nearby Heilbronn and the most northern point of *Ochlerotatus japonicus* observation in the federal state Baden-Württemberg [9]) and going north in direction to motorway junction Hilden (nearby Düsseldorf). North bound motorway routes in this area were generated by OpenRouteService and service stations along the routes were determined by the web service Nominatim. The "fastest route" via the motorways A67 and A3 crosses the north eastern region of further *Ochlerotatus japonicus* foci [12].

*VASim* was initialized with three routes having each 1000 *vehicle objects*. Each *VO* was meant to represent a set of cars with an average of 60 *mosquitoes* per *VO*, an initial, uniform distributed *initial mileage* of 50 up to 250 km, and a *minimum distance between stops* of 200 km. *Figure 3* shows the number of *VOs* ("Cars") and the final number of exposed mosquitos per station. The stations have been sorted by their (Euclidean) distance from the start at Weilheim. *Figure 3* shows that the number of released mosquitos correlates linearly to the number of cars. Despite the uniform distribution of the initial mileage, waves of resting cars become obvious.

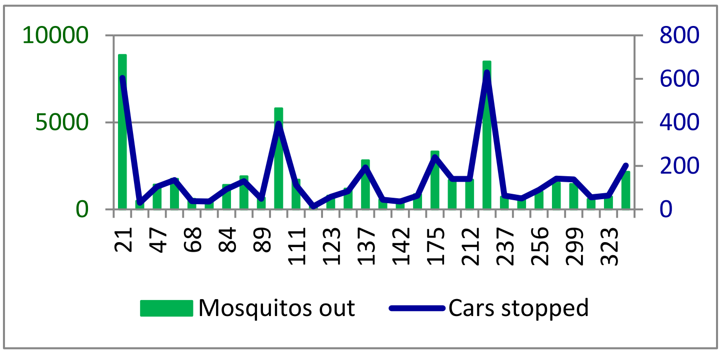



*Figure 3: Distribution of stopping cars (right axis) and released mosquitoes (left axis) per stations. The X-axis shows the distance of the stations to the starting point at Weilheim.*

The *Ochlerotatus japonicus* observations from [12] were located by manually georeferencing the sketch (*Figure 2*). The resulting map was validated using Open Street Map data locations of cemeteries.

Figure 4 shows the modelling results of scenario 2 produced with the *MosquitoCA* tool. For the service station Siegburg West at km 299, an exposure of 1460 Mosquitos was computed by *VASim* and simulated by *MosquitoCA* in order to prove, if the nearby findings at locations in the north, east and south-west can be attributed to exposures at Siegburg West. Each of these positive sites has a distance of about 5 km. With the parameters of the scenario, Corine landcover data with a resolution of 100m×100m and nearly equally sized cells (0.0015×0.0015 square degrees), we found, that only the observations in the eastern location can be explained. Figure 4 shows the simulation after 100 and 200 simulation steps.

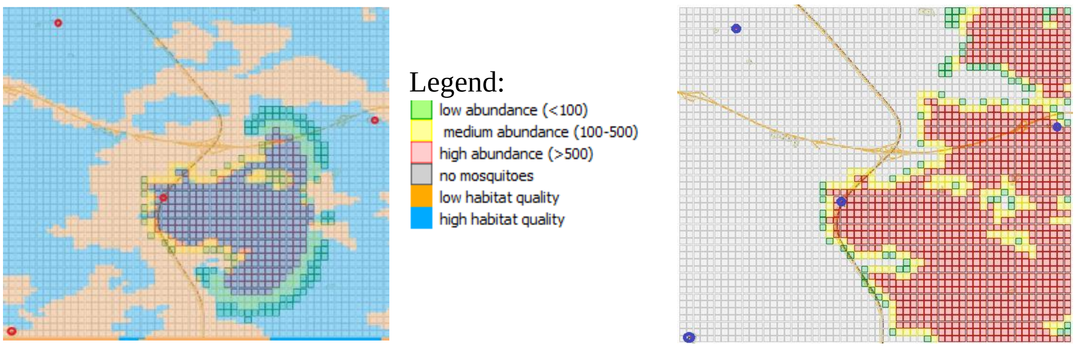



*Figure 4: Simulation starting at station Siegburg West after 100 (left) and 200 simulation steps (right). In the left picture, a map of habitat quality is shown in the background. Due to land use barriers, the dispersal is only directed eastwards.*

As stated above, the tools of *MoSiTo* are only loosely coupled and communicate asynchronously via data files. As a next step, it is planned to allow a tighter and timed coupling between the two layers, which will also allow the integration of seasonal changes in traffic flows as well as in the *mosquitoes' survival* conditions into the model.

## Conclusion

The research on invasive mosquito species predominantly focus on static information about the recent and future distribution based on environmental data and lacks studies and tools to predict and understand the spatial-temporal spread especially on the regional and local scale. The tool *MoSiTo* with its layers *VASim* and *MosquitoCA* is the first approach, combining the natural dispersal and the transportation through human transport via road traffic. From the vector ecologist's perspective, the tools can help to understand the historic dispersal of exotic mosquito species. However, the ultimate objective of this project is the establishment of a tool, which allows predicting the future spread and distribution of the exotic mosquito species. This tool offers extensive application possibilities, e.g. an exact geographic definition for the design of mosquito surveillance or control programs. The next steps in this ongoing project are the evaluation of the system by real world scenarios as well as the enhancement of the layers by a refined concept of time.

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# Towards a semantic framework for wildlife modeling

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### Abstract

In this paper we present work in progress for developing a semantic modeling system for wildlife monitoring, management and conservation. Based on a Greek NGO experience in large carnivores conservation in the mountain ecosystems of northern Greece, we present a generic architecture for wildlife information fusion, sharing and reuse. Our framework employs ontologies for representing the key domain concepts and their relationships, and applies them for integrating sensory information from GPS/GSM animal tracking devices, along with other field data and habitat suitability models.

## 1. Introduction

Integrated environmental modeling deals with modern environmental problems, decisions, and policies. Computer tools can serve as enablers, allowing the environment to be represented in a holistic way [1]. Among the major challenges for integrated environmental modeling and decision support tools, Laniak *et al* [1] identify their capacity to exhibit (a) adaptive decision making, i.e. to be able to "*learn as we go*", and (b) seamless access to environmental data, with an increased capacity of interoperability at a conceptual level. All this is in line with the vision of semantic environmental modeling, introduced by Villa *et al* in [2], and hints to a *knowledge-driven approach* to environmental modeling that employs ontologies for expressing model statements.

The work presented here introduces an adaptive and interoperable decision support system for modeling large carnivore habitat that employs ontologies for integrating animal tracking data with ecological niche modeling. Employing semantics for representing knowledge encapsulated in the domain, either as evidence (data) or as models interpreting the system behaviour, the framework may improve decision in wildlife management, and uses sensory information to adapt to ever-changing environmental conditions, while at the same time maximizing the capacity for data and model reuse.

The paper is structured as follows. Section 2 presents some background on the case study, the project supporting this work and its challenges. Section 3 presents system goals and users, and in Section 4 system components are introduced. The paper concudes with a short discussion in Section 5.

## 2. Case study: From animal tracking data to adaptive decision support

*Callisto* is a Non-Governmental Organization operating in Northern Greece, dedicated to the study, conservation and management of populations and habitats of large carnivores and other endangered fauna species. Over the past 10 years, Callisto has been active in the Pindos, Rodopi and Gramos

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mountains, supporting conservation of the brown bear *(Ursus arctos)* population which is the last stronghold of the species at its southernmost range in Europe, with 350-400 individuals in Greece. During all these years of activity, Callisto has collected an invaluable amount of monitoring information on large carnivores (bears, wolves) that have been used in several projects co-funded by the European Commission [3]. Callisto uses GPS/GSM collars, IR photo-traps and/or transects to identify animal activity and presence.

The ALPINE project, co-funded by the Greek Secretariat of Research and Technology, aims at enhancing this approach by developing low-cost, low-power sensor network solutions that can be used by Callisto for wildlife monitoring. While details on the sensor architecture are outside of the scope of this article, this has been seen as an opportunity to investigate animal monitoring data fusion methods, and develop new tools that enable interoperability and adaptive decision support.

One of the ALPINE project case studies deals with the human-bear interaction in the case of the Egnatia highway, which crosses the Pindos mountain range in northern Greece, an important habitat for brown bears. The Egnatia highway construction has affected bears in several ways: population structure, movement, foraging and breeding patterns have changed due to the destruction of natural habitat. Additional pressure was created by disturbance along the highway, which forced bears to re-adapt to a human-shaped landscape within their original habitat. Furthermore, traffic fatalities involving bearstrying to cross the highway have increased public concern about both bear conservation and human safety. As a result, a bear-proof fence has been installed along 130 km of the highway.

Our case study provides a challenging problem for integrated modeling that calls for both regular re-assessments and adaptive decision support. We aim to dynamically integrate animal tracking data (originating from sensor networks) with state-of-the-art ecological models to assess human-bear interactions. Our system aims to make effective use of semantics for annotating animal tracking streams, along with background data and domain models to analyze them, and eventually produce maps and reports. Such a scientific workflow will be run as required when new data streams arrive from sensors. Capturing the semantics of environmental information in the wildlife domain is one of the key challenges of this work, in order to exploit existing and new resources, to annotate information connected with movement patterns, ecological requirements of wildlife species (bears, wolves), to represent knowledge that can be interpretable by both humans and computer applications, and to simplify the use of automated reasoning in data management tasks.

## 3. System goals and users

The *ALPINE system for wildlife modelling* (hereafter, ALPINE for short) aims to demonstrate how live streaming data from animal tracking sensors can be effectively combined with geo-statistical analysis models, in order to assess habitat suitability, and to quantify the risks of wildlife interaction with man-made infrastructures. The overall system architecture is presented below in Figure 1, and consists of three layers. First is the *data layer* that incorporates animal tracking data, with eco-geographical field data and infrastructure networks. Second, the *integrated modelling layer* employs statistical, geospatial and Bayesian models for ecological niche factor analysis. Third, the *presentation layer* generates maps and reports with the system results.

The system is intended for scientists who aim to answer questions related to habitat suitability and wildlife-human interactions. Indirect users include policy makers, the industry and other societal sectors who are interested in such studies. The ALPINE system enables scientists to hook up sensor data streams coming live from sensors with geographical information and build scientific workflows that enable integrated modeling studies. User requirements are:

a. minimizing human involvement in data preprocessing and manipulation, especially as new data arrive from sensors;

b. easing model re-runs, as new data arrive; and

c. providing tools for exporting results in different formats.

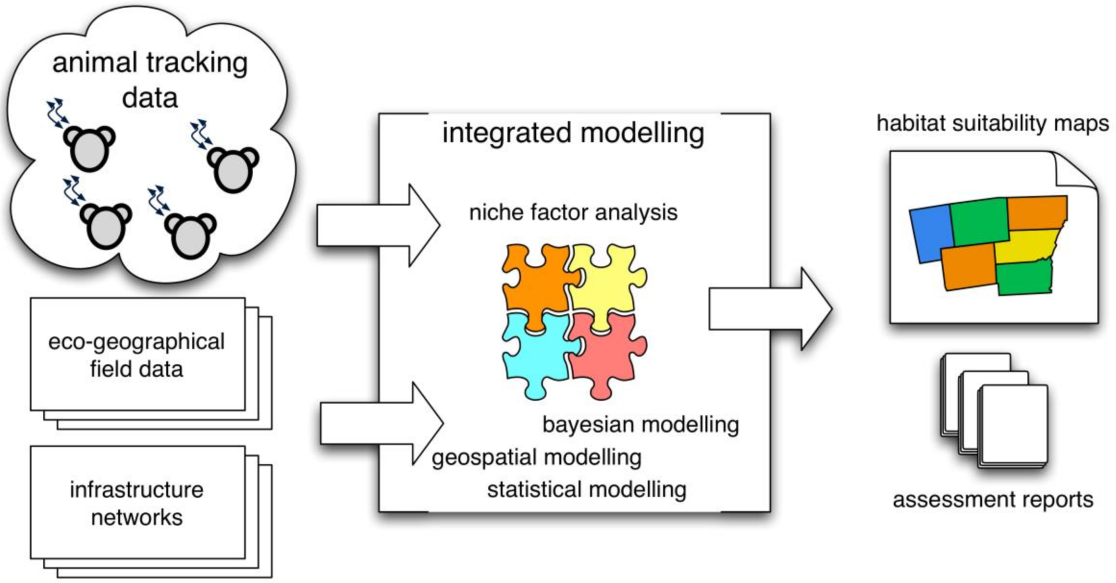


*Figure 1: The ALPINE architecture for wildlife monitoring*

## 4. System components

### 4.1. Evidence from sensor networks

Coupling models with data is a common problem that most scientists face, and e-science tools for integrating models and data came as a remedy that enables the mechanics of integration. Integrated modelling frameworks and scientific workflow engines, as Kepler (Ludäscher *et al.* 2006), OpenMI (Knapen *et al.* 2013), OMS (David *et al.* 2013), or Bioma (Donatelli *et al.* 2014) help scientists with the technical task of linking models to create compositions of different kinds, i.e. workflows that may involve numerical integration, parameter estimation, sensitivity analysis, execution on computer grids, or visual analysis tools. Integrating sensor data with integrated modeling frameworks and/or scientific workflow systems "*presents technical challenges that are difficult for scientists to overcome*" [9], due to the heterogeneity of the data streams and the technologies involved. Sensor data may arrive directly as streams, or become available from archives. In all cases, simplifying access via reusable data protocols and making data discoverable through rich annotations remains a challenge. To this end, the Open Geospatial Consortium provides standards for sharing sensor data such as SensorML or Sensor Observation Service [10], and INSPIRE [21] for datasets of geographical nature (i.e. elevation, land cover, water bodies, etc). New observational (field) data, collected by ALPINE sensors (i.e. from GPS/GSM collars), can be made available in the system using a service-oriented philosophy [12] that follows the Sensor Observation Service or Open Archives Initiative [11] protocols.

## 4.2. Interpretation via modelling

Sensor information alone is not sufficient for answering research questions. Evidence needs to be coupled with models in order to address issues of habitat suitability and estimating risks from human-wildlife interactions. Environmental models provide such interpretations, as they embody explanations or estimations of system behaviour. In the ALPINE system, we identified a need for three kinds for models. First, geo-spatial models that allow operational interpretations of spatial sources are typically used for creating derived information from original data. These include buffering functions, and density analysis. Secondly, Bayesian models should build probabilistic models in order to incorporate causal associations from evidence. For a more detailed discussion on Bayesian modelling for ecological risk assessments see [13]. Third, Ecological Niche Factor Analysis (ENFA) is a statistical procedure that uses only presence data, suitable to compare distributions among spaces that a population has a reasonable probability to occur using eco-geographical variables and the global space [14]. The ALPINE wildlife monitoring system aims to integrate these three components in order to enable scientists to perform their assessments.

## 4.3. Result presentation and communication

The last component of the system deals with presentation of results. Typically scientists spend adequate amount of time in order to analyse their results and post-process them. In the ALPINE system we aim to incorporate such aspects in the workflow, so that maps and reports are generated as new data arrive in the system and assessments are updated. For this we employ reusable templates that will incorporate model results.

## 4.4. Enabling semantic modelling and implementation

Ontologies that define the domain concepts and their interactions remain the heart of the system that will be built upon *Thinklab*, a semantic meta-modelling platform developed initially in the ARIES project [4], and currently under development as an open source software project [15]. Thinklab provides with the main infrastructure for a semantic modelling, as it offers:

(a) a reusable set of core ontologies, for defining domain concepts as observations, and quantify their qualities;

(b) a domain specific language, to define semantic models and prescribe behaviour; and

(c) a collaborative e-science space where modellers may share ontologies, data and models.

Thinklab remain outside of the scope of this paper and the reader is encouraged to visit its website [16]. We consider domain specific programming languages for environmental modelling to be key for advancing the notion of semantic modelling, where all concepts used to model natural systems are explicitly defined by ontologies [17]. Towards this end, we directed our developments for extending Thinklab, in several fronts in order to achieve ALPINE functionality.

First, we are in a process of extending the core Thinklab ontologies in order to accommodate for wildlife trajectory semantics. Based on previous research on semantic trajectories [18], we are investigating how to formally represent animal movements and accompany them with qualities that enable end-users to derive useful knowledge for their studies. A collaborative approach with scientists from Callisto and other organizations is in the process for enabling and validating this approach. The key element of our view is that an animal trajectory needs to encapsulate the species circadian rhythm and express the interactions of an individual with its habitats.

The second challenge is to incorporate sensor stream data sources in Thinklab. By extending the input functionality of the platform we will make available standard protocols for sharing sensor information. Currently, we plan to make sensor data available via simple protocols, like GeoRSS [19] and GeoJSON [20], and more sophisticated ones as OGC Sensor Observation Services [10]. In all cases, our Thinklab extensions will enable annotating sensor streams with semantics, so that they can be used transparently within a semantic modelling workflow. This goes a step ahead of just reading sensor data streams, as it requires associating observational semantics to the streams. As an example, consider the animal tracking data that we will gather from large carnivores collars in the Callisto case. Thinklab will interpret them based on the trajectory ontology under development, and ultimately make them available as such for subsequent use.

Third, we will incorporate the Ecological Niche Factor Analysis (ENFA) in the Thinklab platform. As Bayesian modeling and spatial analysis modeling are already available in the Thinklab platform, we will further extend it with ENFA in order to be able to perform statistical modeling on habitat suitability.

## 4.5. Callisto user story

For the Callisto case, we envisage the following user story. *Yorgos* an ecologist wants to perform a habitat suitability assessment of human-bear interaction in certain parts of the Egnatia highway, where car accidents occur often and involve bear fatalities. The first step is to collect field data for the specific area of study from various sources, including the local government, the ministry of the environment, the company managing the highway, bibliographic information and in-house information. Yorgos, using Thinklab, can reuse field data from previous studies, while he may annotate new public datasets made available with standard protocols. The second step is to capture and install collars on certain individuals, which will eventually start producing animal tracks. Yorgos makes the sensor data stream available in the platform by associating to it with appropriate semantics, and bear trajectories are identified as they arrive. With such information available Yorgos easily hooks up bear trajectories and ecological field data to set up a niche factor analysis model. The result of the model run is a habitat suitability map produced in Thinklab which is directly exported for his report. The workflow remains available in Thinklab and Yorgos may reuse it as new data arrive or in other areas of interest.

## 5. Discussion

In this paper we presented work in progress for developing a semantic framework for wildlife modeling. The system presented employs semantic meta-modeling and ontologies for representing domain knowledge, which includes both data and models. The system under development builds upon Thinklab, an existing open-source software, and extends it with an animal trajectory ontology, tools for reading sensor information from standard protocols and an implementation of the niche factor analysis models. Our implementation will be evaluated for a case study in Greece for assessing habitat suitability, and to quantify the risks of brown bear interaction with man-made infrastructures.

## Acknowledgements

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# A coupled subsurface-flow and metabolism model to study the effects of solute fluxes in the hyporheic zone

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## Abstract

The hyporheic zone and the streambed host a great part of the energy and material fluxes through river ecosystems. However, the role of heterogeneities in the hyporheic zone in metabolism is not clearly understood. This paper proposes a new way to approach the question by using a coupled subsurface-flow and metabolism model for investigating the role of heterogeneities in the hyporheic metabolism. Our results show that (i) our coupled model is feasible for investigating solute fluxes in the hyporheic zone under heterogeneous set-ups, and (ii) the incorporation of heterogeneities seems be of relevance for hyporheic metabolism estimations

## 1. Introduction

Projects in hydro-ecological sciences are often multidisciplinary in nature and involve cooperation from engineers and scientists from different backgrounds. A variety of different models are employed by them e.g. measurement models, laboratory models, simulation models, etc. In multidisciplinary projects, these models need to be integrated into a single system for solving a common problem. One such problem involves studying the effects of hydrogeomorphological heterogeneity on streambed and hyporheic metabolism.

The hyporheic zone (Hz) is a spatially fluctuating ecotone between the surface stream and the deep groundwater where important ecological processes take place [3]. In fact, Hz and the streambed host a great part of stream metabolism, e.g. 97% of whole stream denitrification [2] and 40–93% of whole stream respiration [7]. Metabolism is one of the most integrative ecosystem-level functions in rivers since it gives clues about the energy and material fluxes through ecosystems [6]. Despite the recognition of this fact, there is still a lack of understanding of complex responses of biological processes to the hydromorphology of the Hz [5] and in consequence research tends to consider Hz as a hydrogeomorphologically homogeneous black box. At reach scale, previous research has tried to combine heterogeneity with metabolism, for instance [1] distinguished several zones within the transient storage zone depending on their metabolic activity or [4] differentiated among different zones of the streambed based on their residence time. But a more complex model with heterogeneous hydrogeomorphology is still needed [4]. We propose a bottom-up approach that helps to clarify whether Hz heterogeneity has to be considered when studying stream metabolism. We propose that while aerobic metabolism (respiration) will be accurately represented in a homogeneous approach, anaerobic processes (e.g. denitrification, methanogenesis) will be neglected.

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In combination with measurements in percolated sediment microcosms, we estimate the relevance of heterogeneous hydrogeomorphology on the physical and biological processes in the Hz by coupling a subsurface-flow model with a model simulating the Hz metabolic processes.

## 2. Laboratory Model

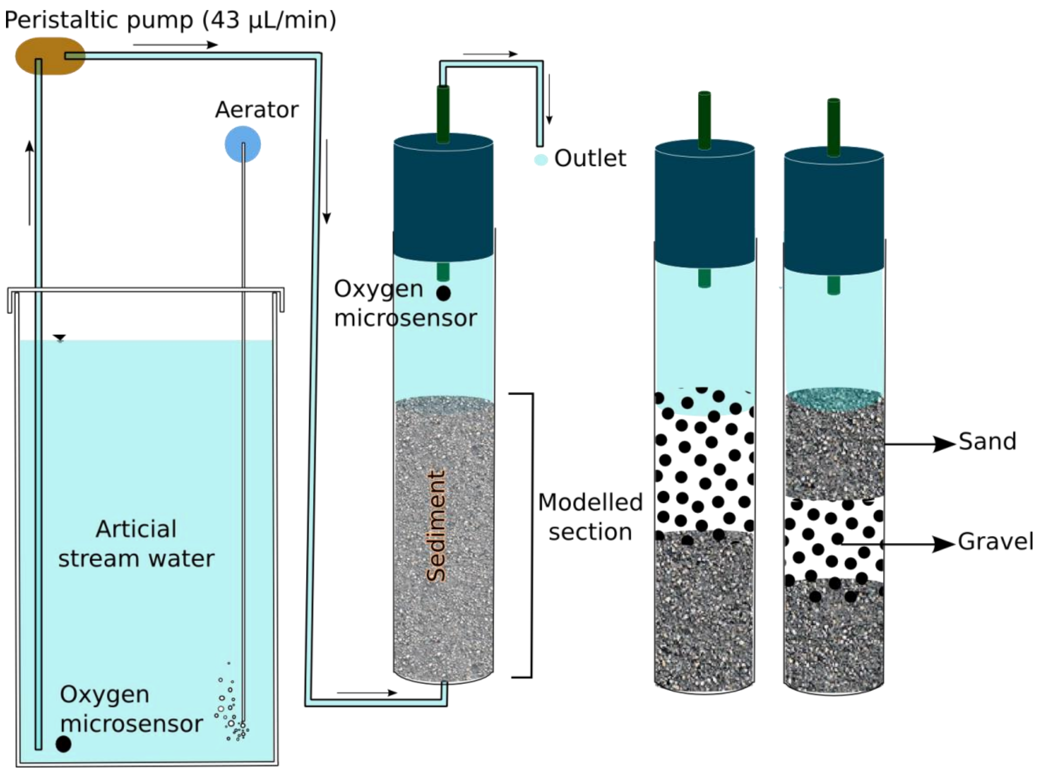


*Figure 1: Schematic representation of the experimental set-up: example with one percolating microcosm filled with uniform sediment, and the different combinations of gravel and sand measured (uniform, 2- and 3-layers perpendicular to flow direction).*

A portion of the Hz was simulated in a laboratory set-up (Figure 1) consisting of a set of percolating microcosms (20mL glass syringes, diameter 2.01cm, Fortuna Optima, Poulten & Graf, Werheim, Germany); peristaltic pump Ecoline; ISMATEC, Glattbrugg, Switzerland) filled with sediment and placed in a water bath at constant temperature (15ºC) and in darkness (F38-EH; Julabo, Seelbach, Germany). Sediment of different permeability and grain size was used: gravel (8–4mm) and sand (0.8–0.4mm), and pre-incubated (3 days, 20ºC in darkness) in a sediment community solution from the experimental catchment Chicken Creek [9]. Each measurement consisted of three replicates of uniform sediment (gravel and sand) and three replicates of heterogeneous arrangement of sand and gravel (Figure 1). All microcosms remained saturated throughout the measurement. The experimental set-up was allowed to run for 5 days and regular measurements were taken for the pumping-rate of water and for the dissolved oxygen concentrations (Microx TX3; PreSens, Regensburg, Germany) at the inlet and outlet of the microcosms, used to calculate respiration rate as a proxy Hz heterotrophic metabolism,. Oxygen concentrations were well above substrate saturation constant for aerobic respiration. Therefore, respiration rate was independent of oxygen concentrations [13].

## 3. Coupled simulation model

A coupled subsurface-flow and Hz metabolism model was used for reproducing the results obtained from the laboratory experiments described in section 2. The two models were set up using parameters that were measured in the laboratory. The exchange of physical state variables between the two models takes place with the aid of a prototype of a software framework for model coupling which is responsible for communication between the model and adaptation of information according to the model requirements.

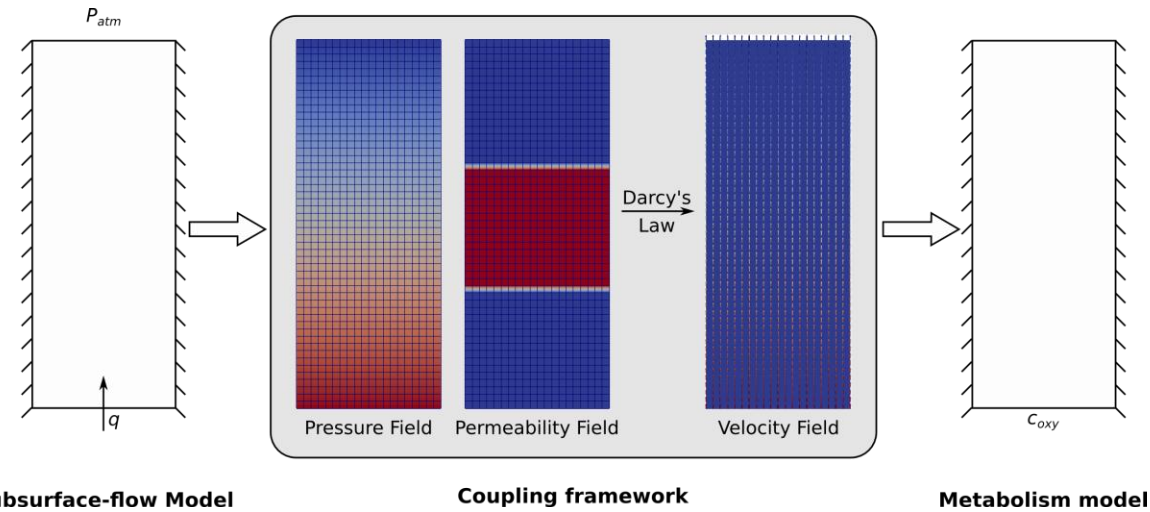


*Figure 2: Schematic diagram of the coupled subsurface-flow and Hz metabolism model with the software framework for coupling models acting as the coupling broker.*

For reproducing the results obtained from the laboratory experiment, a subsurface-flow model was coupled with the Hz metabolism model using a prototype of a software framework for coupling models (Figure 2). The subsurface-flow model is used to compute the pressure-field in the microcosm and the Hz metabolism model makes use of this velocity field to simulate the metabolic activity of the sediment community. A coupling framework is responsible for the communication and information exchange between the models and for transforming information from the models as required e.g. interpolation, transforming the pressure-field to a velocity field, etc. The dimensions and other parameters for both the models are set from the laboratory model.

## 3.1. Subsurface-flow model

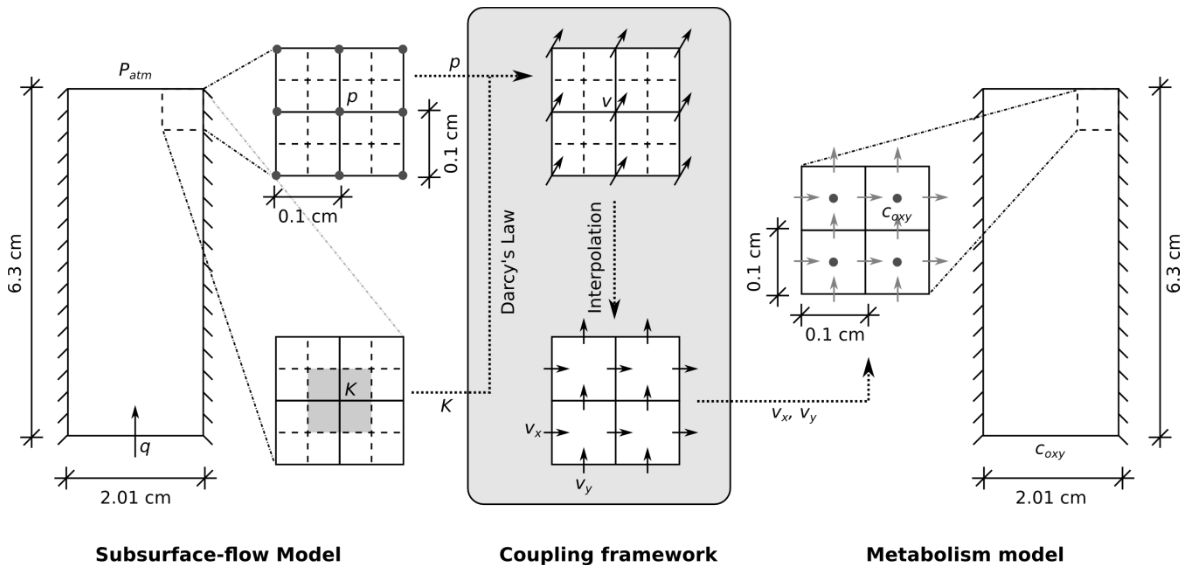


*Figure 3: Dimensions and space discretisation of the subsurface-flow and Hz metabolism model.*

DuMu$^X$ stands for DUNE for Multi-{Phase, Component, Scale, Physics ...} flow and transport in porous media and it is a free and open-source simulator for flow and transport processes in porous media [8]. Since the soil in the laboratory model remains saturated throughout the experiment, a two-dimensional fully-implicit single-phase model is employed for simulating the subsurface flow. The governing equations in this case are the transport equation (equation 1) for the conservation of mass and the Darcy's law (equation 2) for the conservation of momentum:

$$f \frac{\partial r_w}{\partial t} + \underline{\nabla} \cdot \underline{v} = q_w \tag{1}$$

$$\underline{v} = -\frac{\underline{\underline{K}}}{\mu}\left(\underline{\nabla} p - \rho_w \underline{g}\right) \tag{2}$$

Here, $\mu$ is the viscosity of water, $\phi$ is the porosity of the soil, $\rho_w$ is the density of water, $g$ is the acceleration due to gravity, $K$ is the permeability of the soil, $p$ is the pressure and $v$ is the flow velocity, $q_w$ is the source term for water and t is the time.

The dimensions of the subsurface-flow model are set from the laboratory model to 2.01cm × 6.3cm (Figure 3). The space-discretisation is in the form of vertex-centred finite-volume scheme having a regular structured grid with square cells that are 0.1 cm in length. Time-discretisation is in the form of implicit Euler method with adaptive time-step size. For the boundary conditions, the pumping rate of 0.043mL/min, as measured in the laboratory, is set as the Neumann boundary condition at the bottom and atmospheric pressure (patm) as the Dirichlet boundary condition at the upper edge of the model (Figure 3). The lateral edges are treated as closed (no-flow) boundary conditions.

### 3.2. Hz metabolism model

A Hz metabolism model for simulating the metabolic activities of the microorganisms has been developed for this work. Like in the case of the subsurface flow model, the Hz metabolism model computes the distribution of oxygen in the domain using the transport equation (equation 3).

$$\frac{\partial r_o}{\partial t} + \underline{\nabla} \cdot \underline{v} = q_o \tag{3}$$

Here, $\rho_o$ stands for the density of oxygen and $q_o$ stands for the source term for oxygen. Since oxygen is modelled as a solute, the velocity $v$ is provided by the subsurface-flow model.

Like for the subsurface-flow model, the metabolism model has the dimensions of 2.01cm × 6.3cm (Figure 3), set from the laboratory model. The space discretisation is in the form of a cell-centred finite-volume scheme with each cell having the dimensions of 0.1cm × 0.1cm. Time discretisation is in the form of explicit Euler method with a constant time-step size of 100s. The metabolism model is a two-dimensional model with the measured concentrations of oxygen used as the Dirichlet boundary conditions at the lower edge of the model and the lateral boundaries being modelled as closed boundaries. The upper boundary is treated as an open boundary and the oxygen concentrations computed at the outlet are used for validation against the laboratory measurements and for calculating the average respiration rates in the microcosms.

### 3.3. Coupling mechanism

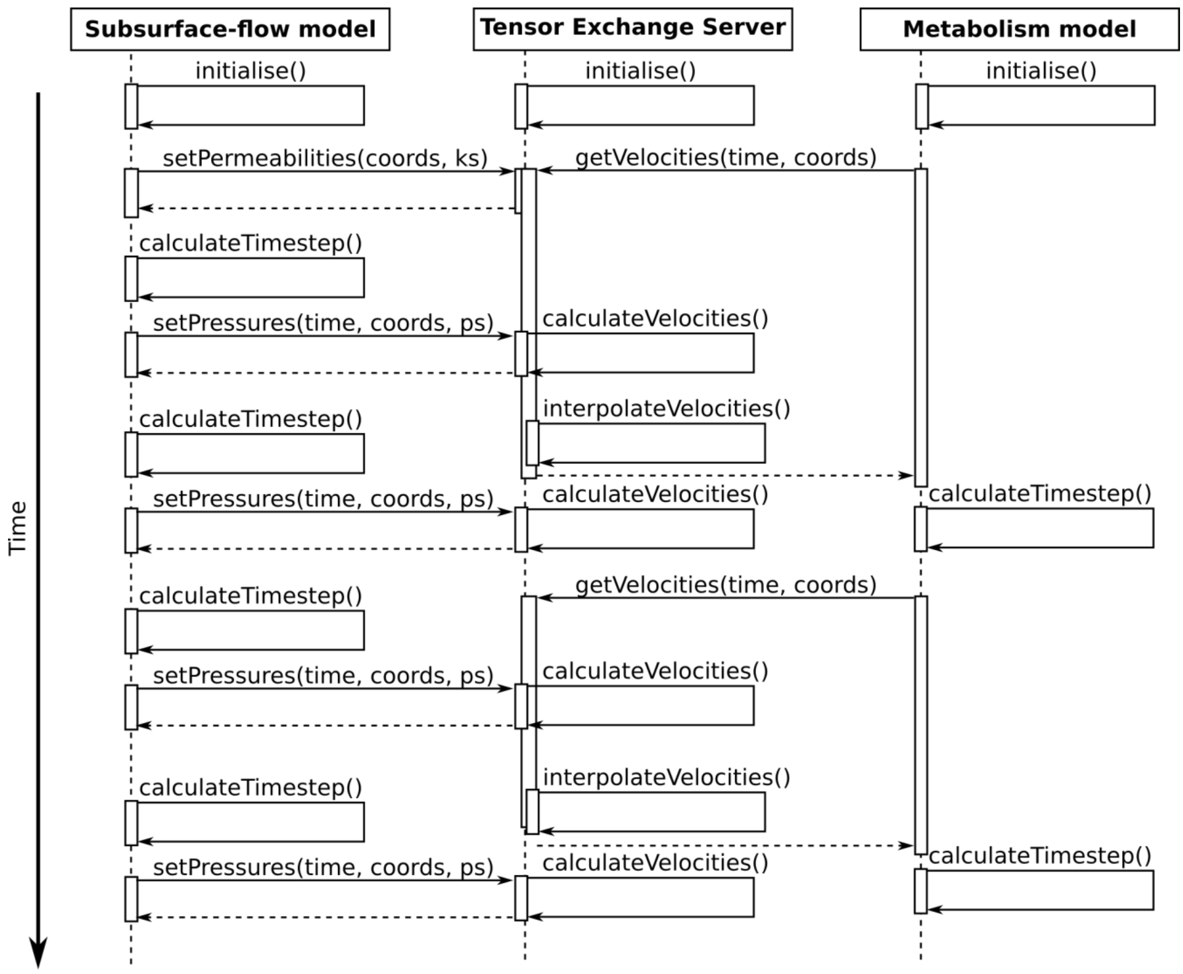


*Figure 4: Coupling mechanism*

To make the task of coupling the subsurface-flow model with the metabolism model easier, a prototype of a framework for coupling of models based on Tensor objects is used [12]. This is shown as the 'Tensor Exchange Server' in Figure 4. The Tensor Exchange Server acts as a broker between the coupled models and is responsible for:

- Providing a generalised and comprehensive representation of physical state variables i.e. the permeability, pressure and velocity fields
- Providing a channel of communication between the coupled models through the use of web-services making use of the XML-RPC standard [14]
- Adapting the information from the subsurface flow model to the requirements of the metabolism model. This includes applying Darcy's Law for converting the permeability and pressure fields from the subsurface flow model to the velocity field required by the Hz metabolism model.
- Performing bicubic interpolation in space for estimating flow-velocities at the centres of the cell-faces of the metabolism model from the results of the subsurface-flow model
- Performing linear interpolation in time of the velocity field for the metabolism model.
- Regulating the coupling process e.g. by making the coupled models wait until the values requested by them from the other model are available

Figure 4 shows a UML representation of the sequence of calls that take place between the coupling framework and the coupled models. In this particular case, the information flows only in one direction. As a result, the complexity involved in coupling of models is relatively simpler when compared to bidirectional flow of information and the models don't necessarily need to run concurrently. The sequence of events involved in the coupling can be summarised as follows:

- The Tensor Exchange Server (TES) and the coupled models start up.
- The subsurface-flow model sends the permeability field to the TES at the beginning of its computation. The permeability field is later used for calculating the velocity field by the TES.
- The subsurface-flow model carries out its calculation and at the end of every time-step sends the computed pressure field to the TES. The TES computes the velocity field from the pressure and the permeability fields using Darcy's law.
- The metabolism model requests the velocity values from the TES.
- The TES waits for pressure values from the subsurface-flow model for computing the velocity field, if they are not already available. The TES interpolates, as required, the velocities calculated in the previous step in time and space, and returns the interpolated velocities to the metabolism model.
- The metabolism model computes the next time step using the values it receives from the TES. At the beginning of the next time-step, it again requests the velocity field from the TES for that time-step.

Compared to other model coupling approaches such as OpenMI [10] where models are coupled with each other directly and the responsibility for understanding, adapting and transforming the information received from the coupled models lies on the models themselves, the use of TES as the coupling broker reduces the effort required in coupling by doing such adaptations and transformations on behalf of the coupled models.

## 4. Results

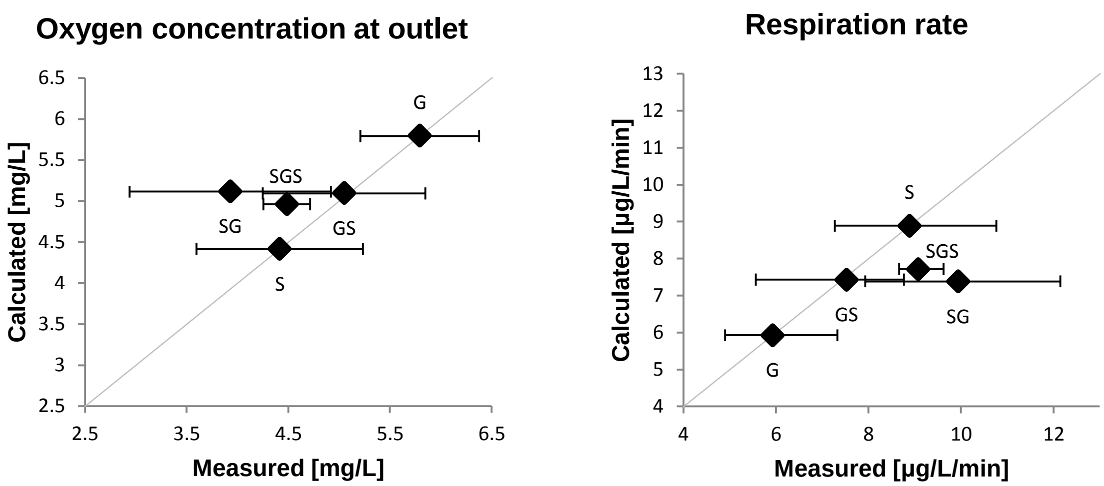


*Figure 5: Comparison of the measured oxygen concentration at the outlet of the microcosm (left) and the average respiration rate in the microcosm (right) (measured values mean ± min/max values, n = 3) with the calculated values (single simulation). Diagonal lines indicates 1:1 ratio. S = Sand, G = Gravel.*

Figure 5 shows the comparison of the results of the coupled numerical simulation to the values measured in the laboratory model. These figures demonstrate that the coupled model is able to simulate very accurately the homogeneous set-ups, while more complex set-ups such as sand-gravel-sand are underestimated as a result of handling heterogeneity in permeability.

As expected in our initial hypotheses, even with our simple heterogeneous set-ups, respiration of the microcosms varied. It is interesting to note that even when used in similar proportions, different respiration rates are observed for the different arrangements of the sediments. Since the metabolism model is based simply on the principle of conservation of mass (section 3.2 above) similar proportions of sediment result in similar values for oxygen concentration being computed at the outlet of the microcosm, irrespective of the order of the sediments. As a result, the simulation model is not able to reflect the heterogeneities observed in the laboratory and further investigations are required to find the impact, if any, of the order of the sediments on the respiration rates and how the simulation model might be able to model these effects.

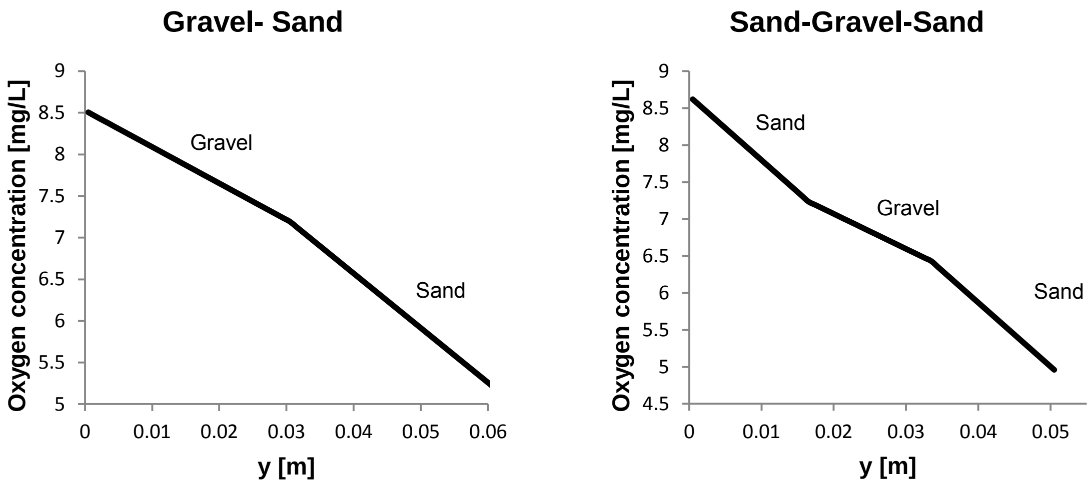


*Figure 6: Longitudinal profile of oxygen concentration through the centre of the microcosms.*

Figure 6 shows the longitudinal profile of the oxygen concentration through the middle of the microcosm as computed by the metabolism model. As expected, the heterogeneities in permeability affect the distribution of oxygen with the oxygen concentration falling more rapidly in the downstream direction in sand than in gravel.

## 5. Summary and Outlook

A coupled subsurface-flow and Hz metabolism model demonstrates that a coupling framework based on Tensor objects facilitates the task of coupling by providing functionality such as a com-munication mechanism between the coupled models, adaptation of information based on the re-quirements of the coupled models through mathematical operations, etc.

- As shown by the results, even with such a simple set-ups, heterogeneity in respiration reflects heterogeneity in the sediments as proposed. Thus our coupled model is feasible for investigating the role that heterogeneities in the Hz play on the solute fluxes and metabolism.
- At our small scale, differences in respiration among sediment combinations might be of low relevance for ecosystem metabolism, however the observed differences point out that when at bigger scale more complex set-ups and other metabolic processes are considered relevant differences for ecosystem metabolism will arise. Therefore, in agreement with [11], it is likely that the understanding of hyporheic flow processes will mature by addressing, rather than bypassing, hyporheic dynamics and heterogeneity

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# Groundwater data management system

Kamil Nešetřil[1], Jan Šembera[1]


## Abstract

We have developed a system to manage groundwater data (geology, hydrology and geochemistry). The system is flexible, readily extensible and adaptable. It can load data in different formats. Loading and cleaning the data is performed by an ETL tool Pentaho Data Integration (aka. Kettle). The coordinates are converted by GeoKettle (spatial fork of Kettle). The database PostgreSQL uses our own data model. Groundwater specialists can visualize data in EnviroInsite desktop software. A non-specialist can visualize data in a web application. Non-point spatial data is stored in a spatial database (PostGIS) and served via a map server (GeoServer) as a map service to our web application or to any geographic information systems (GIS). We have successfully used tools for business intelligence and spatial data infrastructure.


## 1. Introduction and requirements

In order to increase efficiency of hydrogeologists' work it is necessary to properly manage data. It is not a trivial task, because groundwater data consist of data on geology, hydrology and geochemistry. Crucial is the data management of primary measurements and observations obtained from points (e.g. wells, boreholes, sampling objects). Managing spatial interpretations of data (e.g. extent of aquifer, contours of solute concentration etc.) and storing them in a structured form is of lesser importance. The crucial requirement is the capability to readily add imports of new data formats (mostly semi-structured data) and add exports to software for analysis and modelling. Data needs to be accessible, in some extent, also via web client.

There are many environmental data management systems (EDMS) designed to handle groundwater data. Some of them are EQuIS from EarthSoft (earthsoft.com), SiteFX from EarthFX (earthfx.com), GW-Base from ribeka (ribeka.com), EnviroData from Geotech Computer Systems [1], Oasis-montaj from GeoSoft (geosoft.com), HydroManager from Schlumberger Water Services (swstechnology.com) or ESdat (esdat.net). Deployment of those solutions takes some effort because different countries have different data formats and different spatial reference systems. Loading or exporting of specific data formats is not available in existing EDMS and programming new ones is not a trivial task. We developed a new solution (Figure 1) that makes creation of new data imports, exports and conversion of coordinates as flexible and user-friendly as possible.

## 2. Technical solution

### 2.1. Database

It is reasonable to use an existing data model for the newly developed information system. It makes it possible to store all groundwater data in a fixed form and exchange it easily. We have reviewed available data exchange standards and data models. The only truly international standard is Ground Water Markup Language (GWML) [2] from Open Geospatial Consortium (OGC). It is an application schema of Geography Markup Language (GML). GML is significant for European users because it is widely adopted to an EU directive INSPIRE (INfrastructure for SPatial InfoRmation in Europe). Another data model is Hg2O [3] that is planned to be incorporated into GWML.

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ESRI Groundwater Data Model has been implemented in Arc Hydro Groundwater [4] that is an extension of ArcGIS. The last ones are Data Model of National Groundwater Information System [5] and H+. Because primary intention of the developed system is not the interoperability based on aforementioned standards, none of those data models was used. Besides other things some are not suitable for needs of groundwater practitioner (GWML), some are too concise or not sufficiently documented. All data models, data exchange formats and data models of EDMS were reviewed and used as an inspiration for the developed data model.

Visualization of hydrogeological data on desktop computer can be easily performed with EnviroInsite from HydroAnalysis, Inc. (enviroinsite.com) – low priced software in .NET to display maps (including localized tables and graphs), technical documentation of boreholes, geological cross-sections, 3D geological models and interpolation in 2D and 3D. Our data model is based on existing data model of EnviroInsite. Therefore the database and visualisation software has consistent data structure. That reduces need for non-unique data transformation and it does not confuse users.

The original data model of EnviroInsite (9 tables) was extended to 28 tables because the EnviroInsite data model contains data relevant for visualisation only. Original tables were extended by additional fields and the model was further normalized. It contains data on:

- observation objects (wells, boreholes, sampling points with coordinates and detailed description),
- characterisation of geological layers (description of boring logs and it’s interpretation – stratigraphy),
- technical construction of wells (casing, screen and fill of annular space),
- definition of observed quantities (units, chemical formulae etc.),
- standards (action levels, regulatory limits),
- definition of vertical intervals (well screen or sample interval in boring log),
- measurements tied to vertical intervals (e.g. chemical analyses or head measurements),
- measurements tied to specific depth (e.g. geophysical logging),
- samples (metadata about measurements and sets of measurements – sampling methods, conditions, etc.),
- anti-aliasing (e.g. a quantity has different names in different data sources),
- conversion of units (e.g. mg to g) and quantities (e.g. nitrate to nitrogen),
- time intervals, lookup tables etc.

We are using PostgreSQL (postgresql.org) database management system.

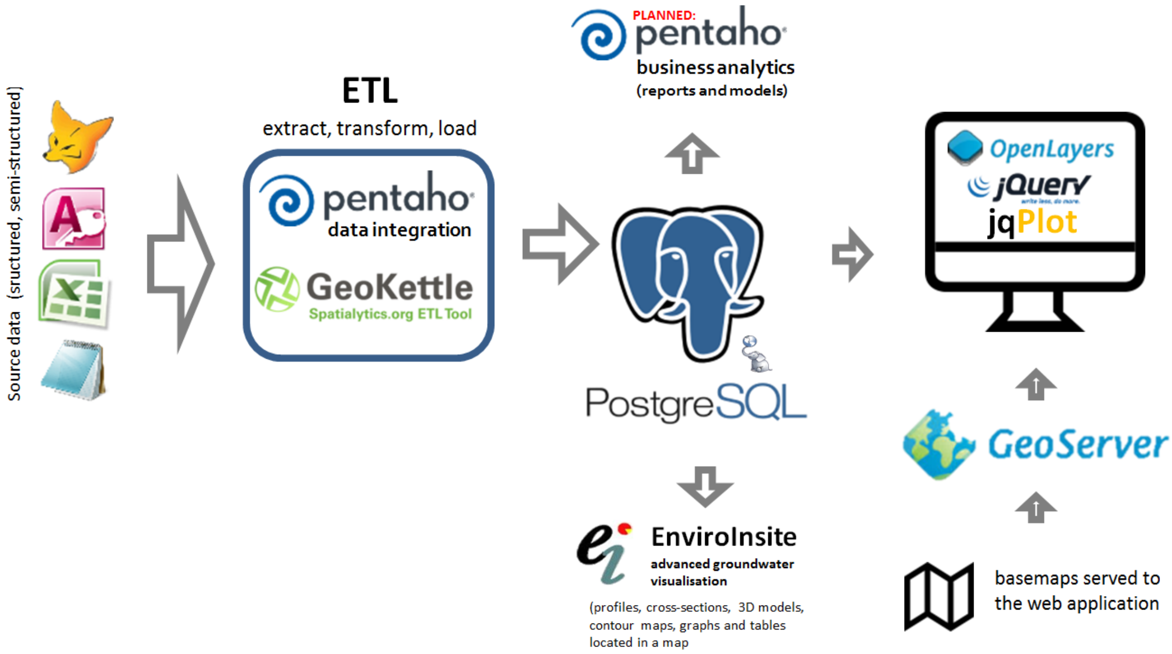


*Figure 1: Schema of the presented system for management of groundwater data*

## 2.2. ETL

The data is loaded to the database by ETL (extract, transform, load) tool Pentaho Data Integration, also known as Kettle [6]. It is an open-source software released under Apache Licence (community.pentaho.com). Data transformations in Kettle can be implemented without coding through an intuitive graphical user interface called Spoon (Figure 2), so they are also easy to maintain. Kettle transformations can be run in command-line interface ("Pan" and "Kitchen") or on an ETL server ("Carte"). We implemented the loading of following data:

- analyses from laboratory information management system Labsystém (provided as 2 xBase files),
- boreholes and groundwater chemism from Czech Geological Survey (provided as MS Access files),
- exploratory boreholes (provided as MS Word documents created by a Geobanka software from Data-PC Sokolov),
- text files with precipitation and temperature served via FTP from a watershed authority (Povodí Ohře s. p.)
- original database format of EnviroInsite (MS Access, MS Excel) and
- "handmade" MS Excel spreadsheets.

Subsequent transformations provide data cleaning, anti-aliasing, validation and loading to the database. Coordinate conversion is performed by a spatial fork of Kettle called GeoKettle [7]. Future versions of GeoKettle should be an extension of Kettle and not a stand-alone application.

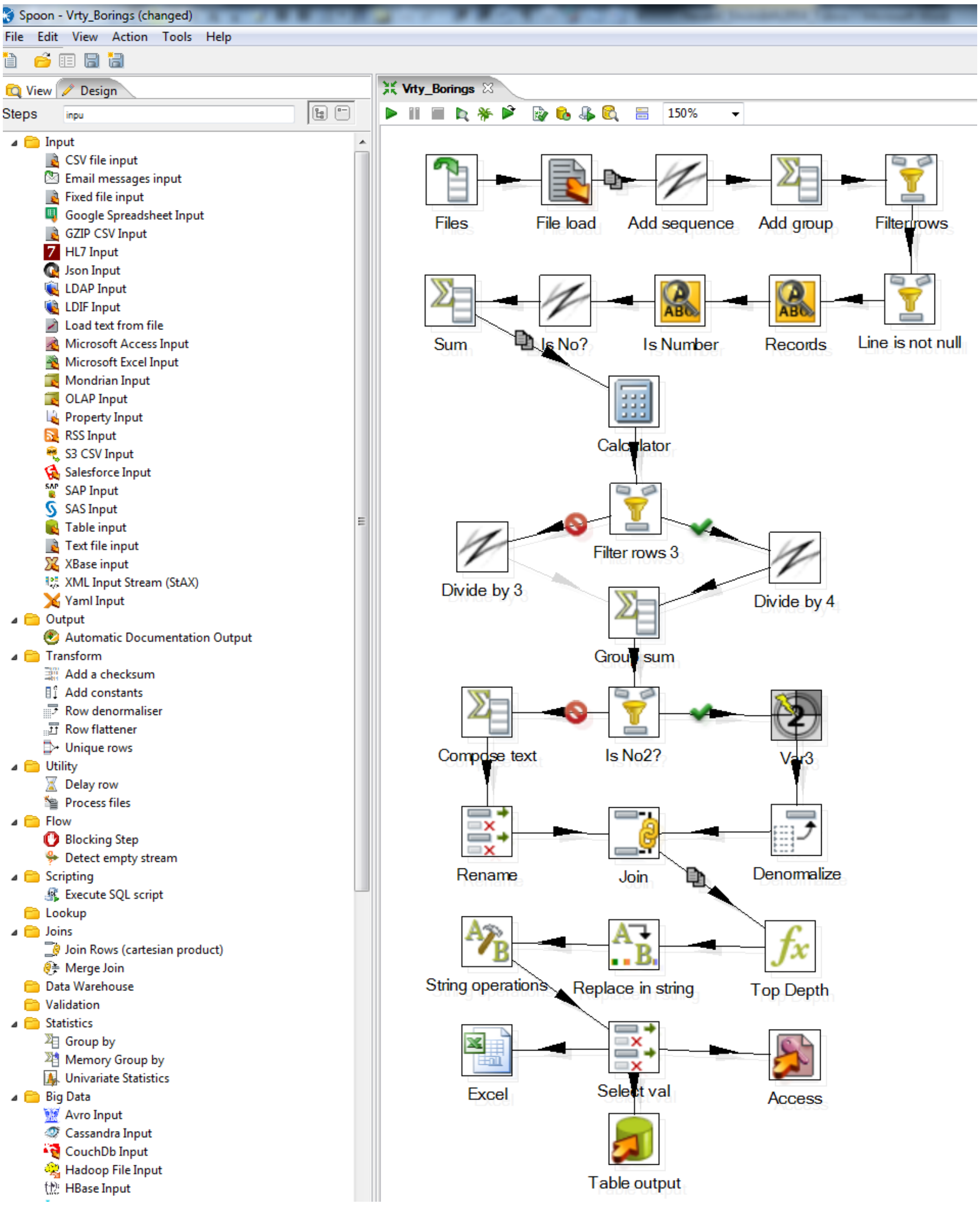


*Figure 2: The data transformation implemented in Spoon (development environment of Pentaho Data Integration aka. Kettle)*

## 2.3. Visualization

Due to the compatibility of our data model with that of EnviroInsite, data can be easily exported to MS Access or MS Excel file and visualized in EnviroInsite. This is suitable for professional hydrogeologists. Stakeholders and other nonspecialists can view data in a web application we have developed (Figure 3). The application combines a table, a graph and a map on a single screen. Upon choosing a borehole on a map and a quantity from a drop down menu, table (in left vertical strip) and graph (in upper horizontal strip) are displayed. Attributes of an observation object are displayed in a pop-up window. Different map layers provided as WMS (Web Mapping Service) and WMTS (Web Map Tile Service) can be switched on and off as basemaps. The application is implemented mostly in JavaScript (jQuery, jqPlot). Maps are integrated with use of widely used JavaScript library OpenLayers (openlayers.org).

Interpretations and non-point data (arcs, polygons etc.) are stored in the PostgreSQL database due to PostGIS. PostGIS (postgis.net) is a spatial extension of PostgreSQL. Those data and georeferenced images are served via GeoServer (geoserver.org) as WMS service. WMS can be loaded as a basemap to our web application or to any geographic information system (GIS).

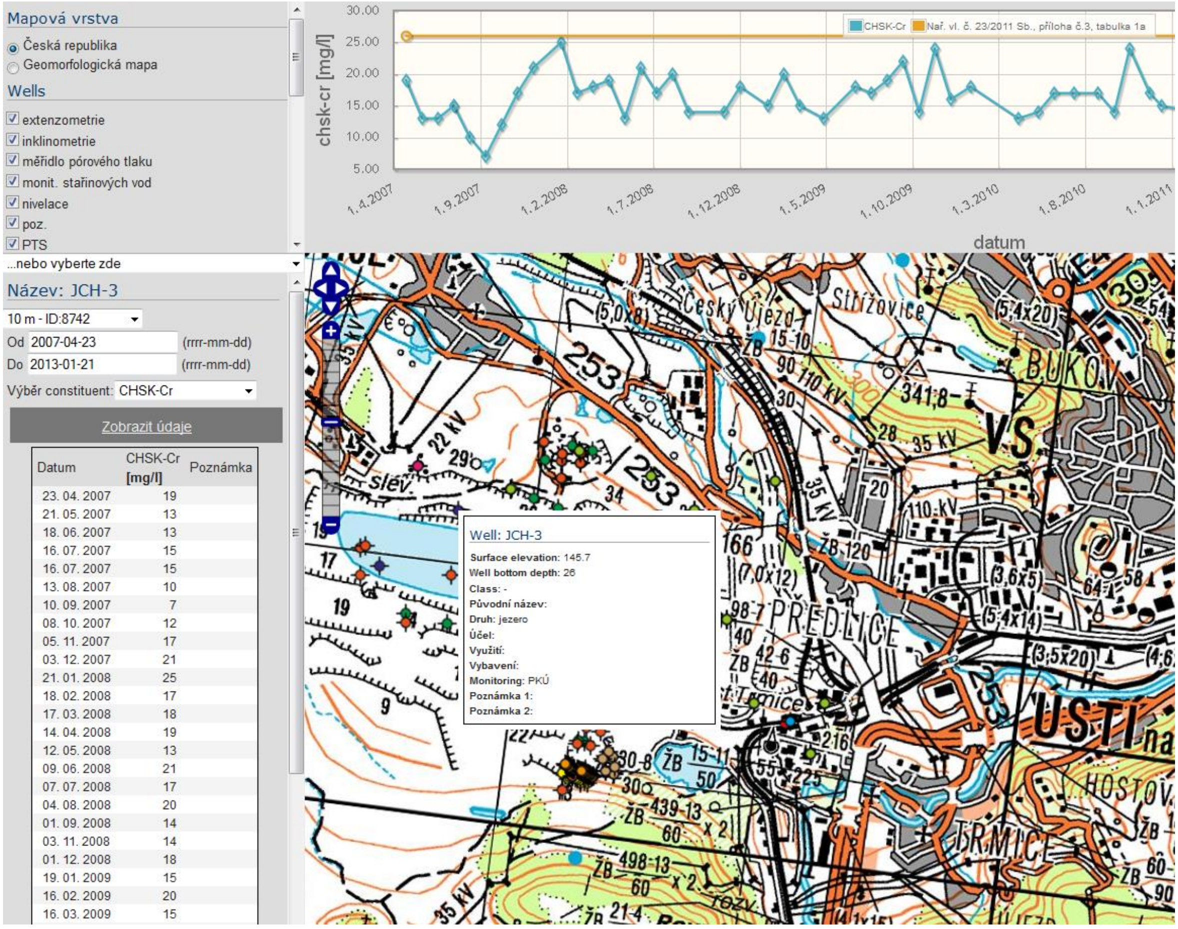


*Figure 3: The web application depicting time series in the table and in the graph*

## 3. Further plans

Common hydrogeologist’s data management tasks are to automatically load data to database, create reports and alerts and export data to a third party software for analysis and modelling. Those tasks are not unique for hydrogeology but can be provided by existing open source business intelligence software. We made a very good experience with the ETL tool Kettle from Pentaho Corporation. Pentaho develops a whole stack of open source business intelligence software such as Pentaho Report Designer, Pentaho Business Analytics Platform (server) and others. By the time of the conference the reporting platform should be deployed. The exporting to third party software for analysis and modelling shall be implemented in Kettle. An alternative to Pentaho BI suite is SpagoBI (spagobi.org) with powerful visualisation and analysis of geodata including non-point data and WMS services.

## 4. Conclusions

We discovered real needs of groundwater professionals, available technologies and tools. We developed a flexible information system focused on needs of practitioners. We used technologies that enable long term maintenance, customization and extensibility. The architecture of the system corresponds to a spatial business intelligence solution (GeoBI) – combination of business intelligence (BI) and spatial data infrastructure (SDI). Therefore it could be used for geographical analyses and management of big data sets. Groundwater practitioners are used to work with GIS software for decades but not with BI tools. Our effort is to introduce BI to groundwater community. The system is available commercially, upon request (contact the corresponding author).

## 5. Acknowledgement

Work of Daniel Vrbík and students David Krejbich (transformations in Kettle) and Tomáš Jodas (web application) is greatly acknowledged. Christopher Jon Pierson proofread an early version of the manuscript.

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# Water network pumps control reducing the energy cost

Jan Studzinski[1], Marek Kurowski[2]


## Abstract

Two algorithms for pumps control reducing the energy cost in the communal water networks are presented in this paper. The energy saving in water and wastewater networks is, beside the reduction of water and wastewater leaks, one of the main operational tasks in the waterworks. As a result an essential cutting of the exploitation costs can be achieved. In the presented algorithms an heuristic method of multi criteria optimization is applied. Both algorithms are parts of the ICT system for complex management of communal waterworks that is under development at the Systems Research Institute of Polish Academy of Sciences. All calculations done during testing these algorithms were made with the real data from Polish waterworks.


## 1. Introduction

The last years are the time of intense implementation of IT solutions in waterworks. GIS (*Geographical Information System*) and SCADA (*Supervisory Control And Data Acquisition*) systems as well as hydraulic models of water and wastewater nets are already regarded as standard ICT tools. They are used as data bases and sources of information for network operators about the work state and work quality of the nets which they are managing. But still the applications dealing with optimization problems that arise in the networks are rather rare among the programs used in the waterworks. There are a lot of such problems: hydraulic models calibration, SCADA systems planning, water and wastewater nets hydraulic optimization, water and wastewater nets planning, networks control etc. [5]. Data stored in data bases of GIS and SCADA systems and results produced by hydraulic models can be used to solve these problems and the received solutions can improve the quality of the network work and reduce operational costs.

At the Systems Research Institute an integrated ICT system for complex management is under development for a couple of years [6]. Its two algorithms for controlling the work of pump stations in water networks by means of a multi-criteria optimization are described in this paper. These algorithms were tested using real data coming from the Polish waterworks in Rzeszow. The aim of the algorithms is the reduction of energy used in the waterworks and the resulting decrease of enterprise operational costs.

The ICT system as the whole is presently introduced in the Upper Silesian Waterworks in Katowice [10].

## 2. ICT system

The ICT system under development is shown in Fig. 1. It consists of 4 functional modules and of 33 applications in total. The module regarded as data source for all calculations consists of a GIS system for generating the numerical map of the considered water net and for exporting the water net hydraulic graphs to water net hydraulic model, of a SCADA system for measuring the flows and pressures in all pipes and nodes of the water net and of a CIS (*Customer Information-Billing System*) system for recording the water amounts supplied to the water net end users.

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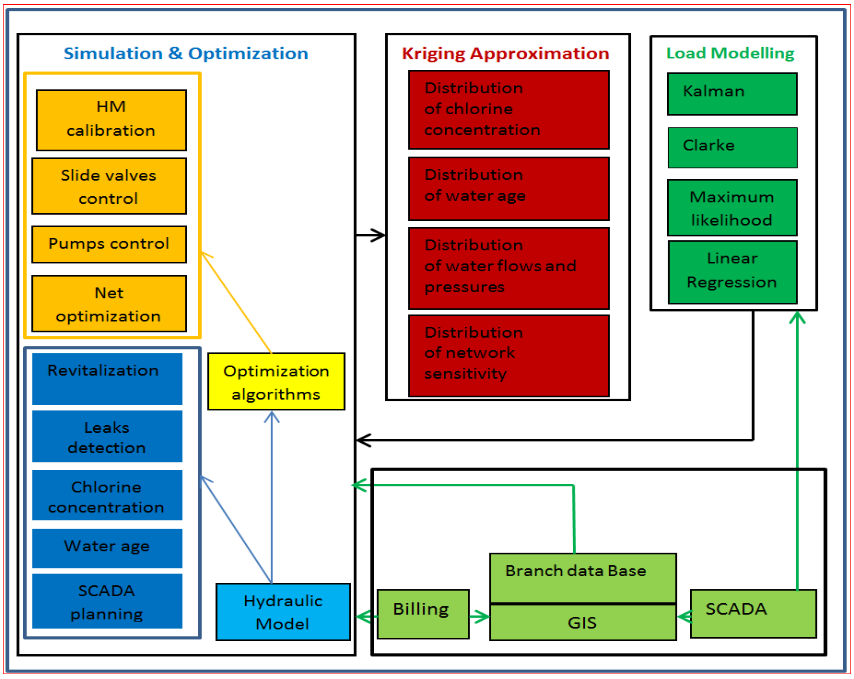



*Figure 1: Structure of the ICT system under consideration with 4 functional modules*

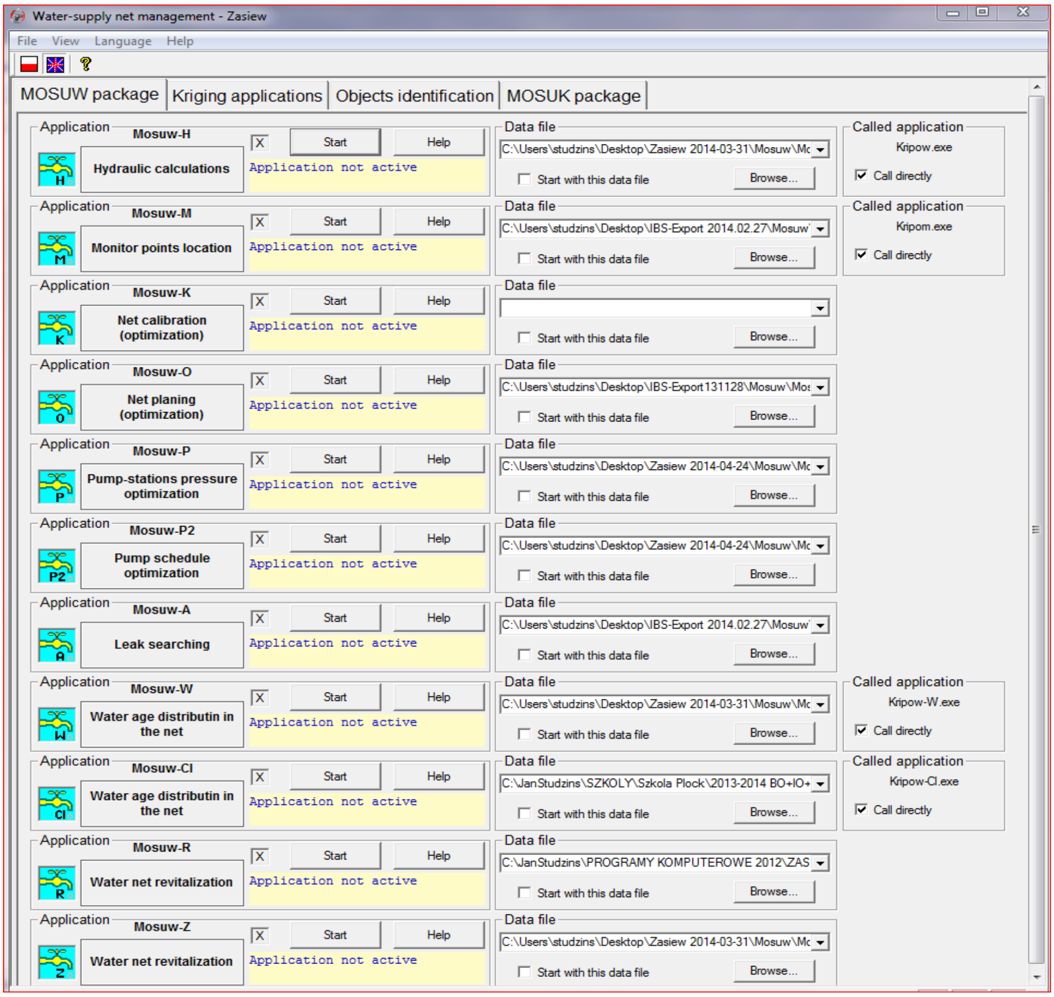



*Figure 2: Module with simulation and optimization algorithms of the ICT system*

The remaining 3 modules include programs for mathematical modeling of the water net hydraulic load [7], applications for designing the distribution maps for some water net parameters like water flows or pressures using the algorithms of kriging approximations [1], and the applications for hydraulic calculation of a water net and its optimization [5, 8]. Two of these applications destined for pumps and pump stations control and algorithms applied in them are described below.

## 3. Algorithms description

The first algorithm has been adapted from the REH program of Straubel [4] and implemented into ICT system. In this algorithm the pump stations installed in the water net are considered to be indivisible units and the principal optimized parameter is their output pressure. The best suited pressure for each of the pump stations is calculated using multi-criteria optimization algorithm with four objective functions:

1. Maximum deviation from individual target pressure for customer nodes.
2. Total power of all pump stations.
3. Maximum output pressure among all pump stations.
4. Actual (simplified) cost of drink water produced.

All objective functions are to be minimized. User can turn off some objective functions from optimization process. The power of a pump station is calculated as the product of the water flow and the pressure (the head supplied) on its output. The efficiency of each pump station is considered to be 100%. The cost of production of 1 $m^3$ of drink water is known (done) for each pump station. At each iteration of optimization algorithm the hydraulic model of the water network is solved and the values of all objective functions are determined.

The multi-criteria optimization algorithm allows the user to execute several different, though connected, tasks:

- Utopian optimization – separated one-criterion optimization run for each objective function in turn.
- Pareto optimization with objective ranks – gives only one solution. Optimization process is performed for each objective function in turn, in diminishing rank sequence. The ranks of objective functions can be changed by user beforehand.
- Pareto compromise set – finding the set of not-dominated solutions. The not-dominated solution is the one for each there are no other solution with all objective functions having better value.
- Pareto compromise set with objectives constraints.

As a result the user can choose the solution that meets best all his demands reducing at the same time the energy cost. The algorithm of optimization is heuristic and each optimization run requires a huge number of hydraulic model calculations.

The second algorithm for pumps control has been developed at IBS PAN. It assumes that each pump station can consist of several parallel working pumps with different work parameters. Each pump has its known head-versus-flow and efficiency-versus-flow characteristics. The idea of the algorithm was inspired by Waterworth who shown in his papers that some combinations of parallel working pumps can consume less energy than 1 pump producing the same water pressure on the pumps station output [9].

The goal of the multi-criteria optimization algorithm is to find the best steering sequence (schedule) for each pump where for consecutive time unit (usually one hour) the pump can be turn on or turn off. There are three objective functions in the algorithm:

1. Cost of electric energy used by pumps (twenty four hours).
2. Number of “pump switches”.
3. Maximum deviation from individual target pressure for customer nodes.

All criteria are to be minimized. The cost of electric energy depends on efficiency of actually working pumps as well as on different energy cost at different day period – especially when water reservoirs (tanks) are present in the water network. Number of “pump switches” is a surrogate measure of pump maintenance cost - a pump’s wear can be indirectly measured through the number of times it has been switched on.

The valid schedule should fulfill some additional constrains:

- At each time unit (hour) the water reserve in the reservoir tanks cannot be lower than the minimum value set by the user.
- At the end of twenty four hours the summarized water reserve in the tanks cannot be lower than the reserve at the beginning of this period.

The optimization run gives at its end the pump work schedule that minimizes overall operational cost of the water network.

## 4. Exemplary calculations

In Fig. 3 the investigated water net is modeled while in Figures 4, 5, 6 and 7 some exemplary pictures illustrating the process of performing the first control algorithm are shown.

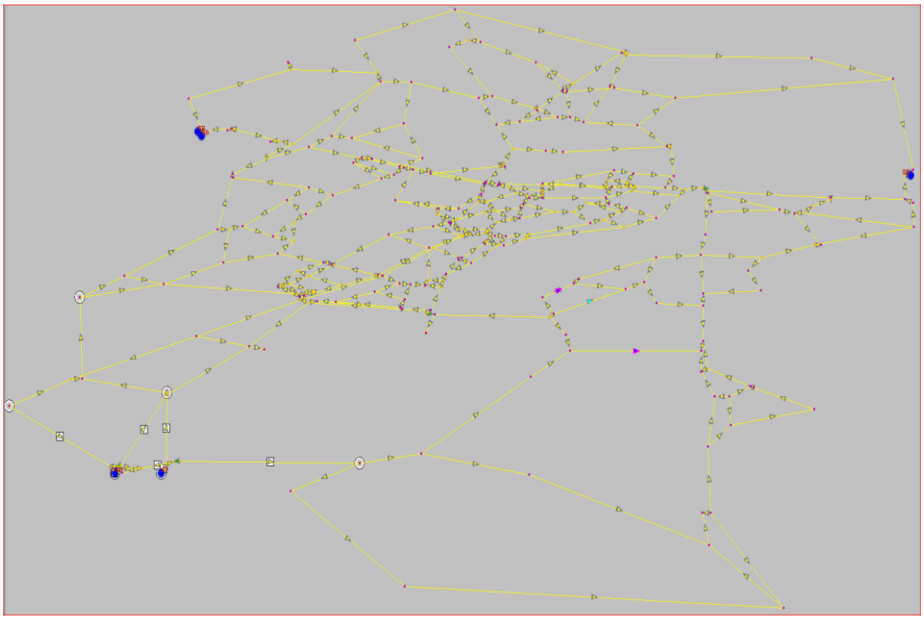


*Figure 3: Calculated water network with 2 pump stations (at bottom left)*

In the water net two pump stations are installed whose output pressures are to be minimized in the third objective function (Fig. 4). Additionally the possibility of installing a new pump station on a given pipe is considered. For all pump stations their lower and upper pressure values are fixed. While controlling the output pressures of the pump stations the water pressures on the output nodes of the water net have to be secured according to the values determined beforehand. The water net investigated consists of 280 nodes and 398 pipes.

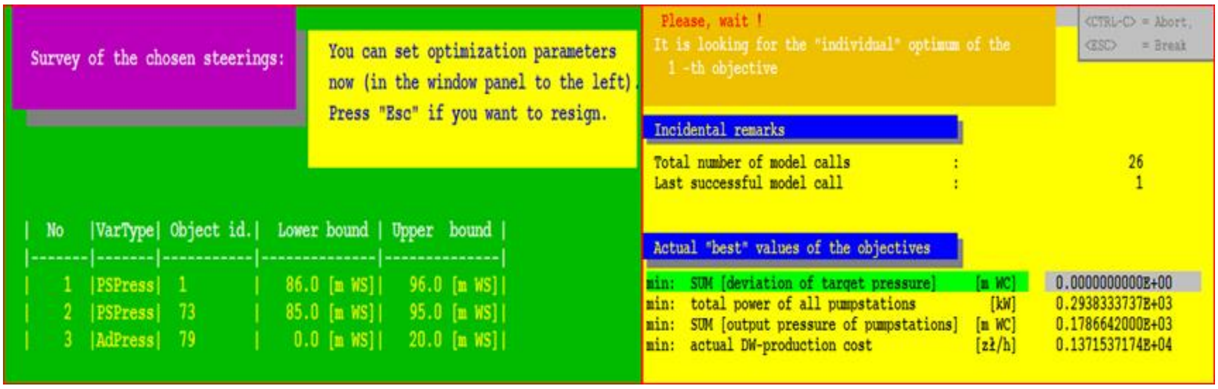



*Figure. 4: Given limiting values of output pressures for the considered pump stations and the calculated objective functions*

While performing the task of utopian optimization the separated one-criterion optimization runs for all objective functions are done (Fig. 5). As a result the optimal values for all criteria are calculated that can be regarded as reference values by the following Pareto optimization tasks. Some exemplary results of the solution of the Pareto optimization task with objective ranks are shown in Figures 6 and 7.

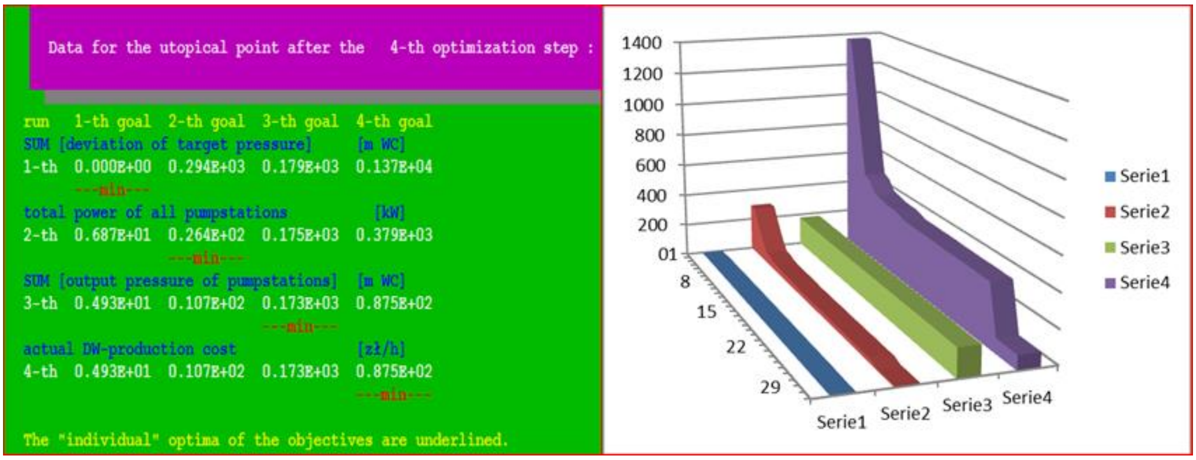



***Figure 5.** Results of the utopian optimization for the first control algorithm*

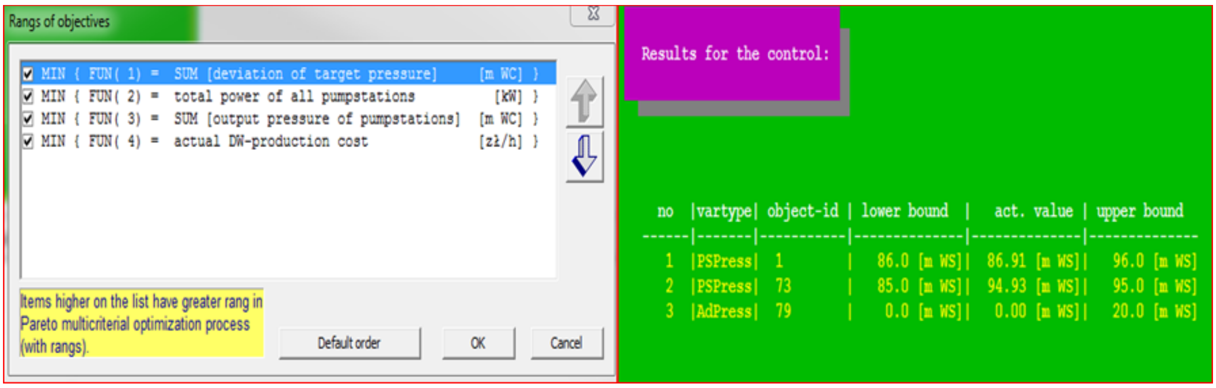
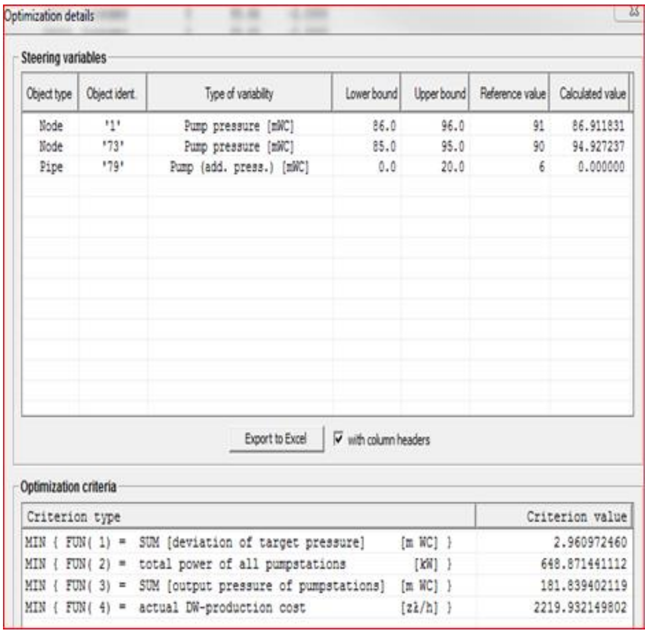



***Figure 6.** Objective functions for the Pareto optimization task with the objective ranks given and the resulted control parameter values for 3 pump stations considered.*



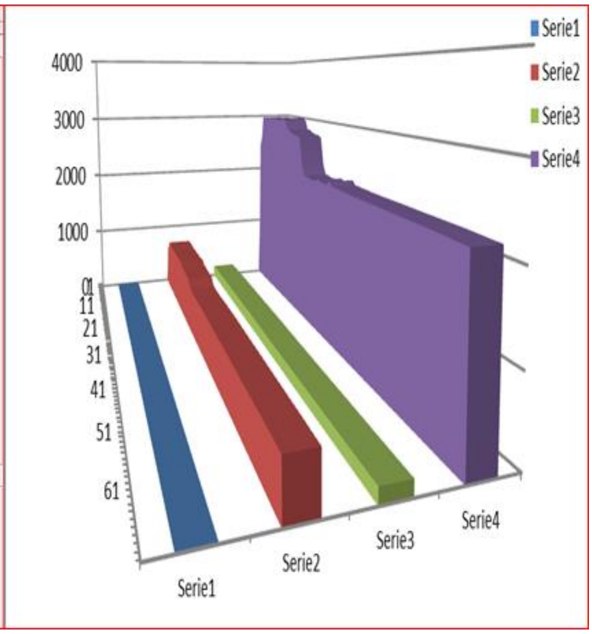



*Figure 7: Given lower and upper limiting values of output pressures for the considered pump stations and the resulted control parameter values for calculated objective functions*

One can see by the comparison of the tables in Figures 5 and 7 how big are the differences between the optimal and quasi-optimal results received for the utopian and Pareto optimization tasks respectively (Table 1). Although the results obtained for the first three criteria while solving the Pareto optimization task are acceptable then the water production cost are much too high. The reason for it is placing this criterion at the end of the criteria ranking list what results in a very limited area of steering values while searching for the criterion optimal point. Now in the management of the water net operator is to decide what is more important for the waterworks: to pay less for the water production or to secure right water pressures on the end nodes of the water net or to take care about the rational operation of the pump stations. Depending on his decision the sequence of the objective functions can be change in the rank list.

| **Objective function** | **Utopian task** | **Pareto task** | **Unit** |
|---|---|---|---|
| FUN(1) | 0,00 | 2,96 | m WC |
| FUN(1) | 26,4 | 648,9 | kW |
| FUN(1) | 173,0 | 181,8 | m WC |
| FUN(1) | 87,5 | 2.219,9 | PLN/h |

*Table 1: Comparison of the results for utopian and Pareto optimization tasks*

While calculating the second algorithm only the task of Pareto optimization with ranks has been tested. For the calculation the following assumptions have been made:

- In the calculation only control of two pump station installed in the water net is considered.
- One of the stations has only 1 pump and the other one has 2 pumps which are to be controlled.
- For all pumps their characteristics of output pressure in [m WC] depending on water flow in [l/s] and of efficiency in [%] depending of water flow are set (Fig. 8).
- The time step of pump work equals to 2 h what means that in the period of 24 hours there are 12 time periods in which each pomp can be switched on or off.

- The hydraulic load of the water net for 24 hours is set in advance (Fig. 9).
- The control schedule being the result of the calculation will show the operation cycles for 3 pumps in 2 hour time steps.

In this algorithm a singular calculation of the criteria values requires the multiple run of the hydraulic model (24 times) considering the water consumption in the network end nodes for each hour. However in the first algorithm the hydraulic model was run only once for singular calculation of the criteria values.

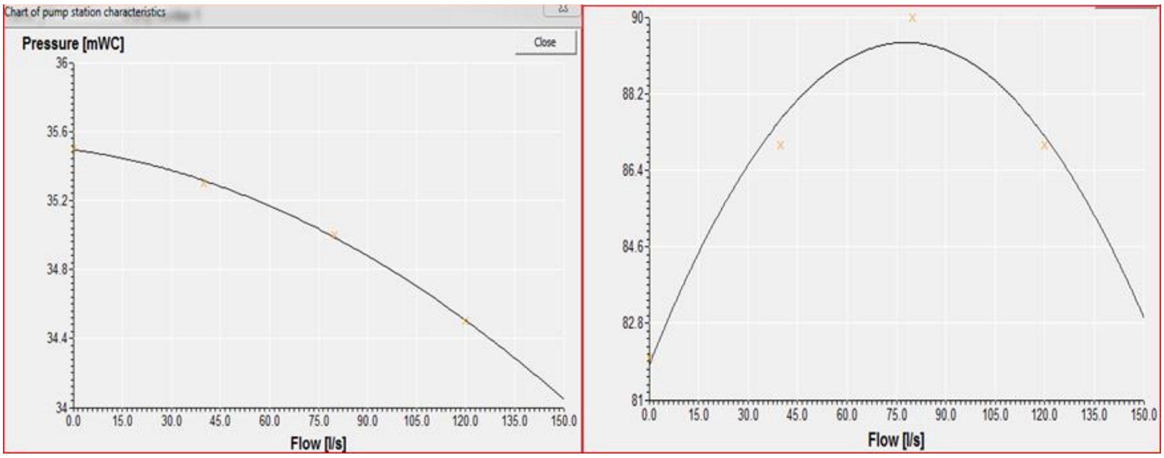



*Figure 8: Exemplary working characteristics for 1 pump*

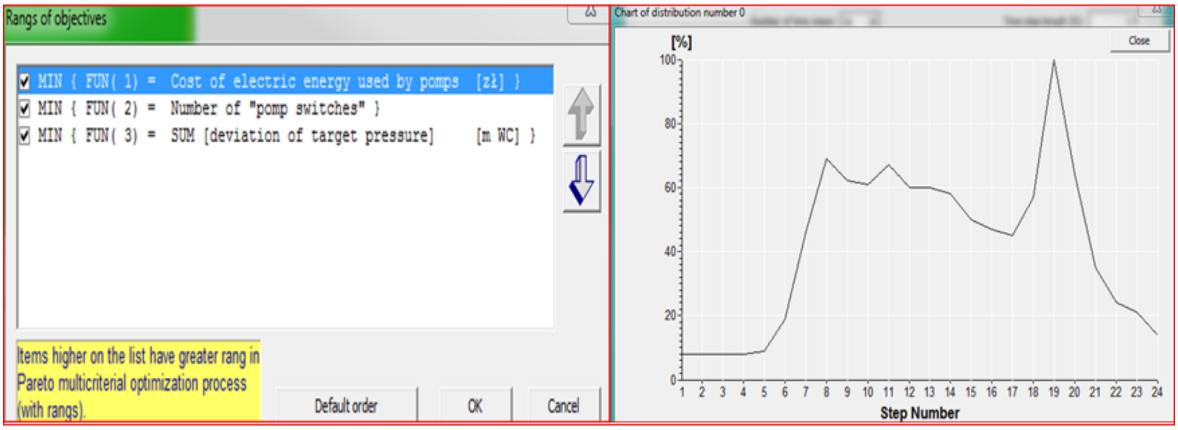



*Figure 9: Objective functions given for the second control algorithm and the function of the hydraulic load of the water net*

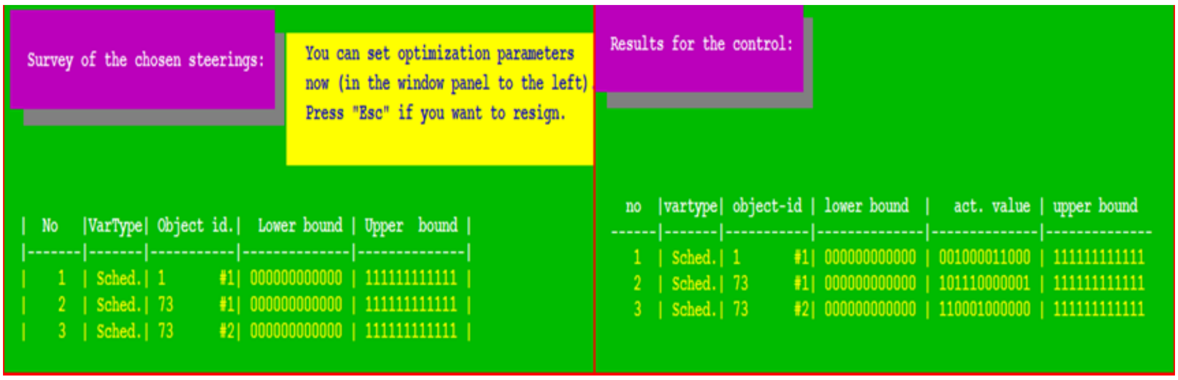



*Figure 10: Given lower and upper limiting values for pump schedules and the resulted control schedules for calculated objective functions*

The results of calculation are shown in Figures 10 and 11. One can see from the table in Fig. 11 that the first two criteria have got their quasi optimal values acceptable but in third criterion the difference between the required and calculated pressures in the end nodes of the water net seems to be quite big (2.018,8 m WC = 202 atm.). But it is the sum of pressure differences for all output nodes, and the value for each node is the total for each of 24 hours. As in case of the first algorithm the improvement of the results could be achieved by changing the sequence of the objective functions in the rank list. The decision for such the action is on the side of the water net operator.

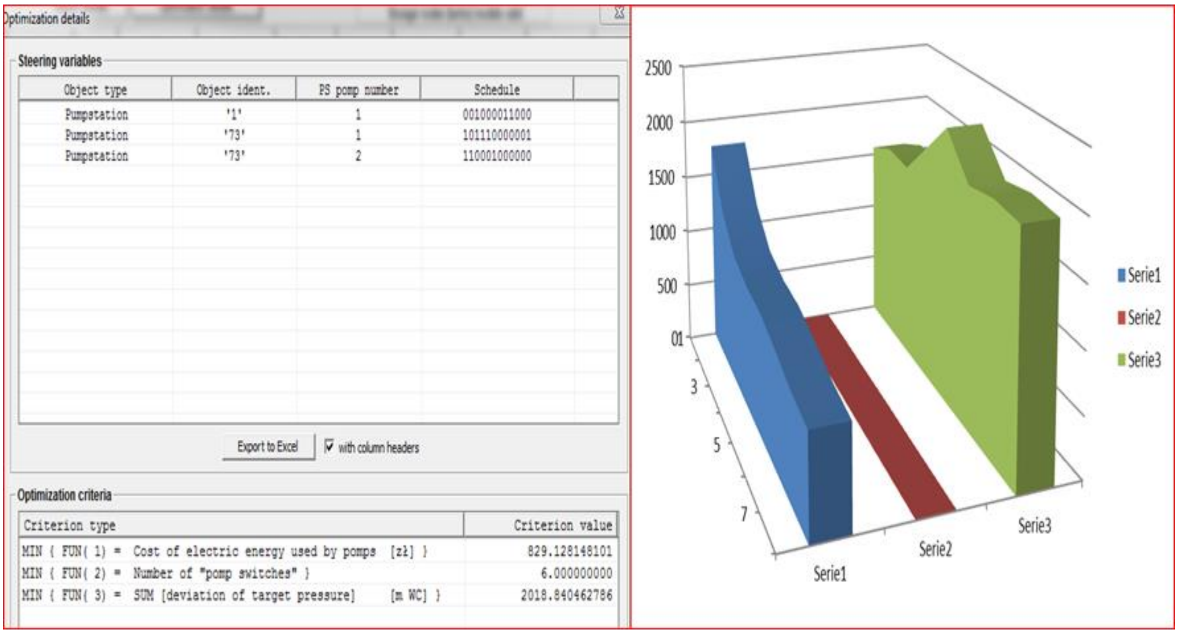



*Figure 11: Results of calculation for the second algorithm*

## 5. Conclusions

A central production and distribution of water for cities realized by waterworks creates a complex of research problems consisting of water network control belonging to technical tasks and of water network management belonging to organizational tasks. The main goal of each waterworks is the production of drink water that will be provided to the individual or collective consumers in amounts needed, in a good quality and with a possibly small price. The implementation of the presented ICT system in waterworks shall cut down the operational costs of the water net, boost its reliability and ensure a high and homogeneous quality of the water. The integrated ICT system shall also improve and make easier the job of water net operators and planners and of the management staffs of waterworks. In case of operators the improvements will concern the operational control of the water network, in case of planners they will concern better and faster planning of the investments regarding repairs, modernizations and expansions of water networks and in case of management staffs the improvements will concern the complex and more effective waterworks management. The implementation of the ICT system shall be especially important and useful for city agglomerations running complex and wide spread water networks. Such the networks are characterized usually by great exploitation costs resulted from water losses caused by water net damages and from the great costs of the energy used [3, 9]. The last trend in development of complex ICT systems is to include the IT systems concerning the management of waterworks into wider systems prepared for Smart City management [2]. In such cases the waterworks systems are integrated with other systems dedicated to traffic, persons and streets monitoring, air pollution forecasting, flood threat modeling, rescue management etc.

## Aknowledgement

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# Research the applicability of IFAS model in flood analysis (Pilot at Bang Giang river basin in Cao Bang Province)

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## Abstract

In climate change context, the increase of seriousness of natural disasters including flood is considerable. Thus, flood monitoring has been used to understand its rule and increase human subjective sensitivity on this catastrophe, in order to find management solution. However, this is not an easy job at national, regional and organizational levels because of lack of monitoring equipment, operational fund or lack of reliable data.

To solve this problem, IFAS (Integrated Flood Analysis System) model was built. By using the input data which can be downloaded completely free for research, such as land use, elevation, especially rainfall data - this is completely new method comparing to current hydrological models. In this study, IFAS model is implemented at Bang Giang river in northeastern Vietnam. Through the algorithms of model, outputs are water level and discharge of surface, subsurface, aquifer, river course and vertical seepage in 3 forms: map, chart and table, showing the detailed information related to the flood. Assessing accuracy of the flow simulation model by relative error of the peak of flood ($\Delta Q$) and Nash–Sutcliffe coefficient (R) shows that the flow simulation model achieves high accuracy in large rivers ($\Delta Q$= -13.63%, R=0.93) and low accuracy in small river branches ($\Delta Q$=+57.64%, R=0.44).

## 1. Introduction

Flood is considered as the most dangerous disaster in Vietnam – an agricultural country. There are about 7 storms per year, occurs mostly from July to October, brings large volume of runoff to the relatively large catchment areas and causes damage to people and property.

Common hydrological models in Vietnam includes: Rational, HEC-HMS, TANK, SSARR, NAM, VRSAP, DHM, etc. These models are tested at many different rivers in Vietnam e.g. Tuy Loan, Hong, Thai Binh, Thu Bon rivers [1, 2, 4, 6] to solve problems of flood forecasting and analysis, and obtained helpful results. However, most of them faced difficulty in providing input data (due to poor data, especially high and rural areas where don't have observation stations). IFAS model solves this problem by using satellite data which are available on the Internet. Thus, it can work for anywhere and anytime (satellite data has range from 2003 to present)

Bang Giang river is the main river in Cao Bang province, located in northeastern Vietnam where has the annual rainfall over 1500mm, focus from June to October. This river flows from Ha Quang district, passes through Hoa An district, Cao Bang city, Luc Hoa district (Vietnam) and finally comes to Quang Tay province (China). Its length is 108 km and total of basin area of approximately 4,200 $km^2$.

Aims of study:

(1) Apply IFAS model flood analysis in Bang Giang river basin, Vietnam

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(2) Assess accuracy of the satellite rainfall data and accuracy of the flow simulation model

(3) Assess applicability of IFAS in small scaled river basin

## 2. Material and Methodology

### 2.1. Material

IFAS is a deterministic model, founded by ICHARM (International Center for Water Hazard and Risk Management) of Japan for analysis flood on the basin river. It calculates flows basing on the amount of rainfall similar to tank principles of TANK and NAM models.

Input data of IFAS are base map and satellite rainfall data, which are available on the Internet.

- Background map are derived from Global Map4 - Digital geographic information in 1 km resolution covering the earth's surface with standardized specification and available to everyone at marginal cost. Global Map data have 8 layers: Boundaries, Drainage, Transportation, Population Centers, Elevation, Land use, Land Use, and Vegetation. Two layers which are used in IFAS, are Elevation and Land use.
- Global rainfall information observed by satellite is free for downloading on the Internet. The products called 3B42RT (provided by satellites TRMM/TMI, SSMI, IR of NASA) and GSMaP (provided by satellites TRMM/TMI, Aqua/AMSR E, ADEOS II/AMSR, DMSP/SSMI) are such rainfall data set.

After setting coordinates of study area and importing input data, boundary, river course and parameters will be created. Time scale is from 07/01/2009 to 07/15/2009.

### 2.2. Methodology

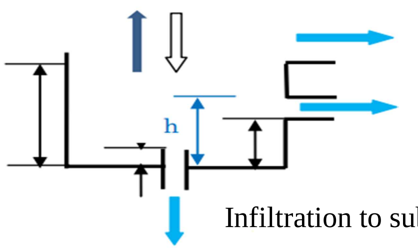
To simulate flood process, IFAS uses the theoretical of tank model and Manning's law, Darcy's law and kinematic wave method.

When the horizontal and vertical flows are formed, IFAS divides them into 4 types of model: Surface tank, Subsurface tank, Aquifer tank, River tank.

#### 2.2.1. Model outlines [5]

**a) Surface tank model**

The surface tank model is a model used to divide the rainfall to surface, rapid intermediate, and ground infiltration flows.




Surface flow (Mainning's law): $Q_{sf} = L\frac{1}{N}(h - S_{f2})^{5/3}\sqrt{i}$

Rapid unsaturated subsurface flow:

$Q_{ri} = a_n.A.f_0 \frac{h - S_{f1}}{S_{f2} - S_{f1}}$

Infiltration to subsurface tank

$Q_0 = A.f_0 \frac{h - S_{f0}}{S_{f2} - S_{f0}}$

*Figure 1: Flows in surface tank model*

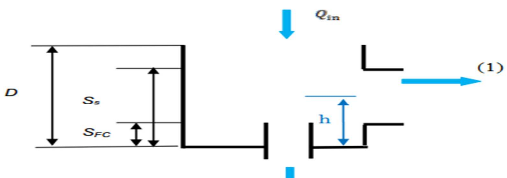
With:

[4] See http://www.iscgm.org

| | |
|---|---|
| R: rainfall | h: water height for the tank |
| Eps: Evapotranspiration | Sf2: height from which surface flow occurs |
| Q0: infiltration to lower tank | Sf1: height from which rapid unsaturated subsurface flow occurs |
| Qsf: surface flow | Sf0: height where ground infiltration occurs |
| Qri: rapid unsaturated subsurface flow | A = L*L : mesh area with L, mesh length |

**b) Subsurface tank model**

The subsurface tank model makes it possible to simulate low flow conditions as well as long-term periods.




Slow unsaturated subsurface flow (Darcy's law): $Q_{s1} = K_x.D.L.i$

Infiltration to aquifer (Darcy's law): $Q_{s2} = K_z . A$

*Figure 2: Flows in subsurface tank model*

If $h \geq S_S$, then the subsequent flow is considered coming out from the surface tank as rapid unsaturated subsurface flow.

With:

| | |
|---|---|
| Eps: Evapotranspiration | SS: height when θ=θS, soil moisture is equal to soil moisture at saturation and θS=SS/D |
| Qin : flow entering the subsurface tank | |
| QS1: slow unsaturated subsurface lateral flow | |
| QS2: slow unsaturated subsurface vertical flow | SFC: height when θ=θFC, soil moisture is equal to soil moisture at wilting point and θFC=SFC/D |
| D: maximum water height for subsurface tank | |
| h: water height for this tank | θ: soil moisture content (=h/D) |
| i: slope with the adjacent cell | KX: horizontal hydraulic conductivity at θ |
| A: mesh area. | KZ: vertical hydraulic conductivity at θ |

**c) Aquifer tank model**

The configure ration of aquifer model is shown as the Figure below. The top right and bottom right orifices represent the unconfined and confined aquifer outflows, respectively. Outflow of ground water is considered as a fraction of confined aquifer to h, and of unconfined aquifer to $h^2$. These relationships were determined experimentally.

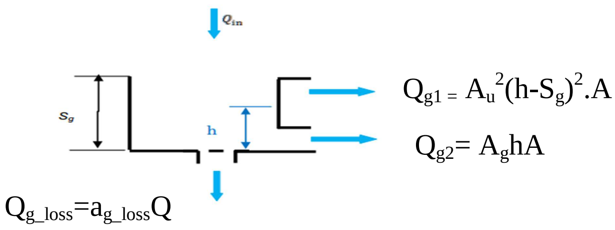



*Figure 3: Flows in aquifer tank model*

With:

$Q_{in}$: inflow to the aquifer tank

$Q_{g\_loss}$: unaccountable aquifer loss

h: water height of model

$Q_{g1}$:slow saturated subsurface flow

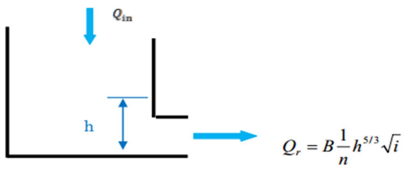
$Q_{g2}$:base flow

$S_g$: height from which slow saturated subsurface flow

**d) River course tank model**

For river discharge calculation, the equations used differ according to the cell type.

River discharge calculation for cell type 1 and 2: Outflow from the river course tank is based on Manning equation for cell type 1 and 2.




$$LB\frac{\partial h}{\partial t} = Q_{in} - Q_r$$

*Figure 4: Flow in river course tank model*

With:

$Q_{in}$: flow entering the river course tank

L: length of river course

$Q_r$: outflow from river course

B: breadth of river course

The river course breadth is calculated according to the Resume Law:

$B = cA^s$ (c and s are constants, generally s<1).

Because the model is considering runoff, the influence on the river course outflow is omitted

For river course tank in cell type 3, the river routing method is the kinematic wave method using the difference method:

$$\frac{\partial Q}{\partial t} + C\frac{\partial Q}{\partial x} = 0 \qquad \text{With } C = \frac{dQ}{dA}$$

C: the kinematic wave celerity

### 2.2.2. Assessing method

Accuracy of the model is assessed basing on satellite rainfall and discharge of river.

| Satellite rainfall | Discharge of river |
|---|---|
| Correlation coefficient:<br>$r_{xy} = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}.\sqrt{n(\sum y^2) - (\sum y)^2}}$<br>y is the measured rainfall<br>x is the satellite rainfall<br>n is the number of measurements<br>And difference in total rainfall d(%) = $\frac{\sum y - \sum x}{\sum x}$ | Relative error of the peak of flood<br>$\Delta Q\ (\%) = \frac{Q_{model} - Q_{\max measured)}}{Q\max measured}\%\Delta$;<br>Using Nash–Sutcliffe coefficient [3]:<br>$R^2 = 1 - \frac{\sum_{i=1}^{n}\left[Q_{obs,i} - Q_{sim,i}\right]^2}{\sum_{i=1}^{n}\left[Q_{obs,i} - \bar{Q}_{obs}\right]^2}$<br>where $Q_{obs,i}$: flow measured at the time of the $i^{th}$ |

| | |
|---|---|
| | $Q_{sim,i}$: flow calculated at the time of the i$^{th}$<br>$\overline{Q}_{obs}$ : Average measured flow all time |
| If $r_{xy}$ > 0,6 and \|d\| < 30%, the satellite-based rainfall data is usable. | If R > 0,7 and \|ΔQ\| < 30%, simulation model is acceptable. |

## 3. Results and Discussion

### 3.1. Results

Parameters such as initial water height, surface roughness coefficient, saturated moisture content, moisture content at field capacity, etc., are calibrated to suit with characteristics of study area.

Figure 6 shows simulated hydrograph before and after calibration compared with measured base on heavy rain in August 2008.

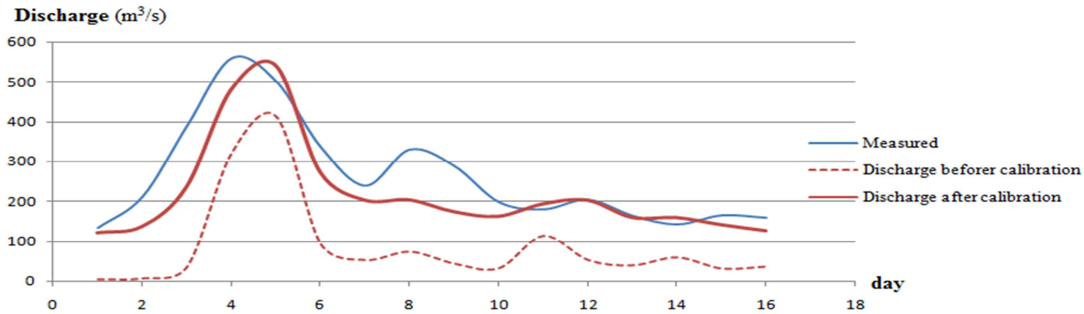



*Figure 5: Simulated hydrograph before and after calibration (8/01/2008 to 8/16/2008)*

By using parameters calibrated and the calculations mentioned above, IFAS model gives results in 3 formats: map (which can be exported to Google Earth), chart and table for each hour and each cell. Output information is water level and discharge of surface, subsurface, aquifer, river course and vertical seepage.

**Results with image format**

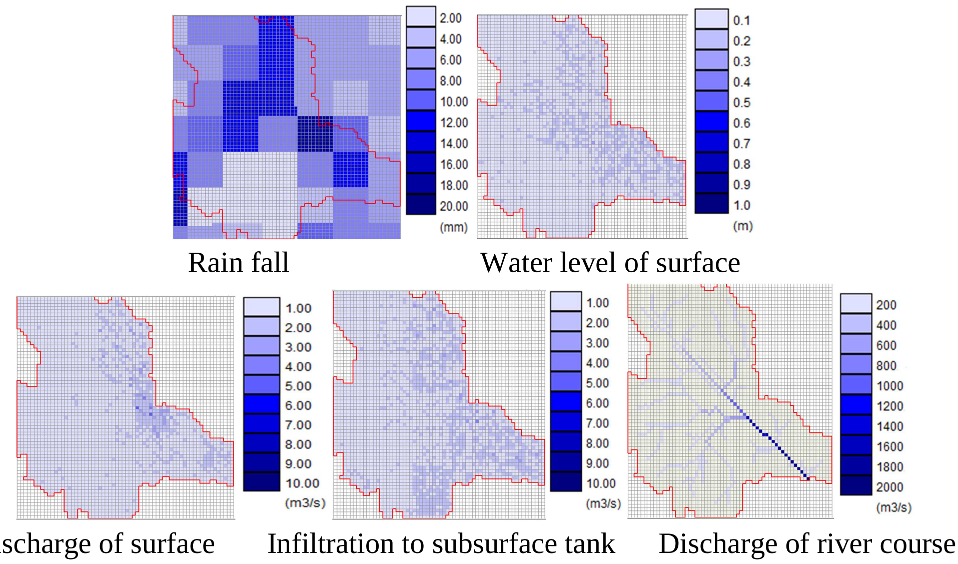



*Figure 6: Result images at 18:00 07/03/2009*


*Figure 7: Discharge of river course is exported to Google Earth*

Exporting results to Google Earth supports observations more exactly.

**Results in table and graph**

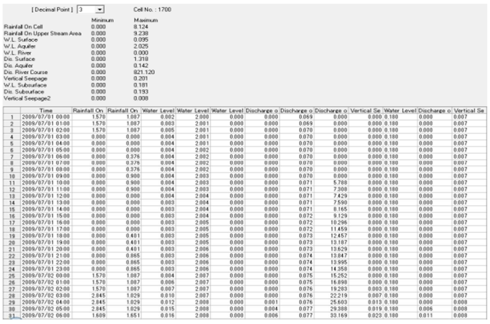


*Figure 8: Result table in Cao Bang city*

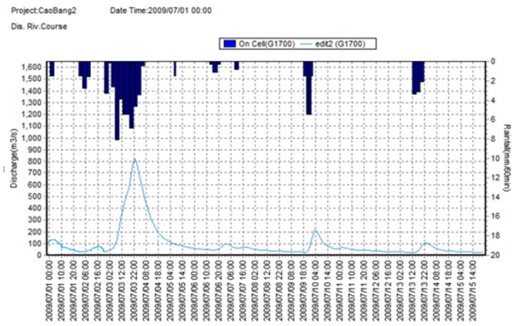



*Figure 9: Result graph in Cao Bang city*

The results show that there was a big rain from 2009/07/03 02:00 to 2009/07/04 08:00. It made water level of surface in some monitoring points increased by 0.2m and discharge of river course in the upstream up to over 2000 $m^3/s$ at 18:00 07/03/2009 (Fig 6). In Cao Bang city, discharge of river course is lower with the peak of it 800 $m^3/s$ at 22:00 07/03/2009 (Fig 9).

## 3.2. Assessing the model

### 3.2.1. Assessing the accuracy of the Satellite-based rainfall data

Satellite-based rainfall data is compared with measured rainfall at 2 observation stations: Cao Bang city (106°16' E, 22°39' N) and An Lai (106°19' E, 22°43 N).

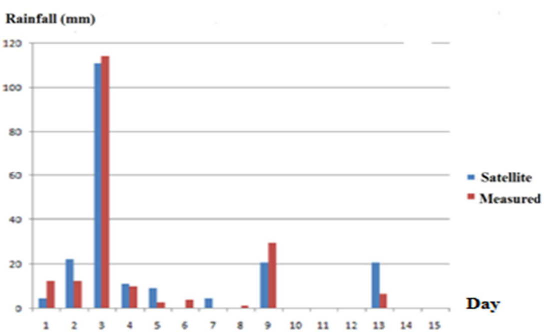



*Figure 10: Graph of satellite rainfall and measured rainfall in Cao Bang*

$d = +6.2\%$ ;

$r_{xy} = 0,978$ ;

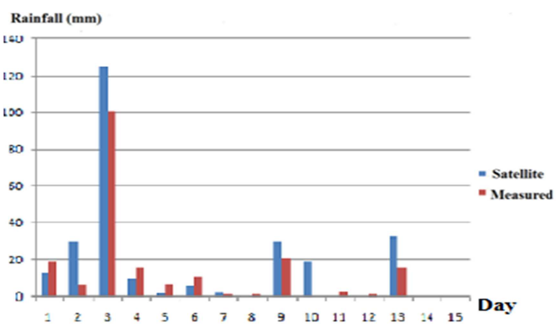



*Figure 11: Graph of satellite rainfall and measured rainfall in An Lai*

$d = +25.76\%$

$r_{xy} = 0.95$

The result of correlation coefficient showed that satellite-based rainfall reliable for calculation.

### 3.2.2. Assessing the accuracy of the flow simulation model

Discharge of river of model is compared with discharge of river measured at 2 observation stations: Cao Bang city (106°16' E, 22°39' N) and Duc Thong (106°15' 0" E, 22°30 N).

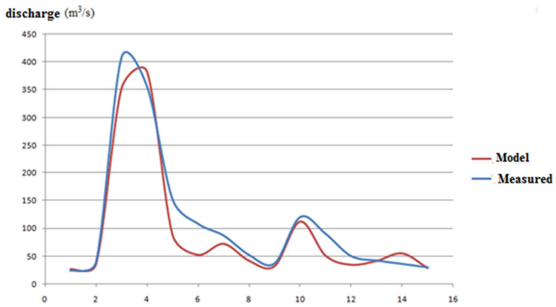



*Figure 12: Discharge of river of model and measured in Cao Bang*

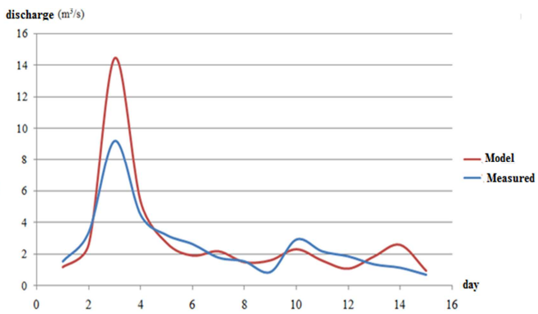



*Figure 13: Discharge of river of model and measured in Duc Thong*

ΔQ = -13.63%;
R = 0.93;
→ Simulation model is acceptable

ΔQ = +57.64%

R = 0.44

→ In this situation, simulation model is not acceptable.

Through the test at Cao Bang and Duc Thong, the results show the ability of flow simulation model achieve has high accuracy in large rivers and low accuracy in small river branches.

## 4. Conclusion

(1) With using the input data available on internet, including: satellite rainfall data, elevation, land use, parameters and the algorithm: Manning, Dancy, kinematic wave method, IFAS model calculate to give results in 3 formats: map (be able to connect with Google Earth), chart and table for each hour and each mesh. Output information are water level of surface, discharge of surface, water level of subsurface, discharge of subsurface, water level of aquifer, discharge of aquifer, vertical seepage, discharge of river course.

Results show that discharge of river course went to peak rapidly only after an hour rainfall got max (Fig 9). People in Cao Bang need to prevent before it is rain. In addition, most of water level and discharges are high in the southeast of river basin (Fig 6). Therefore, managers should pay attention to this area.

(2) Assessing accuracy of the satellite-based rainfall data by correlation coefficient and difference in total rainfall show that satellite-based rainfall data is completely reliable.

(3) Assessing accuracy of the flow simulation model by relative error of the peak of flood and Nash–Sutcliffe coefficient show that the ability of flow simulation model achieve has high accuracy in large rivers and low accuracy in small river branches. The large size of pixel (1km) can be reason for this. Model should be improved by decreasing the size of pixel. Besides, adding Soil layer and Geology layer to background map (now only Elevation layer and Land use layer) is necessary for IFAS to increase accuracy.

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# Computational method for prediction enhancement of a river flood simulation

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## Abstract

The occurrence of flood events has become more frequent in many parts of the world over the past 30 years and, consequently, more people are exposed to flood damages. Modeling and computational simulation provide powerful tools which enable us to forecast, in order to reduce flood damages. This work is oriented to address input parameter uncertainty toward providing a methodology to tune the flood simulator and so achieve lower errors between simulated and observed results. Even a much reduced parameter set is considered to run the flood simulator, the search space is large. The results obtained by using a parametric simulation heuristic and a clustering technique are promising and a reduction of the search space was achieved, consequently we could reduce the computational cost of the search for the best scenario and the optimization scheme implemented enables us to get a better understanding of the problem.

## 1. Introduction

Flooding is one of the most common natural hazards faced by the human society. Future climate change and its impact on flood frequencies and damages, make this problem a serious environmental problem. Flood damage refers to all varieties of harm caused by flooding. The computational simulations are used extensively as models of real systems to evaluate output responses. In particular, computational models are used to reach a better understanding on inundation events and to estimate flood depth and inundation extent. For these reasons, simulation becomes a powerful tool for predicting flood events and minimizing their environmental effects.

Predictions of flood simulation extent have been made possible by advances in numerical modelling techniques and increases in computer power. Nevertheless, a series of limitations cause a lack of accuracy in forecasting, such as the case of uncertainty in the values of the input parameters to the flood model. Hydrodynamic modelling of a fluvial channel involves defining certain parameters as input variables which, for various reasons, may incorporate uncertainties in the results. Firstly, these parameters are measured or estimated in certain particular points but the value of such parameters must then be interpolated to the whole domain. For example, levees height can be measured in some sections but then it is necessary to estimate the heights for the other sections. Secondly, the parameters measurement is not direct, as it involves an estimation error associated with the estimation methodology [1]. The parameters uncertainty has an important impact on the simulation output, which is far from approaching the actual observed data [2].

To overcome this problem, in our previous work, we implemented a parametric simulation in order to find the best set of parameters, or adjusted set, which will be used as the input set for the underlying flood simulator emulating an "ideal" flood simulator as much as possible. The main objective of this work is to add an optimization process to the classical prediction approach to tune

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input parameters, in order to minimize the difference between real and simulated result. The optimization method results in a large number of scenarios carrying out the search for the optimal, or suboptimal, set of input parameters. This process requires a huge amount of computation and it is on possible with resources in parallel programming and high performance computing.

Our work takes advantage of the results performed by the research group of High Performance Computing for Efficient Applications & Simulation at the University Autonoma of Barcelona, with close collaboration of the hydraulic engineering team at the National Institute of Water of Argentina. To conduct the research we selected the computational model EZEIZA V (Ezeiza), currently used as one of the tools of the Hydrologic Alert and Information System of the National Institute of Water (INA) at Buenos Aires, Argentina, in order to alert as early as possible on the occurrence of extreme water level events at the Paraná River basin, in South America [3]. The main limitations of this computational model are related to the reduced scale of the problem resolution (1D) and the inaccuracies in the river geometry representation. The model challenges are related to the uncertainty reduction in determining the flood peak arrival. This work goes in this direction by providing a better model calibration [4].

## 2. The flood wave simulator

Our work starts using a computer model of a real system such as flood events. The computational model is the conceptual model implemented on a computer, and the conceptual model is the mathematical representation of the physical problem to be modelled [5]. The selected software, Ezeiza, is a computational implementation of a one-dimensional hydrodynamic model for a flow net, based on the Saint Venant equations [6].

Ezeiza software family started to be developed in the '70s and its ongoing updating is performed by the INA staff. This computational model was chosen because of its simplicity when exporting results to output files, which can be processed by statistical and/or mathematical software, and for its convenience when running parametric simulations by changing the parameters values in the input files [4]. These features are very useful to take forward the tuning methodology.

An exhaustive study of the Paraná River model performance was carried out later by Ing. Latessa at INA, who stated the need to improve Ezeiza simulated results [7]. The utility of several efficiency criteria to evaluate hydrological performance model is addressed in [8]

## 3. Paraná River Model

La Plata basin is one of the most important rivers systems in the world. The Paraná River is one of the main rivers that form the basin. This is the second longest of South American rivers and it has a length of 4000 km alongside its major tributary, the Paraguay River (2550 km). The stretch of the Paraná River simulated by Ezeiza extends between the Yacyretá dam (Corrientes) to Villa Constitución (Santa Fe), both in Argentina. The Paraguay River runs from Puerto Pilcomayo (Formosa) to its confluence with the Paraná. Both river basins were divided into a number of sections, to measure rivers flow or height in each of them.

Large areas of land along the Middle and Lower Paraná margins are frequently subject to extended floods, which cause considerable damage. During the highest floods, monthly discharges at Middle Paraná exceed twice, and even three times, the mean discharge. A complete description of the highest floods at the Paraná basin and the possible climate forcing of such events are shown in [9].

The simulator Ezeiza prediction method is for height prediction in Parana River. In other words, Ezeiza is used to forecast daily water level variations at the Paraná River basin. The data required to define the modelled river system, as shown in Figure 1, is as follows:

- Initial conditions: levels and flow at every point of the river's domain.
- Boundary conditions: time series of rivers levels and flow at upstream and downstream points.
- Geometry data: data on the topography of the system.
- Input Parameters: Manning values and levees height, at every river sections.
- Observed data: water heights of Paraná River measured at each monitoring station.

This information was provided by INA, including the observed (actual) data of 1994 - 2011 period of time whose values are daily heights measured at 15 monitoring stations placed along the Paraná River basin.

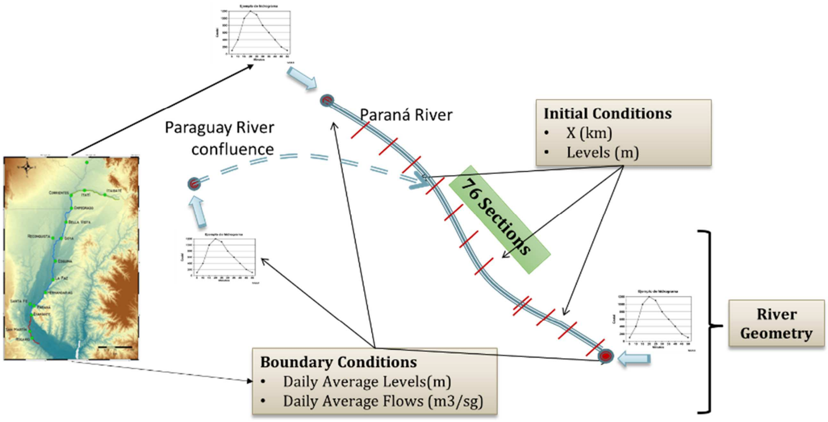


*Figure 1 Flow net topology*

Despite following 15 control stations, the levels are modeled throughout the length of the river. To define the flooding areas, the information of the modeled height should be crossed with ground levels. In general, every city has predefined levels of warning and evacuation.

When a simulation is run, Ezeiza returns a time series of heights values, which are calculated at each one of the 15 monitoring stations. These simulated data and the observed data, for the simulated period of time, are compared with each other to determine a *similarity index* (SI) that will be used to measure the simulation accuracy, to which we will return later.

The more sensitive input parameters of the flood routing models are the rugosity coefficient, or Manning values, and the levees height. Manning values for flood plains can be quite different from values for channels; therefore, manning values for flood plains are determined independently from Manning values for channel [10]. Finding an adjusted set of parameters is a key issue for our work, because it is the major step in order to develop a tuning methodology.

## 4. The Tuning Methodology

### 4.1. Parametric Simulation

The parametric simulation consists of changing the values of the internal input parameters and launching as many simulations as different combinations of parameters values are possible. In this kind of experiments it is possible to make deliberate changes in the parameters values. A scenario is defined by a particular setting of the set of parameters.

The number of possible scenarios is determined by the cardinality, $C_i$, for each of the $N$ parameters considered. For each parameter $i$ we define an associated interval and an increment value, which are used to move throughout the interval. For example, given the parameter $i$ we define the associated domain and step values with the tuple: $< [Limit_{inf}^{i}, Limit_{sup}^{i}], Step_i >$

$$\# \, Scenarios = \prod_{i=1}^{N} C_i \qquad (1)$$

$$C_i = ((Limit_{sup} - Limit_{inf}) + Step_i)/Step_i \qquad (2)$$

We show in equation ( 2) the cardinality expression for parameter *i*, where #Scenarios, in equation ( 1), is the calculation of the total number of scenarios that we obtain after performing all the possible combinations of parameters values. As we perform an exhaustive parametric simulation in this phase, we define each new scenario by changing a single parameter, leaving the other fixed.

Paraná River basin, which represents the model domain, was divided into 76 sections in order to measure river flow and height in each of them. Each section is characterized by a Manning value for floodplain, another value for riverbed and a levee height. Here we itemize the parameters domain:

- Manning values for floodplain are within the [0.1, 0.2] range, with an ideal step of 0.01
- Manning values for riverbed are within the [0.015, 0.035] range, with an ideal step of 0.005.
- Levees height is within the 5m to 50m range with a step of 5m. (The step value is set according to the local geography)

### 4.2. The Optimization Problem

In order to tune the simulation, a specific objective of this work is to implement an optimization process to find the best set of parameters. We mean, our objective is finding the combination of input parameters that minimizes the deviation of the simulator prediction from the real scenario.

Optimization is generally defined as the process of finding the best or optimal solution for a given problem under some conditions. Formal optimization is associated with the specification of mathematical objective function (called f) and a collection of parameters that should be adjusted to optimize the objective function. Mathematically an optimization problem can be stated as:

$$\begin{gathered} max/\min f(x) \\ subject\ to\ x \in S \end{gathered} \qquad (3)$$

Where $x$ is the variable; $f$ is a function $(f : S \rightarrow \mathbb{R})$; S is the constraint set, and $\exists\, x_0 \in S$ such that $f(x_0) \leq f(x)\ \forall x \in S,$ for minimisation, and $f(x_0) \geq f(x)\ \ \forall x \in S,$ for maximisation.

In this work, the optimization process, expressed by equation ( 3), can be defined as follows: We find the parameters vector $\overrightarrow{x^*} = [x_1^*, x_2^*, \ldots, x_N^*]$, N-dimensional, which optimize equation ( 3), where $\overrightarrow{x^*} \in S$ and the domain $S \subseteq \mathbb{R}^N$ represents the constrain set defining the allowable values for the $\overrightarrow{x^*}$ parameters. The search space of the problem is the S-dimension. In our problem, the search space consists of as many vectors as different combinations of parameter values are possible; so, we can say that S-dimension states the number of scenarios. Furthermore, we have to define a process to find a setting for the parameter vector $\vec{x}$, which provides de best value for the objective function $f(\vec{x})$. When there is no explicit form of the objective function and the parameter settings or design variables are discrete values, thus the optimization problems became discrete optimisation via simulation problems. We use the results obtained by [11] [12] [5].

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As simulation is computationally expensive, in particular when we need a greater search space, i.e., when we include more sections in the parameters vector, a new alternative was explored. The Monte Carlo (MC) based approach is one of the most popular, even though if the yield solution could be not the global optima, but rather an approximate good solution. MC is a statistical sampling method used to approximate solutions to quantitative problems.

### 4.3. Problem Delineation

An exhaustive search always guarantees finding a solution, if there exist a solution. In order to determine that solution, it may be necessary to test each possibility and verify if it satisfies the statement of the problem. The computational cost is high because it is proportional to the search space dimension. The search space for this model's parameters is determined tacking into account: a) the parameters corresponding to 76 sections along the river basin, b) considering that each section is divided into 3 to 5 subsections and c) the parameters domain, as we described in a previous section.

In an initial approach, the search of the optimum was done through an exhaustive search technique, even though it implies a lot of search time, it is guaranteed that the optimum is found. We combined only the Manning values, leaving aside levees heights. On this basis, if we had implemented an exhaustive search to find the adjusted parameters we would have launched $112^{76}$ simulations; this means that Ezeiza should have be executed $10^{154}$ times. With the aim to reduce the search space ($\mathbb{R}^N$), we had implemented a parametric simulation algorithm combining the possible Manning values in sections 70 – 72 – 74 and 76. The domain experimentation cardinality, which is shown in Table 1, was calculated using equation ( 2). We run the simulator 4096 times: $(4 \text{ x } 2)^4$. Even with this reduced setting of the parameter vector dimension, the search space is large. The observed data and the simulated data are time series of daily river heights at each monitoring station. The period simulated was 365 days (1999 year).

| Manning | Interval | Cardinality | C value |
|---|---|---|---|
| Floodplain | <[0.1, 0.2], 0.1> | ((0.2-0.1)+0.1/0.1 | 2 |
| Riverbed | <[0.010, 0.04], 0.01> | ((0.04-0.01)+0.01)/0.01 | 4 |

*Table 1: Domain cardinality for Manning values*

We implemented a solution to the "search problem", so we say to the "optimization problem", by using a parametric simulation technic applied to the reduced search space. We used the root mean square error (RMSE) as a metric to calculate the SI index, in order to evaluate the simulator response for each simulation scenario launched with Ezeiza and to find the minimum SI. We described in detail the steps involved in this methodology in [13]. The improvement percentage experiences, regarding simulated results come from INA's scenario currently used, ranges from 33% to 60% in the best three predicted stations. Running a full simulation under the conditions stablished lasted 2 minutes. When we run the 4096 scenarios, the execution time lasted 8192 minutes (137 hours). We used a master-worker approach to parallelize the method and reduce the computing time, this solution, however, is not sufficient when the dimension of the parameter vector grows. The computational cost grows exponentially in function of the number of section considered. In the future, it will be necessary to address this issue with a lower computational cost. Therefore, a better approach optimization technique, rather than an exhaustive search, must be used. Now, this approach, in a first phase, is using a computational process based on an iterative method of MC scheme, which is combined with a K-Means clustering method, in order to identify the regions where the optimum is. A second phase consists in a reduced exhaustive search [14].

The selected scenarios that have a better mean SI value than the previous ones are accumulated, in order to reuse past information. The MC program stops when two consecutive iterations cannot be able to improve the SI value, i.e., it becomes stationary or asymptotic, and the MC stores the last time when the average mean value was improved. We mean, it stops when the prediction error cannot be improved by the method. At each MC iteration, the parameters values of the input scenario were randomly selected to be fed into the simulator Ezeiza. To evaluate the improvement achieved by the method, we measured the SI for each scenario, which provides an adjustment rate between simulated results and observed data at each monitory station, taking into consideration the complete time series.

The final SI value is the mean of the RMSE calculated in the 15 output stations. The best SI value is compared with the SI reached by running Ezeiza with the INA scenario. The INA simulated results are the reference point to get the improvement rate achieved. This rate resulting of MC method can be expressed as follows:

$$Improvement_{Station} = \frac{abs(SI_{INA,} - SI_{\widehat{Scenario}})}{SI_{INA}} \qquad (4)$$

where $\widehat{Scenario}$ represent the best scenario, the $SI_{\widehat{Scenario}}$ is the minimum prediction error and $SI_{INA}$ is the INA prediction error.

## 5. Experimentation

The simulator is used as a black box, even though the more realistic the simulator is. We used the reduced search space of 4096 scenarios, which is the same domain configuration as the one used in our previous work. The same period of time was used to carry on the simulation and 4 section were selected, which are located at the lower Paraná. We remained the same conditions to evaluate the utility and reliability of this optimization method and compared both final results.

The objective of the index SI is to provide a metric to select the best scenarios. Each scenario configuration is represented by the objective function, and this function depends on the vectors $\overrightarrow{Sim}$ and $\overrightarrow{Obs}$, whose components are the simulated and the observed data respectively, for each output station and for each simulation day. The restrictions are the possible ranges of values that the parameters can take. This optimization problem is expressed mathematically in equation ( 5)

$$\begin{array}{ll} Minimize\ prediction\ error\ (SI) & f(\overrightarrow{Sim}, \overrightarrow{Obs}) \\ subject\ to & dias \in [01-01-1999 \,..\, 31-12-1999] \\ & 0.1 \le MannPlain \le 0.2 \\ & 0.01 \le MannBed \le 0.035 \\ & Section \in \{selected\ sections\} \subseteq \{76\ sections\} \end{array} \qquad (5)$$

Table 2 shows the scenarios resulting of minimum average of the index SI. These are the scenarios that allow us to reach better simulated results than the INA scenario results, where M-F is the Manning value for floodplain and M_R for riverbed. We mean that the improvement rate, as we show in equation ( 4), are the best achieved.

We are measuring the index mean for the 15 stations, so we cannot reach rates upper 15% yet for all the stations at the same time. In the other hand, some individual stations were improved in 30-40% and sometimes two stations resulted enhanced (Rosario 28% and San Martín 25%, but these enhancement were achieved in different scenarios). This situation needs to be improved in the future.

| | Section 70 | | Section 72 | | Section 74 | | Section 76 | | Improv. rate |
|---|---|---|---|---|---|---|---|---|---|
| | M-F | M-R | M-F | M-R | M-F | M-R | M-F | M-R | |
| Sce-1 | 0.02 | 0.1 | 0.02 | 0.1 | 0.03 | 0.2 | 0.03 | 0.1 | 14% |
| Sce-2 | 0.02 | 0.2 | 0.02 | 0.1 | 0.03 | 0.2 | 0.03 | 0.1 | 13% |
| Sce-3 | 0.03 | 0.1 | 0.02 | 0.1 | 0.03 | 0.1 | 0.03 | 0.1 | 12% |
| Sce-4 | 0.02 | 0.2 | 0.02 | 0.2 | 0.02 | 0.1 | 0.03 | 0.1 | 11% |
| Sce-5 | 0.02 | 0.1 | 0.02 | 0.2 | 0.03 | 0.1 | 0.03 | 0.1 | 14% |

*Table 2: The best scenarios selected by the first phase of the optimization scheme*

| Section | 70 | 72 | 74 | 76 |
|---|---|---|---|---|
| Mann.RiverBed | 0.02, 0.035, 0.03 | 0.02 | 0.02, 0.025, 0.03 | 0.03 |
| Mann.FloodPlain | 0.1, 0.2 | 0.1, 0.2 | 0.1, 0.2 | 0.1 |

*Table 3: Restrictions to the parameters values for the second phase*

This phase was successful. The search returned 4 scenarios with an improvement rate between 30% and 40% in 3 stations. We selected the best:

*Section 70: (0.03, 0.2), Section 72: (0.02, 0.1), Section 74: (0.035, 0.1), Section 76: (0.030, 0.1)*

with an improvement rate of : Station Rosario: 31% , Station San Martín: 35% and Station Diamante 38%. We point out that these ratios were achieved with the same scenario.

## 6. Results and Conclusions

In our previous work, the parametric simulation allowed us to test the goodness of the method and find 5 scenarios whose prediction error were less than the RMSE reached with INA’s scenario and the improvement was greater than 30% for each station. We run all the possible scenarios and we concluded that we could not get the same good results for more stations, at the same time and with the same scenario. Now, in this work, we use a two phase scheme. Firstly, we get the best (adjusted) set of parameters using a MC asymptotic scheme. MC + K-means arrived to the end in 4 steps, is said in 800 simulator running. If the new SI is not lower than the last one stored then there is no need to run MC again. We stopped the process when the new SI is not better than previous one. Secondly, we run a reduced exhaustive search for the reduced search space resulting from the previous phase, is said 76 simulator running were added. In this step we repeat the search used in the previous approach. We got an improvement of 30% to 40% and it is worth pointing out that we reduced the time of all the process. First, we needed to launch 4096 simulations and now we needed to launch 876 simulations. We have to enhance the prediction and adjust the heuristic technique but the results are promising and a better understanding of the problem was achieved. As future work, the MC method + K-Means clustering technique must be tested for all the sections and a huge amount of parameters values should be computed. Just this situation requires high performance computing. This will be a key resource to tune the simulator Ezeiza for a more accurate forecasting.

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# Application of hydrogeological modelling methods in forecasting seawater intrusion of Pleistocene aquifer in Thai Binh area

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## Abstract

This paper presents the application of hydrogeological modelling methods in forecasting seawater intrusion in Thai Binh area. Exploitation by UNICEF well systems have increased both inflow and outflow rate in Pleistocene aquifer by 2.4 times. Model is revised by solving steady state and transient models, all input coefficients have been identified (with Kx = 17.3, Ky =17.3, Kz =1.73, specific storage μ*= 0.0036, specific yield μ= 0.16 and effective porosity n0 = 0.16). By modelling two scenarios, we can show that Thai Binh province can keep on exploiting with the current rate Q = 31500 m3/day, the seawater intrusion in the Pleistocene aquifer is still developing but very slow (remain 99% current freshwater area in 2050). However, Thai Binh groundwater reserves cannot meet 50% of water needs in 2050 (if the exploitation rate is increased to 68000m3/day, only 95% current freshwater area remains in 2050).
*Keywords: hydrogeological modelling, Thai Binh, Visual MODFLOW, Pleistocene aquifer.*

## 1. Introduction

### 1.1. Case study

Thai Binh, a coastal plain province, where is an agriculture and industry center in the Red River delta. With the complicated hydrogeology conditions, although having abundant reserves of groundwater, but almost aquifers are confronted with seawater intrusion. Although there is not any large-scale groundwater exploited station, but thousands of UNICEF wells had been drilled uncontrollably to meet the freshwater demand having reduced the water table. It may be the main reason of seawater intrusion. We use hydrogeological modelling methods to identify effect of UNICEF wells to inflow and outflow rates of Pleistocene aquifer and use the revised input coefficients to forecast seawater intrusion in 2050. Actual state, rate, forecasting and protection of seawater intrusion should be considered to exploit the groundwater resources sustainably.

### 1.2. Geological setting

The study area is located in the longitude $106^0 06'33''$E to $106^0 37'35''$E and the latitude $20^0 05'15''$N to $20^0 43'57''$N. It is about 1542 $km^2$ and consists of eight districts and one city. The topography of the study area is quite flat. The average elevation is 1-2.5 meter above the sea level. The Quaternary alluvium sediment, including the mud clay, stiff clay, silty-clay, silt-loam, sand, and gravel, covers it completely. The Quaternary sediment may be divided into 5 units: Le Chi unit ($Q_I$lc), Ha Noi unit ($Q_{III-II}$hn), Vinh Phuc unit ($Q_{III}^2$vp1), Hai Hung unit ($Q_{IV}^{1-2}$hh1), and Thai Binh unit ($Q_{IV}^3$tb). There is unconformity separating the Quaternary sediment and the older sandstone,

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siltstone and limestone aged Paleozoic – Neocene. There are three aquifers in Quaternary sediment being the Upper Holocene aquifer (Qh2), the lower Holocene aquifer (Qh1) and the Pleistocene (Qp) and unconfined layer, Hai Hung sub-formation ($Q_{IV}^{1-2}$hh2) and upper Vinh Phuc sub-formation ($Q_{III}^{2}$vp2) in Quaternary sediment. According to the hydrogeology data, the main aquifer in Quaternary sediment is Pleistocene. It is considered to be at depth of 26-143 meter and its average thickness is about 29-127 meter. The water qualifies of Pleistocene aquifer can be divided clearly into 2 parts: the seawater (TDS >1000mg/l) is in the southern part and the fresh water (TDS <1000mg/l) is in the northern part of the province.

## 2. Materials and methods

This study based on hydrogeological modelling methods [8] and calculated by Visual Modflow software.

### 2.1. Hydro-geological modelling method

**Groundwater flow equation:** The movement of groundwater is simulated by linear parabolic partial differential equation. It is derived from the mass balance equations of the water volume distribution in aquifers and Darcy's law.

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t} \quad (1)$$

Where: $K_{xx}$, $K_{yy}$, $K_{zz}$ is the aquifer permeability by the x, y and z directions ($K_{xx} = K_{xx}(x, y, z)$, $K_{yy} = K_{yy}(x, y, z)$, $K_z z = K_{zz}(x, y, z)$). z is the vertical direction.

h: is the water level at the position (x, y, z) at time t.

W: is a real recharge (plus sign) or discharge (minus sign).

$S_s$: is specific storage ($S_s = S_s (x,y,z)$).

Equation (1) describes water level in conditions of inhomogeneous and anisotropic environment. This equation with the boundary conditions and original condition of the aquifers form mathematical model of groundwater flow.

**Solute transport equation:** the differential equation simulates solute transport in groundwater in case of ignoring the declining of solute concentration due to chemical reactions or radioactive decay:

$$\frac{\partial}{\partial x}\left(D_{xy}\frac{\partial C}{\partial y}\right)-\frac{\partial}{\partial x}\left(v_x C\right)+q_s\frac{C_s}{\theta}=R\frac{\partial C}{\partial t} \quad (2)$$

Where:

$D_{xy}$: Hydrodynamic dispersion coefficient

$v_x$: the real velocity of ground water

C: Concentration of transport solutes

$q_s\frac{C_s}{\theta}$ : Additional source of solutes

R: Retard factor, which indicates the influence degree of the solutes transport by absorbing or releasing.

So far, equations (1) and (3) were solved quite completely by the finite difference and finite element methods. Many hydrogeological laboratories in the world have built modeling programs to calculate groundwater flow model and forecast material transport to apply in hydrogeological studies and pollution forecast.

### 2.2. Visual MODFLOW

Visual MODFLOW software package includes three main software and many support modules. MODFLOW software is used to calculate the volume, quality and distribution of groundwater flows. Function of ModPath software is calculating the direction and speed of flow when it moves through aquifer system. MT3D software is used to calculate diffusion and transportation processes with chemical reaction of solutes in groundwater flow system [9].

The original version is made by Nilson Guiguer, Thomas Franz, Partrick Delaney and Serguei Shmakov. The commercial version is provided by Waterloo Hydrogeologic Company.

### 2.3. Input coefficient definition

**Grids:** The grid system which simulate environment of modelling area, is the finite difference grid. The cells outside the edge is assigned inactive and will not participate in calculation. The finite difference grid is established to calculate in model consists of 130 rows and 111 columns, to be distributed equally with the distance $\Delta x=\Delta y$ = 420m, total number of grid cells is 11430.

**Layers:** the *"Final report of drawing Thai Binh hydrogeology map, scale 1:50.000"* [4] and *"Final report of finding groundwater in Thai Binh province"* [1] show that cross section of study area consist of 5 layers. Because the 1$^{st}$, 2$^{nd}$ and 3$^{rd}$ layers are totally seawater, so in this study we only focus in the 4$^{th}$ and 5$^{th}$ layers:

**- The 4$^{th}$ layer:** is the low permeable layer in Pleistocene sedimentary formations in Vinh Phuc Formation. The average thickness is 12.8m, variation 3-30m. Hydraulic conductivity K = 0.0015m/day; specific storage $\mu^*$ = 0.0032; effective porosity $n_0$ = 0.01; total porosity n = 0.25.

**- The 5$^{th}$ layer:** is the Qp aquifer in Pleistocene sedimentary formations in Ha Noi Formation. The average thickness is 62.25m with variation 29-68.5m. Permeable layer with high water storage. Average hydraulic conductivity K = 12.43, varies 5 – 18 m/day. Specific storage $\mu^*$ = 0.003616, specific yield $\mu$ = 0.1677; effective porosity $n_0$ = 0.18, total porosity n = 0.3. This layer is confined aquifer. Most of this aquifer is seawater, the north of study area is freshwater with TDS < 1000 mg/l. Static water level varies 0.523 – 2.277 m from the ground.

**Border and boundary conditions:** Thai Binh province is bounded to the West, South West and South by the Red River, the East and the North Sea by Luoc River. Also, in the center of the study area, Tra Ly River crosses from west to east and enters the sea at Tra Ly estuary.

Results of previous geological and hydrological studies of Red River Delta region have confirmed a hydraulic relationship between Red River and the groundwater aquifers [2][4]. However, depending on the region, depending on the distribution of the aquifers and the level of the river cut into the aquifer, the river is high or low affected with aquifers. Red river affects directly to Qh2 aquifer and slightly to Qh1 aquifer. Red river doesn't affect to Qp aquifer. The analytical results show that the particle composition of river bottom sediments generally have small permeability coefficient about (1 - 2.5) x$10^{-3}$ m/s.

The inner boundary conditions in model is the hydraulic relationship between Qp aquifer and Qh1 aquifer by infiltration (the 3$^{rd}$ and 5$^{th}$ layers). According to previous study documents and the National observation construction data. Between Holocene aquifer and Pleistocene aquifer is the Vinh Phuc low permeable layer [7]. In addition, data of observation constructions (Q.156, Q.158 and Q.159) have shown that: water level in Pleistocene aquifer decreases due to exploitation while in Holocene aquifer, water level is almost unchanged. Therefore, boundary conditions type I, H=const, is above Pleistocene aquifer.

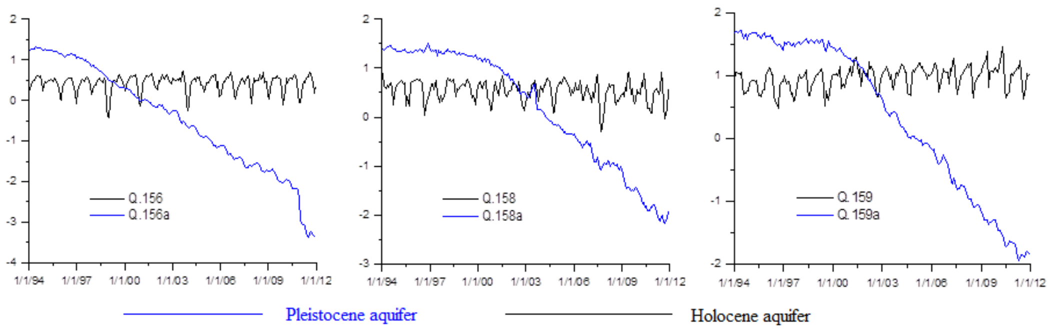


*Figure 1: Water level graphs of Pleistocene and Holocene aquifers*

The outer boundary conditions: the Pleistocene aquifer has not hydraulic relationship with rivers. According to "Partition Map of groundwater movement Red River Delta region", [7], the inflow is from northwest direction and flow out to Tokin Gulf (figure 4). To simulate the inflow from northwest direction, model use the boundary condition type II, Q = const, the flow rate is determined by the stability problem in natural conditions.

Tokin Gulf is the eastern boundary of the study area. The sea is the junction of the aquifers. The Pleistocene aquifer is not connected directly with the sea (Tokin Gulf). Go far to the coast, sediment become smoother and finally block water completely. Therefore, the boundary condition used here is type I, H= f(t).

**Recharge from precipitation and evaporation:** because in this study, the Pleistocene aquifer is the deepest layer, so cannot be affected by precipitation and evaporation.

**The original conditions:** with the groundwater flow equation is static water level map of Pleistocen aquifer in 1996 [4] and water level isodepth map of Pleistocene aquifer in 2012 (Trinh Hoai Thu, 2012). With the solute transport equation is TDS map of all aquifer in Thai Binh province, 1996 [4] and TDS map in Pleistocene aquifer in Red Delta regions, 2012. The boundary between fresh water area and seawater area is boundary of TDS 1000mg/l, which is identified from the previous study (Trinh Hoai Thu, 2012).

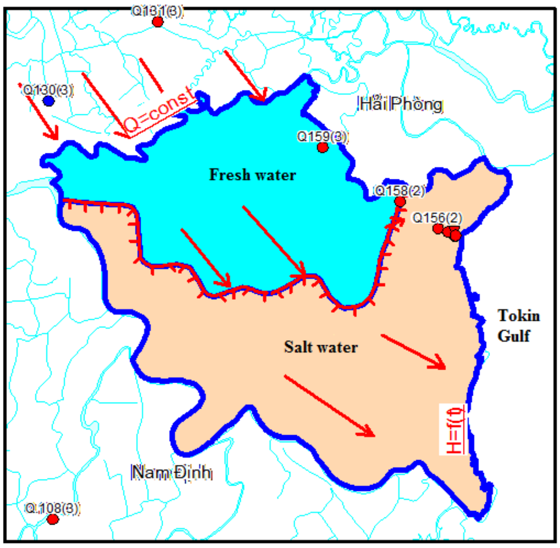


*Figure 2: Boundary conditions of Pleistocene aquifer*

## 2.4. Revising model

Model is revised by resolving two models:

Steady-state model: is solved to revise hydraulic conductivity K and revise boundary conditions preliminarily. The target is recovering the static water level in Pleistocene in 1996s (still not be exploited).

Transient model: purpose of resolving unsteady-state model is revising Specific yield and specific storage, keep on revising hydraulic conductivity. In addition, unsteady-state model has mission to revise and correct solute movement. Therefore, this problem has to solve both Groundwater flow and Solute transport equation.

The original condition of unsteady-state model is Water level map of Pleistocene aquifer in 2012 (the results of Steady-state inverse problem). With Solute transport problem is Distribution of TDS in Pleistocene aquifer, 2012 [5]

## 3. Results and Discussion

### 3.1. Results of steady-state and transient models

**Steady-state model**: the results are showed in the below table:

| | $Q_{in}$ ($m^3$/day) | [%] | $Q_{out}$ ($m^3$/day) | [%] |
|---|---|---|---|---|
| Northwest boundary | 10000 | 73.36 | 0.00 | 0.00 |
| Holocene aquifer | 9.68 | 0.07 | 25.57 | 0.18 |
| Exploited wells | 0.00 | 0.00 | 0.00 | 0.00 |
| Seawater area | 3578.6 | 26.25 | 13620 | 98.08 |
| Total | 13632 | 100.0 | 13886 | 100.0 |

*Table 1: Water balance of Pleistocene aquifer in original condition*

Results of water balance in the original conditions show that the $Q_{in}$ of the Northwest boundary accounts 73.6% the total inflow rate ($Q_{in}$). Infiltration from Holocene is only 9.68$m^3$/day (accounts 0.07% total inflow rate) while the inverse infiltration from Pleistocene is 25.57$m^3$/day (accounts 0.18% total outflow rate), because in original condition water level in Pleistocene is higher in Holocene. Water flow mainly from fresh water area to seawater area (account 98.08% total outflow rate) – “push seawater to the sea”.

**Transient model:** Similar to Steady-state, this problem is solved by iterative methods.

Unfortunately, in the Thai Binh area, there is not many observation constructions, especially in centre. In the national observation system, there are only 3 observation bores, 2 bores in Thai Thuy district are Q156 (Thuy Lien commune) and Q158 (Thuy Viet commune); 1 bores in Quynh Phu district is Q159 (An Viet commune). Observation data of bores Q156, Q158 and Q159 are used to revise transient model in exploited condition. The reliability of the model can be assessed through the mean square error.

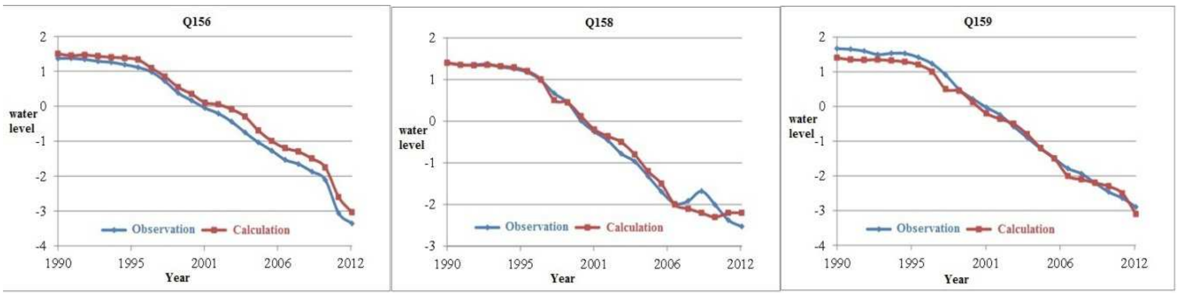


*Figure 3: Observation water level and calculated water level at Q156, Q158 and Q159*

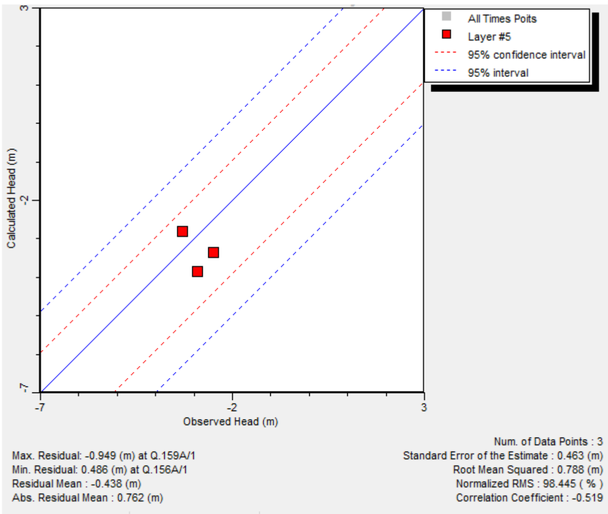


*Figure 4: Correlation between calculated water level and observed water level*

Error when revise model with transient model, were within permitted limits, average square error reach 0.788m (figure 7).

| | $Q_{in}$ ($m^3$/day) | [%] | $Q_{out}$ ($m^3$/day) | [%] |
|---|---|---|---|---|
| Water in Pleistocene aquifer | 6.5 | 0.02 | 267 | 0.81 |
| Northwest boundary | 10000 | 31.09 | 0.00 | 0.00 |
| Holocene aquifer | 188.03 | 0.58 | 0.00 | 0.00 |
| Exploited wells | 0.00 | 0.00 | 31500 | 96.12 |
| Seawater area | 21974 | 68.31 | 1005.6 | 3.07 |
| Total | 32162 | 100.0 | 33634 | 100.0 |

*Table 2: Water balance of Pleistocene aquifer in exploited condition*

Water balance calculation results show that by the impact of exploitation, water inflow and out flow rates are changed significantly. The both inflow and outflow rates increase by 2.4 times.

| Layer | $K_x$ (m/ng) | $K_y$ (m/ng) | $K_z$ (m/ng) | μ* | μ | $n_0$ |
|---|---|---|---|---|---|---|
| $Qh_1$ | 1.10 | 1.10 | 0.11 | 0.0028 | 0.14 | 0.14 |
| Low permeable layer | 0.001 | 0.001 | 0.0001 | 0.0013 | 0.02 | 0.02 |
| Qp | 17.33 | 17.33 | 1.73 | 0.0036 | 0.16 | 0.16 |

*Table 3: Summary table of input coefficients after revising*

We can show that the revised input coefficients is suitable with previous studies [1].

### 3.2. Seawater intrusion forecasting

Based on real situation of exploitation and water needs in the future, we propose two exploited scenarios to calculate developments of seawater intrusion in 2030, 2050.

**Scenario 1:** Keep exploitation rate of groundwater in Pleistocene aquifer equal to present Q = 31500 $m^3$/day.

**Scenario 2:** Increase exploitation rate to Q = 68000 $m^3$/day, account to 50% of water needs in 2050 (according to population growth rate of Thai Binh province (Statistics Yearbook, 2010)).

**Results:**

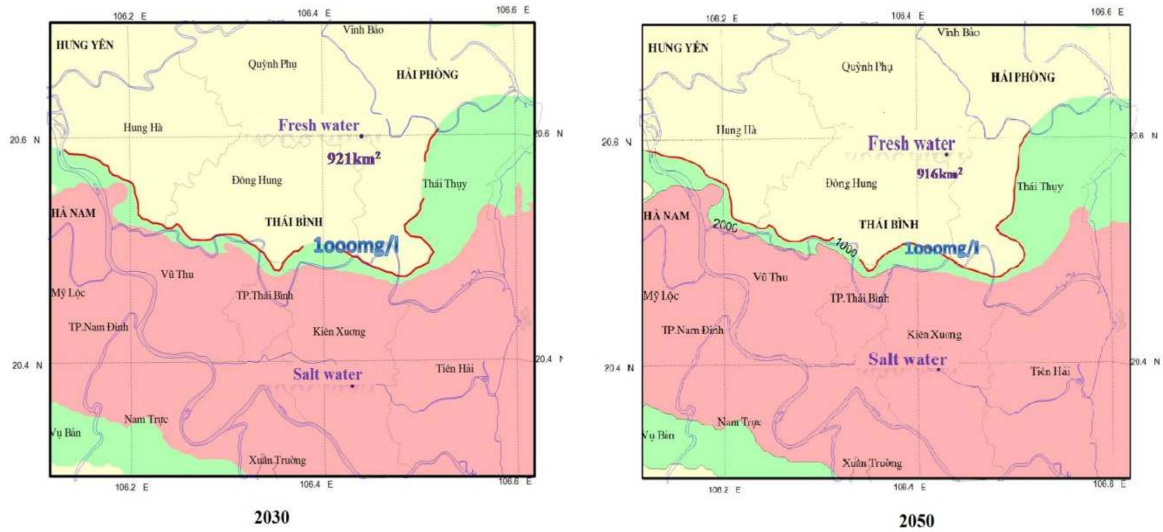


*Figure 5. The boundary line 1000mg/l scenario 1*

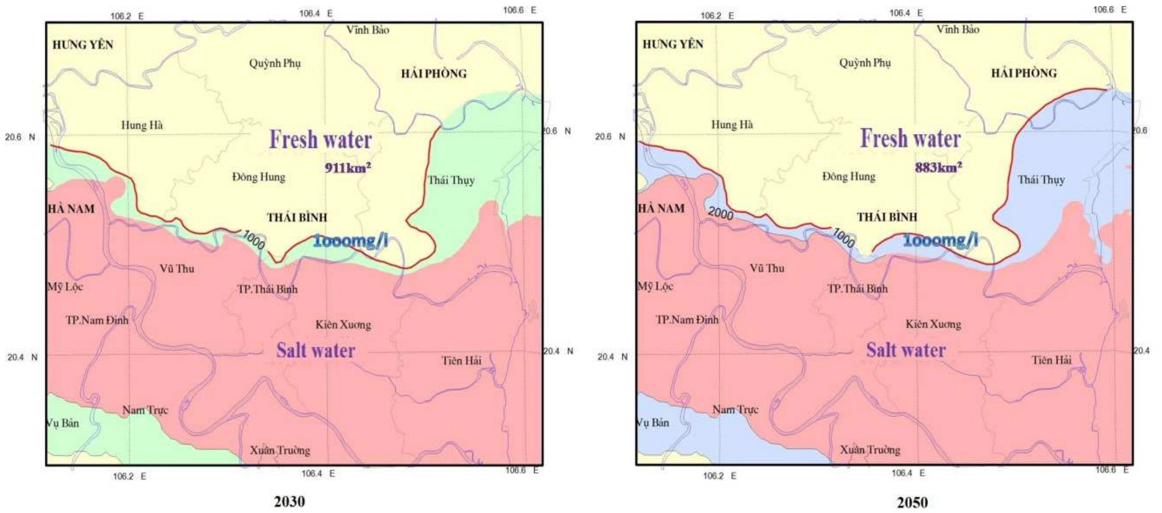


*Figure 6. The boundary line 1000mg/l scenario 2*

*Scenario 1*: With Q = 31500 $m^3$/ day boundary of TDS is 1000mg/l, the total area of fresh water in study area is 925 $km^2$ in 2012; 2030 decrease to 921 $km^2$ (99.56%), in 2050, decrease to 916 $km^2$ (99%). The seawater intrusion is developing but the rate is very slow.

*Scenario 2*: With exploitation rate 68000 $m^3$/day and boundaries of TDS is 1000 mg/l, the total area of fresh water in the study area is 911$km^2$ in 2030 (account 98.4%), 2050 decreased to 883$km^2$ (account 95.4%). Therefore, compare with scenario 1, we can see that by the exploitation process increases the salinization process in more depth.

## 4. Conclusion

By solving Steady-state and Transient models, all input coefficient have been identified with $K_x$ = 17.3, $K_y$ =17.3, $K_z$ =1.73, specific storage $\mu^*$ = 0.0036, specific yield $\mu$ = 0.16 and effective porosity $n_0$ = 0.16.

Groundwater exploitation from UNICEF well system has increased both inflow and outflow rate in Pleistocene aquifer by 2.4 times.

Forecasting model of seawater intrusion of Pleistocene aquifer in Thai Binh area have showed the changes of TDS level in study area and forecast to 2050. The total area of fresh water in study area is 925 $km^2$ in 2012 (boundary of TDS is 1000mg/l); With exploitation rate Q = 31500 $m^3$/ day in 2030 total area of fresh water decrease to 921 $km^2$ (99.56%) and in 2050, decrease to 916 $km^2$ (99%); With exploited rate 68000$m^3$/day , the total area of fresh water in the study area is 911$km^2$ in 2030 (98.4%) and in 2050 decreases to 883$km^2$ (95.4%).

With current exploited rate, the seawater intrusion keep developing but the rate is very slow. Thai Binh area can still exploit groundwater with the rate Q = 31500 $m^3$/day. This is a useful information for further studies and sustainable exploitation for study area.

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# Scalable Integration of 4GL-Models and Algorithms for massive Smart Grid Simulations and Applications

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## Abstract

This paper presents a scalable integration approach for algorithms and models written in fourth generation (programming) languages for massive Smart Grid simulations as well as applications. While fourth generation languages (4GL) focus on rapid application development and the reduction of lines of code, they lack of integration and scalability features. Nevertheless, they are widely spread and often used by engineers. The scalable integration of such elements is achieved in this paper by wrapping the 4GL-models and algorithms with established web technologies like RESTful web services and load balancing. The provision of a seamless integration concept allows engineers to focus on rapid application development and liberates them from integration efforts.


## 1. Introduction

Today's energy grid undergoes a structural change towards the so-called Smart Grid. The power grid will no longer be dominated by a relatively small number of large coal and nuclear power plants, but rather by a large number of distributed, renewable energy resources (DER). Hereby the control and coordination of this large number of DERs in order to balance the generation and demand is the main challenge. Due to the quantity and restrictions of the involved components it is a challenging task. With respect to the grid stability control strategies need to be developed as well as evaluated and tested particularly. To achieve this a wide range of simulation scenarios have to be established facilitating an economical transition towards a Smart Grid and ensuring its reliability [13]. The approach presented in this paper introduces a concept for the scalable integration of 4GL-models and algorithms for such Smart Grid simulations. It is also used in an ongoing industrial project dealing with the load-management of electrical heaters.

Fourth generation languages (4GL) are programming languages focussing on rapid application development while reducing the lines of code. The expression 4GL was coined by [9]. Recently this interpretation has gained new attention through the introduction of model based software development [1]. Examples for such 4GLs are MATLAB, Simulink, Modelica, GAMS (General Algebraic Modelling System) and many more. These languages respectively the languages offered by the according software products are used in many research projects for rapid prototyping as well as the realization of models or algorithms, e.g. for demand side management and the integration of regenerative energy resources into smart grids [4]. They reduce the overall development effort through the usage of comprehendible application-oriented paradigms. Furthermore, both the good

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readability and the user-oriented representation of 4GL programs facilitate the maintainability as well as the extensibility. This results in a significant reduction of development time and costs.

The integration of such 4GL models or algorithms into operative systems or large-scale simulations is a considerable challenge, as most of them have to be executed on their specific runtime environment. Even if they can be exported as independent external models and therefore be integrated into the infrastructure of operative systems (resp. simulations), a scalability problem remains. One possible solution is to rewrite the algorithms and models so they use the same programming language as the operative system or simulation. This may solve the integration and scalability problems, but it raises new problems and accordingly efforts: these rewritten parts have to undergo the whole process of validation and verification again in terms of ensuring their correct behaviour. In addition to these efforts also comes the task of rewriting the code in a different programming language with possibly lesser application-specific language elements.

The remainder of this paper is structured as follows. The next Section introduces related work on simulation interoperability and presents previous work, which forms the fundament for this approach. Section 3 introduces the scalable integration concept for 4GL elements that avoid the afore-mentioned integration problems and efforts by wrapping them with established web-technology and using load-balancing techniques to ensure scalability. The Section also describes how the integration approach is embedded into a service based simulation framework and how it can be facilitated for combined hard- and software Smart Grid simulation models. Section 4 concludes the paper and gives an overview about future work.

## 2. Simulation Interoperability

There exist many different tools and approaches for the simulation of Smart Grid scenarios or simulation interoperability in general. The military domain has been a major driver in this field. The development of simulation interoperability standards started in the early 1990s and resulted in the High Level Architecture (HLA), an IEEE Standard for modelling and simulation [8]. The HLA is a technical architecture developed to facilitate the reuse and interoperability of different simulation systems and assets. It provides a general framework, which can be used by developers to structure and describe their simulation systems and to interoperate them with other simulation systems. But due to its complexity it is hardly used outside the military domain [3].

A more specific approach is introduced in [2]. The IPSYS framework is a versatile framework for the simulation of integrated power systems with multiple forms of energy- and control-structures. It focuses on the system performance of large amount of renewable energy resources. However standardized interfaces to the simulated power systems are currently not offered, which makes it difficult to integrate external resp. heterogeneous simulation models.

The GridLAB-D simulation tool [5] is a more recent approach. It is developed by the U.S. Department of Energy (DOE) at the Pacific Northwest National Laboratory (PNNL) in cooperation with industrial partners. It allows the specification of a wide-range of simulation scenarios and the simulation of millions of independent devices. External links to 4GL-simulation models, e.g. MATLAB or MySQL are also supported.

Another interesting approach is the Mosaik framework [12,13]. Compared to the GridLAB-D framework it is more explicitly designed for the composition of heterogeneous simulation models. It enables the reuse and combination of existing simulation models and simulators to create large-scale Smart Grid scenarios. This is achieved by the interaction of four main components:

- A programming language independent API that allows the integration of existing simulators, simulation models or control strategies into the Mosaik framework. This enables e.g. the integration of MATLAB models as described in this paper.
- A scenario definition API for the description of large-scale simulation scenarios. Here, different simulation processes as well as models or the connections of the different entities can be described.
- A simulation manager, that is able to start simulators resp. to connect to an already running instance.
- An event-discrete simulation execution to coordinate the execution of all simulators. Therefore, each simulator or sub-simulation can have a different step size, which may even vary during the execution of the simulation.

The approach presented in this paper originates from the work undone in [4] where the load schedules and load shifting potentials of a high number of electrical consumers were determined using massive simulation. The simulation was realized by stand-alone models of heat pumps, night storage heaters and the supplied building, which were built and validated using Matlab/Simulink. These models were exported as dynamic link libraries (DLL) and integrated into a Java-based multi-agent platform using Java Native Access (JNA)[5]. The resulting multi-agent based simulation system was able to simulate up to 10.000 households, where each household was represented by an agent encapsulating an exported Matlab/Simulink model. This approach was consequently extended to the more versatile and scalable approach presented in this paper by using established technology like REST web services and load-balancers.

Contrasting to IPSYS [2], GridLAB-D [5] or Mosaik [12,13] the work presented in this paper focuses on the seamless integration of 4GL-models and algorithms for both Smart Grid simulations as well as applications. By using standardized REST web services as a wrapping mechanism ,the wrapped 4GL-models and algorithms can be integrated in both operative systems and simulations without any further efforts. Therefore, the approach presented in this paper does not concern the composition and coordination of simulations or the formal description of simulation scenarios. A further differentiation follows up in Figure 1. It shows how the approach presented in this paper complements the related approaches, which focus on the functional requirements of simulations like the provision of semantic models of the according application domain. The approach presented in this paper complements these approaches by focusing on the fulfilment of non-functional requirements like the application independent technical integration of 4GL models for simulations and also operative systems.

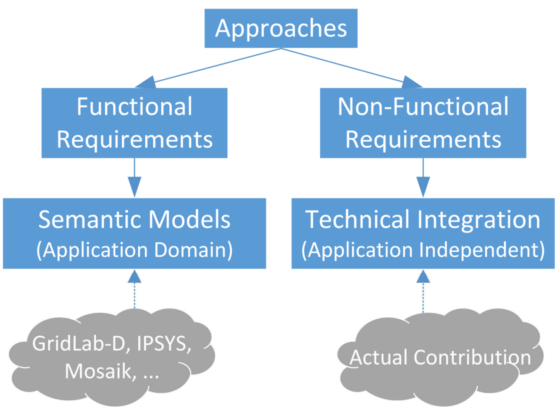


*Figure 1: Comparison of related approaches and the presented one.*

[5] https://github.com/twall/jna

## 3. Scalable Integration of 4GL-Models and Algorithms

This Section describes how the scalable integration of 4GL-models and algorithms for both Smart Grid simulations and applications can be achieved. First, the integration approach is described on a conceptual level before it is architectural embedded into a service-based simulation framework. An example on how the proposed approach can be facilitated into a combined hard- and software Smart Grid simulation model concludes the Section.

### 3.1. Integration Concept

The scalable integration of 4GL models and algorithms is based on standard web technology. The functions offered by the 4GL elements are wrapped by REST web services following the service-oriented architecture (SOA) paradigm [6]. Thus, each 4GL model or algorithm that shall be called from a productive or simulation system is accessible as a REST service method. Figure 2 depicts an integration example for 4GL code exported from MATLAB. With the *Builder JA*[6] MATLAB code can be exported into Java archives (JAR) allowing the code to be called directly from any Java application. However, in case of MATLAB exports, the machine executing these JARs still requires the MATLAB Compiler Runtime (MCR) to be installed. The MCR is a self-contained set of dynamic libraries called by MATLAB applications outside of a MATLAB installation. As the MCR is thread-safe, it is not possible to execute (even independently) exported code parallel within one enclosing process. Therefore, in order to allow a scalable execution of exported MATLAB code, multiple processes are required. Figure 2 shows how the proposed scalable integration approach could solve this issue. The functions offered by the JAR files are wrapped by REST web services [7] and deployed to a Tomcat[7] application container. Each Tomcat instance is a single operating system process allowing the parallel execution of (independent) MATLAB functions. In order to achieve a scalable solution, multiple Tomcat instances are required. The propagated approach makes use of a load balancer that distributes the REST web service calls to multiple Tomcat instances (on single or multiple machines). A first proof of concept uses the open source Apache HTTPD[8] web server combined with the *mod_jk*[9] module as a load balancer. This configuration utilizes round robin scheduling to distribute the service calls to the according Tomcat instances. The load-balanced distribution of the service calls is carried out transparently for the calling application. In case of bottlenecks new Tomcat instances can be added effortless without the need of changing any code on the calling side thus allowing a scalable integration of MATLAB code (or any other exported 4GL code). Additionally it is possible to use the integration concept with a different load balancer utilizing a more complex, application-dependent scheduling algorithm.

The here-described approach is used in a current industrial Smart Grid project dealing with the load-management of electrical heaters. Control algorithms written in MATLAB are exported into JARs, which are wrapped by REST service interfaces and deployed to a Tomcat application container. These services are used for the integration of 4GL-models into a large-scale multi-agent simulation for validation, as well as in the actual operative systems. An optional load-balancer ensures the scalability and fast response times for both the large-scale simulation and the operative application.

[6] http://www.mathworks.de/products/javabuilder/index.html

[7] http://tomcat.apache.org/

[8] https://httpd.apache.org/

[9] http://tomcat.apache.org/connectors-doc/

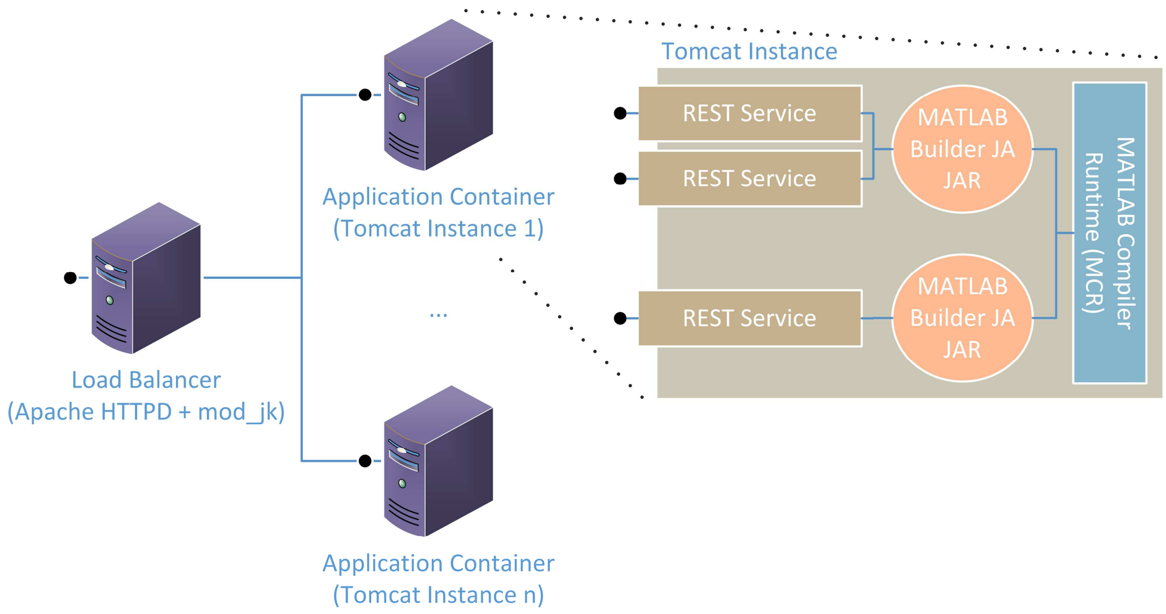


*Figure 2: Scalable Integration of MATLAB Code*

### 3.2. Simulation Integration

In [10] a component-based architecture for a service-based simulation framework is presented in order to integrate microscopic and macroscopic (sub-)simulations. All components communicate through a Service Bus and are able to offer simulation services via well-defined interfaces. The framework supports a domain-specific declarative description of simulation scenarios. These descriptions are processed by a Scenario Manager and contain information about all simulation components required for a specific scenario. The according requests from the Scenario Manager are routed to the Simulation Component Manager utilizing the Service Bus. This scalable component handles the lifecycle of all simulation components. According to requirements it starts additional components of the required type and sends corresponding requests via the Service Bus. Heterogeneous simulation components based on different technologies are connected to the system through an attached Adaptive Manager component. This manager masks the specific properties of a simulation component with generic interfaces (black-box) and extends it with adaptive behaviour. Therefore, they can be integrated into existing simulation systems. The Adaptive Manager allows to monitor the execution state of a simulation component and if necessary also to control it. In case of a simulation request the Adaptive Manager can access existing simulation data (Database) or execute a corresponding (sub-)simulation. Thus, the system is able to dynamically execute macroscopic simulations with regard to mesoscopic effects [11].

Figure 3 illustrates the architecture and shows how the scalable integration of 4GL code fits into it. Following the concepts proposed in [10] the Apache HTTPD used as a Load Balancer adopts the role of an Adaptive Manager. It handles the service requests, monitors the execution state of the Tomcat instances and calls the corresponding web services offered by the Tomcat container. In this context a Tomcat instance wrapping the 4GL code is a simulation component that offers specific simulation services. According to e.g. a Multi-Agent System consisting of multiple agents such a scalable 4GL model simulation component may consist of multiple duplicated Tomcat instances. Of course these adaptive simulation components containing a Load Balancer and multiple application containers may occur several times within a complex simulation systems.

In conclusion, the proposed concept enables the scalable integration of 4GL models and algorithms for massive (Smart Grid) simulations and allows a fast transition to operative systems. This is achieved by combining the advantages of fourth generation languages widely spread in engineering disciplines with the advantages of advanced high-level programming languages.

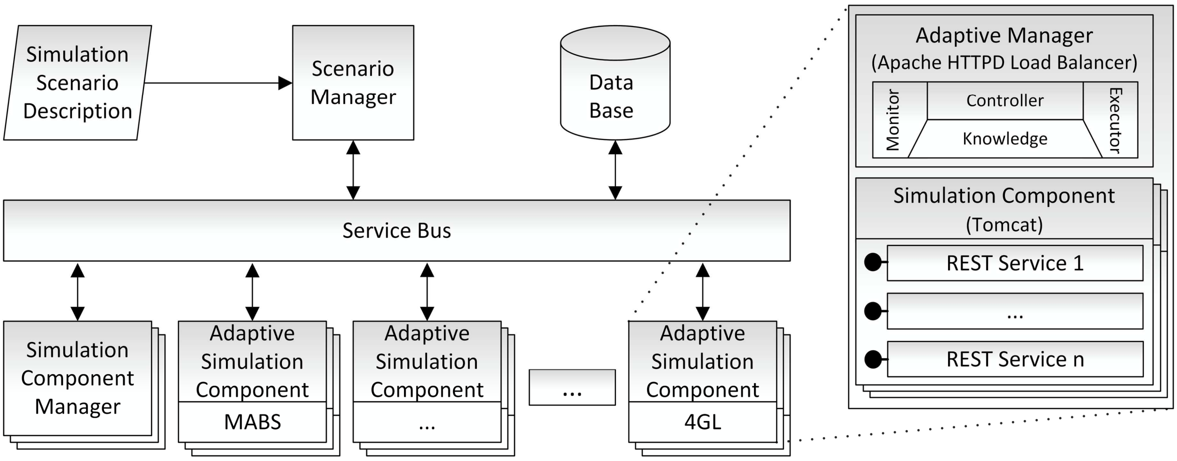


*Figure 3: Scalable Integration of 4GL Models in a Component- and Service-based Simulation Framework (extending [10])*

### 3.3. Example: Combined Hard- and Software Smart Grid Simulation Model

Because the standardized REST APIs can be used via different wide area networks (WAN), e.g. the Internet, the proposed solution for the integration of 4GL-models and algorithms can also be used for interconnected hard- and software simulation models in different organizational structures (resp. networks). Therefore, it is required that the physical devices also offer REST APIs, so that they are able to communicate with software models resp. either simulated or actual users. Figure 4 illustrates this concept. The depicted Smart Grid simulation model consists of three different domains. The User Domain maps the user interactions with the system. This might be a technical user who starts and stops the simulation or a functional user who utilizes the simulation system in order to validate the systems behaviour to the given inputs. The Simulation and Control Domain maps the simulated entities, e.g. household or devices models, which simulate their actual counterparts and the control and regulation structures of the system. In this domain the proposed integration approach can be used to integrate 4GL-models (simulation) or algorithms (control) in a scalable fashion. The last domain is the Physical Domain where the actual hardware and devices are situated. Similar to a hardware-in-the-loop (HIL) simulation the simulated entities can either be used to test the physical devices. Vice versa the physical devices can be used to test control structures and algorithms in combination with the simulated ones.

## 4. Conclusion and Future Work

In this paper we proposed a solution for the scalable integration of 4GL-models and algorithms into Smart Grid simulations and applications. Fourth generation languages (4GL) focus on rapid application development and the reduction of lines of code. They are widely spread across engineers also in the Smart Grid domain but they lack of integration and scalability features. By wrapping the models and algorithms with established REST web services and applying load-balancing techniques to the services the scalable integration is achieved. The proposed solution allows engineers to focus on the application development using their well-known tools and liberates them from integration efforts by providing a seamless integration concept. This concept allows it to integrate the models and algorithms into simulations as well as operative systems without requiring further efforts. We presented the integration concept and its interaction with an envisioned service-based simulation framework. A short example showed how the approach supports the combination of hard- and software Smart Grid simulation models.

The presented approach does not concern with the composition and coordination of simulations or the formal description of simulation scenarios. As described in Section 2 there exist many other approaches, like e.g. IPSYS, GridLAB-D or Mosaik for the interoperability of simulations and the integration of heterogeneous simulation models, which exceed the presented approach in these terms.

Future work will include the integration of the proposed approach into the envisioned service-based simulation framework as well as the realization of a massive multi-agent based simulation system utilizing the approach to integrate MATLAB-models and algorithms. The purpose of this simulation is to test algorithms for a smart load-management of electrical heaters.

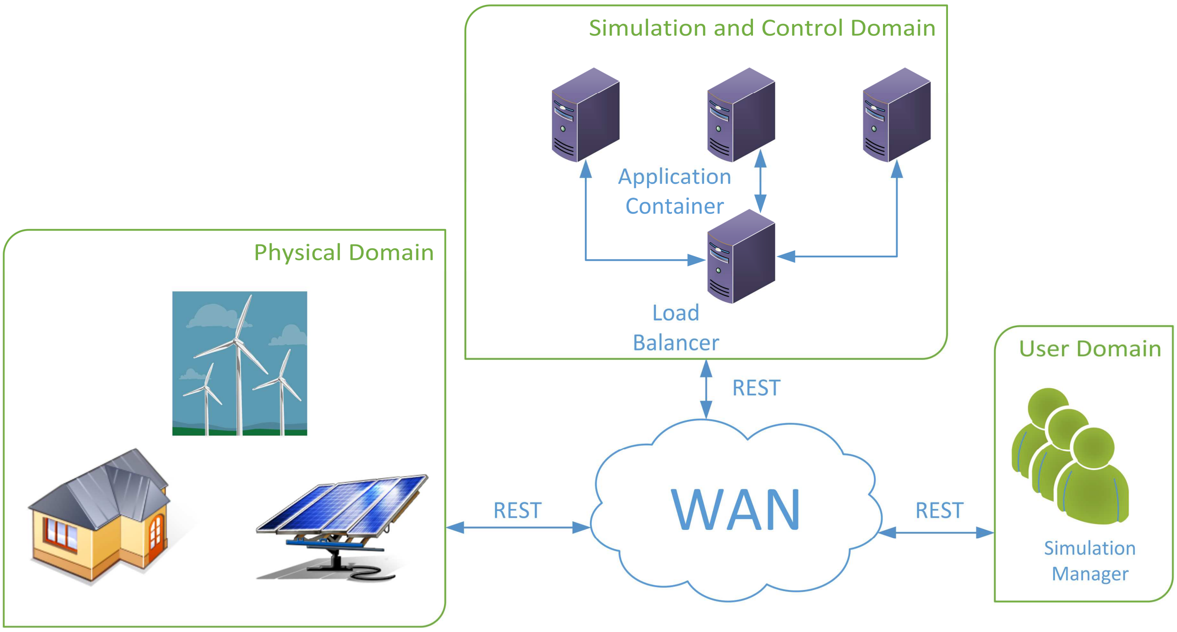


*Figure 4: Combined Hard- and Software Smart Grid Simulation Model*

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# A consumer-orientated Architecture for distributed Demand-Side-Optimization

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## Abstract

Demand-Side-Management (DSM) is one of the key applications in the future smart grid, creating a new degree of control in order to reduce losses and fluctuations caused by volatile distributed energy resources (DERs). To integrate the consumer side, several approaches like flexible tariffs, have been proposed and tested. However, many of these approaches not have been adopted widely yet because of the needed sophisticated (and often expensive) command and control infrastructures or their impact on the user comfort. In this paper an architectural approach for a lightweight demand-side-application will be proposed. Utilizing methods of peer-to-peer (p2p) networks and abstraction patterns the architecture will be enabling consumers to form spontaneous demand-side optimization networks in order to optimize their load and to provide energy services to the Smart Grid of the future. Because of the decentralized characteristic of the architecture, the aggregation instance does not need detailed information of the optimization network, while the approach is scalable.

## 1. Introduction

Apart from traditional top-down planning of the demand for electricity by electric utility planners, the rising degree of distributed energy resources depending on environmental conditions like wind or sunshine leads to more and more challenging energy-planning [1]. To increase the efficiency and reliability, controlling loads on the consumer-side of the meter with Demand-Side-Management (DSM) has become an additional degree of freedom for planning and controlling the grid [2, 3]. Through the growing dissemination of affordable automation and the spreading Information and Communication Technologies (ICT) infrastructure, the integration of the demand-side becomes achievable. Since then, many projects, like the e-energy projects [4], addressed different exemplary DSM applications, trying to integrate local demand-side entities into the Smart Grid. Due to the availability of household appliances for DSM-activities, a wide-scale concept for the DSM-integration of the appliances into energy related services like control energy is still a matter of concern. The highly distributed and heterogeneous devices require adaptive and scalable solutions for a reliable scheduling and optimization of the loads in order to reach prequalification levels and business-relevant integration and impact.

In this paper, a distributed architectural approach on indirect control without the direct participation of the electric utility or the aggregator of such dynamic loads will be proposed. The generic descriptions and architectural concepts may not be limited to the domestic household domain. The remaining paper is structured as follows: in the next Section an overview on established approaches

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on dynamic load control will be given. In Section 3, the architectural concept will be introduced and the most important components described, followed by an use-case study in Section 4. Section 5 concludes the paper.

## 2. Approaches on dynamic load management

Regarding the short-term Demand-Side-Management techniques [3], influencing the time-of-use of the loads is one of the most common approaches [5]. Being able to alter the consumers' consumption pattern enables the utility or aggregator of loads to provide energy related services for the grid like control energy, load optimization and other.

In the scope of short-term DSM, two major approaches on dynamic load control can be deviated. The first approach is the classical direct load control (DLC) by the utility or an according entity [6]. Based on the targets of the controlling entity, the loads can be fully or partly controlled via Energy Service Interfaces (ESI), in order to achieve the intended behavior. This top-down oriented approach implies that the controlling entity either maintains all the information about the controlled loads or has statistical models to make a reasonable planning of the resources [2]. Beside this precondition, security and privacy aspects can be problematic. Also, centering the ability to control large numbers of loads in one entity may result in unpredictable security risks for the grid and the end-users as well. The precise scheduling of loads via DLC allows the utility to quick respond on gird or market conditions with a reliable response of the controlled system. An application of direct load control can be found in [7].

The second established approach for DSM is an extension of the classical tariff-model, broadcasting varying tariff-signals to the consumers and thus provoking reactions. Applications implementing varying tariffs were developed and tested in many projects like [8] or [9]. Despite the obligation in § 40 (5) "Energiewirtschaftsgesetz" (Energy Act) by the German government to increase the number of intelligent metering devices capable of dynamic pricing in domestic households, the dissemination and acceptance yet stays relatively low because of the expensive (and often proprietary) hardware and sophisticated software [10]. Legal and privacy concerns of the interfaces not only accessed by the utility are also under discussion currently [11]. Especially interesting business models with substantial financial advantages for the consumer-side are rare. The according ICT-architectures for such business-models must act highly autonomous and automated in order to keep the entrance barriers and time-efforts for the consumers low.

## 3. Concept of a consumer-oriented Architecture

Demand-Side-Management applications usually consist of large number of highly heterogeneous loads which are represented in an according DSM-application architecture. Regarding DSM potentials and their representation resp. their aggregation potential, three levels of abstraction can be distinguished (see fig. 1). The device-level is the software-representation of the actual physical load, making it available for home automation and managing through ICT. The second level is the domestic household itself, optimizing and planning the own demand for energy and DERs like solar panels and energy storages. The household may also offer numerous services to the grid through the Energy Service Interface (ESI). Aggregating several domestic households and other DSM-capable loads with ESIs, like industrial or commercial entities, to a Virtual Power Plant (VPP) allows entering markets on larger scales as described in [1, 12]. The proposed architecture addresses especially this last DSM optimization-level with regard to the heterogeneity of the loads. One matter of concern in the field of DSM-applications in the domestic household domain is the (statistically) broad availability of the dynamic potentials while the actual loads of the devices are relatively low. The architecture proposes an ICT infrastructure that enables the aggregator or utility to connect different dynamic loads, typically in one control zone, through a virtual network.

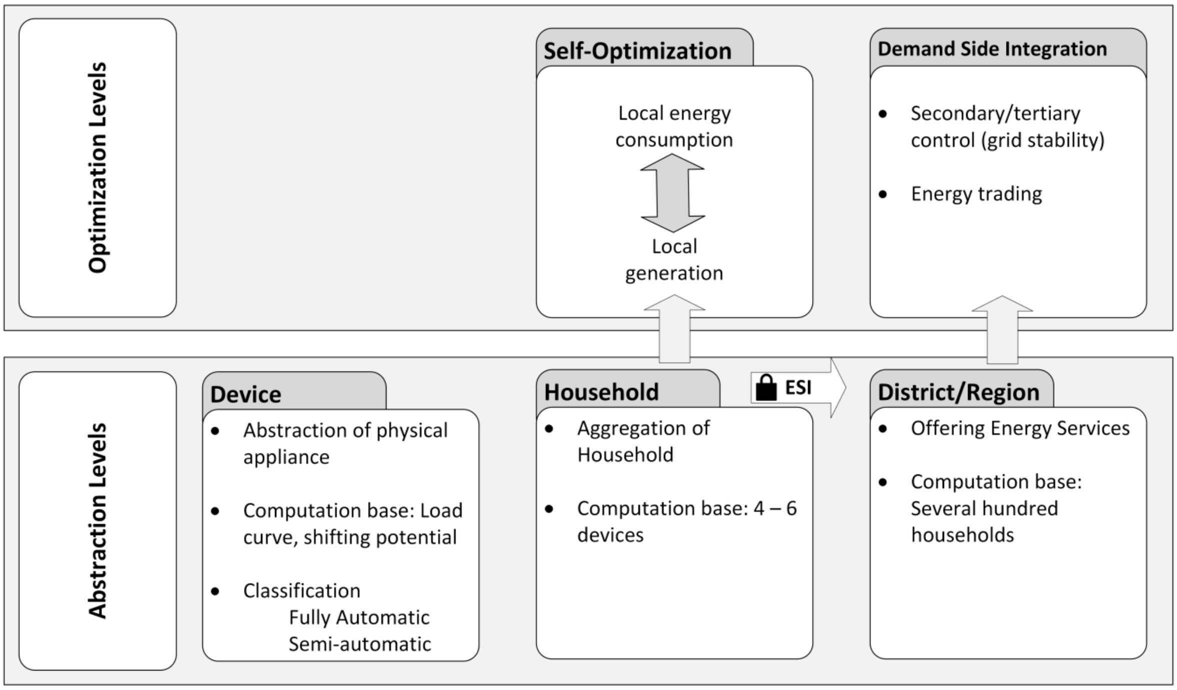


*Figure 1: Aggregation and optimization levels.*

The overall proposed architectural concept (see fig. 2) will be described according to the NIST Domain Model of the Smart Grid Roadmap [13] and focuses on three for the DSM important components: Energy markets, where the prices and tariffs were made, Energy Management Systems as an interaction and interface platform between markets and the consumer-side, and the consumer-sided Energy Service Interfaces.

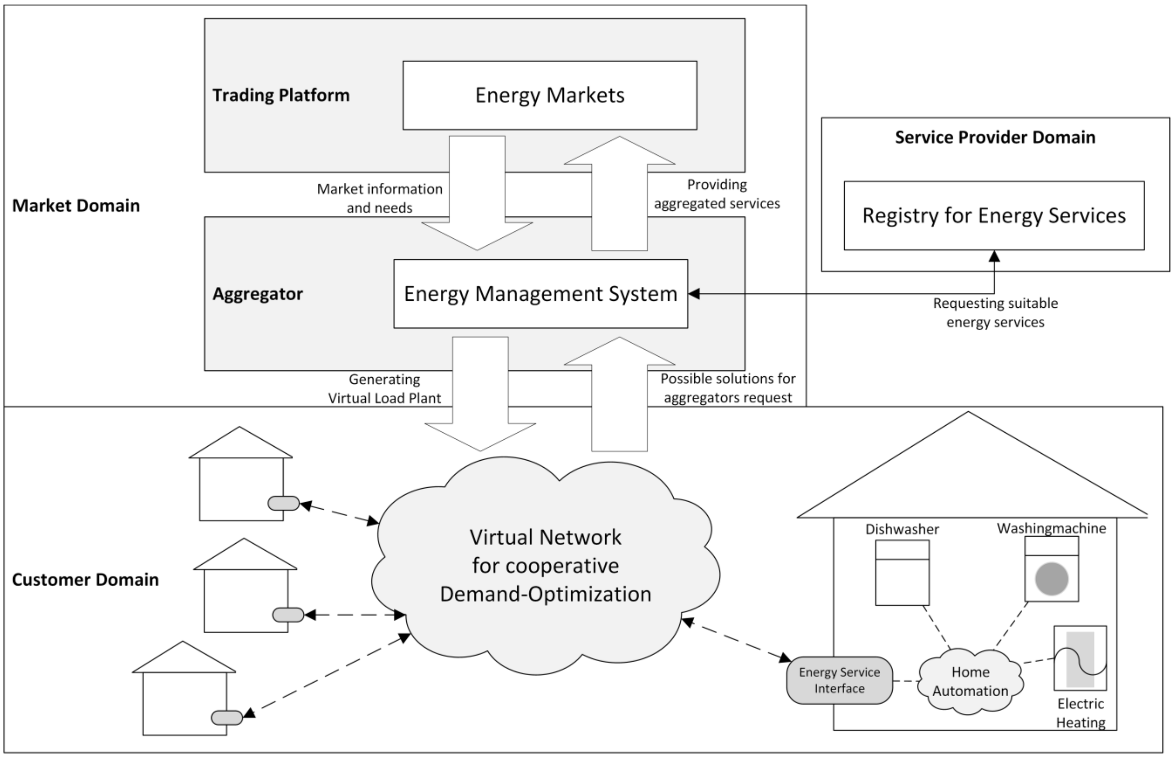


*Figure 2: Architecture model with domain-specific components according to the NIST Framework domain model.*

### 3.1. Energy Markets

The architecture of the market model is inspired by stock exchange markets and the actual energy markets in central Europe like the EEX. For each discrete timestep, a trader can place or accept offers, according to the generated or demanded energy. Each offer consists of a certain amount of power and a price per trading unit. With this model, most of the current business cases related to energy market and trading could be represented. Beside the traditional energy market, alternative open markets for energy services may be created e.g. markets for control energy capabilities. Currently most energy markets are not open for DSM efforts because of the high prequalification borders.

### 3.2. Energy Management System

The Energy Management System (EMS) describes a service platform for the aggregator's role in the domain model. Monitoring the needs of the energy market and offering energy services like volt/var control or other for the smart grid, the aggregator combines smaller entities to enable the DERs to act and trade in these markets.

Managing the signals from the energy market, the aggregator generates tariff-structures for the demand-side, depending on the intended business plan or behavior of the VPP. These tariff-structures can provoke different responses from the demand-side. Consider a classical variable tariffs approach for business-models, where the response of the VPP can be estimated, or commodity-exchange inspired tariff-models, in which certain energy-amounts were offered with different prices for business models where the energy scheduling must be quite accurately. Imperative for efficient DSM activities is the planning horizon for the loads. Real-Time-Pricing (RTP), where the market development is directly forwarded to the demand-side and the consumer must bet on the development of the market-prices, has proven quite inefficient beside some stabilizing effects [2]. To use the full dynamic potential of loads, a certain planning horizon must be provided by the aggregator. In order to achieve these tasks, the EMS needs access to a service where available energy services can be found and booked. This Registry of energy services is part of the service provider domain, and offers search and booking services [14].

An aggregator forms Virtual Networks out of the loads intended to be part of the VPP-structure and broadcasts the tariff-model. To address the issues of direct load control and the indirect tariffs as stated in the Sections before, the Energy Service Interfaces of the households have the abilities to optimize their demand cooperatively and propose a scheduling of the participating loads to the ESM. Thus, the scheduling is not made in the EMS by the utility or the aggregators like in traditional approaches.

### 3.3. Energy Service Interface

The Energy Service Interface (ESI) is the household's interface to the Smart Grid. It manages the different appliances and devices of the household in order to make their dynamic load-potential available for the utility or aggregators. In Fig. 3 the internal architecture of a basic ESI is stated. It is parted into two components with different functionalities. The user controlled area represents the classical implementation of an ESI as implemented in OGEMA [15] or OpenADR [16]. The communication interfaces can implement a variety of bus systems e.g. I²C, ModBus in order to communicate with a wide variety of household appliances.

The Device Simulation Modules contain important configuration details about the connected devices in the household. As stated by [17] two types of devices are interesting for DSM applications with dynamic loads:

a. **Program-Driven Devices** like washing-machines or dishwashers that need the user to load and start the device and then offer a certain dynamic potential for DSM activities.

b. **Fully-Automatic-Devices** that have sensors and actors to keep a certain state like thermal loads (electric heating/cooling). Under the assumption that the next planning step of a fully automated device might depend on its state, most of these devices could be planned iteratively.

The users' preferences and constraints for the whole energetic behavior as well as for single devices could be entered through the User Control Interface, which could be realized through web-interfaces or apps.

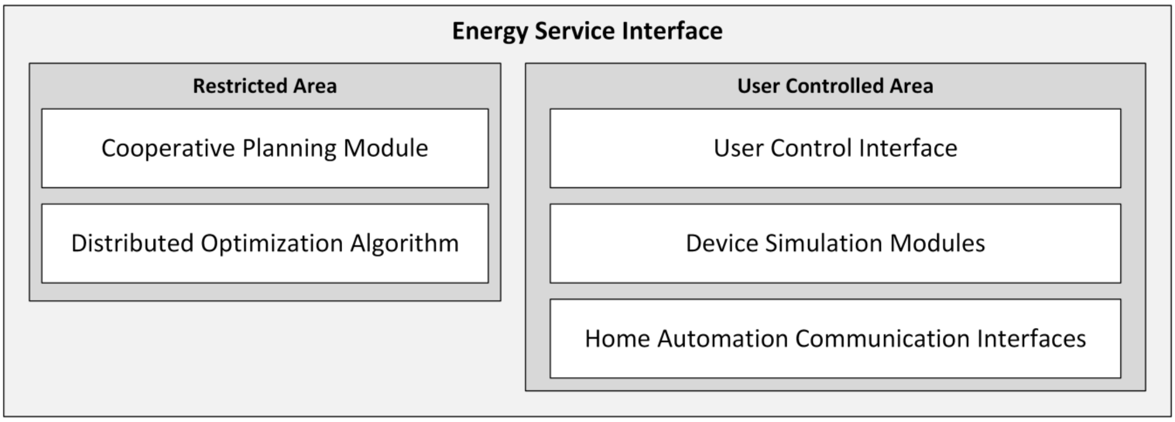


*Figure 3: Energy Service Interface*

The second part of the ESI contains the access-restricted planning component for the coordinative scheduling. This part communicates with the other ESI planning components about the dynamic potentials of the other loads and thus must be hardened and secured against external access through encryption and user-restrictions. The planning module provides services to request the dynamic potential of the household for optimization purposes based on the Device Simulation Models and the user's restrictions. Running on an embedded device, the computational power may be used to perform a part of a distributed optimization algorithm to solve the scheduling problem.

In the most basic implementation, the planning module of the ESI provides methods to request the possible discrete runtimes of a device, which can be used by an optimizer to schedule the load. Planning a fully-automated device can be done iteratively. For most e.g. thermic loads, the next possible timeframe for operation depends on its condition. Communicating these conditions with the timeframes to the optimizer, the optimizer chooses a runtime and its dependent condition according to the applied optimization algorithm and retransmits it to the ESI where the following timeframe is calculated. The ESI thus remains stateless and can provide its capabilities to many distributed optimization entities.

## 4. Use-Case Study: Shifting operation

A functional prototype of the above described system, containing several key components, like a basic EMS, was implemented in a simulation tool built with JADEX Active Components [18] in order to demonstrate the capabilities of the approach. In the Smart Grid, shifting operations are an interesting approach on managing the consumption [3], as for example shifting loads from peak hours to off-peak hours or to reduce the peak-to-average-load ratio [19].

The scenario contains of a virtual optimization network, containing 100 domestic households with several dynamic loads like washing machines and electric heating per household. The mean, non-optimized load of the virtual optimization network is shown in Fig.4 as black line. The EMS broadcasts a load-limited shifting signal at time 65 (based on 15-minutes-timeslots). The signal requests a shift of the demand from timeframe $\{66, \dots, 73\}$ to the timeframe $\{74, \dots, 82\}$. Using a distributed Ant Colony Optimization Algorithm described in [20], the households try to optimize their demand and shift their loads according to the request.

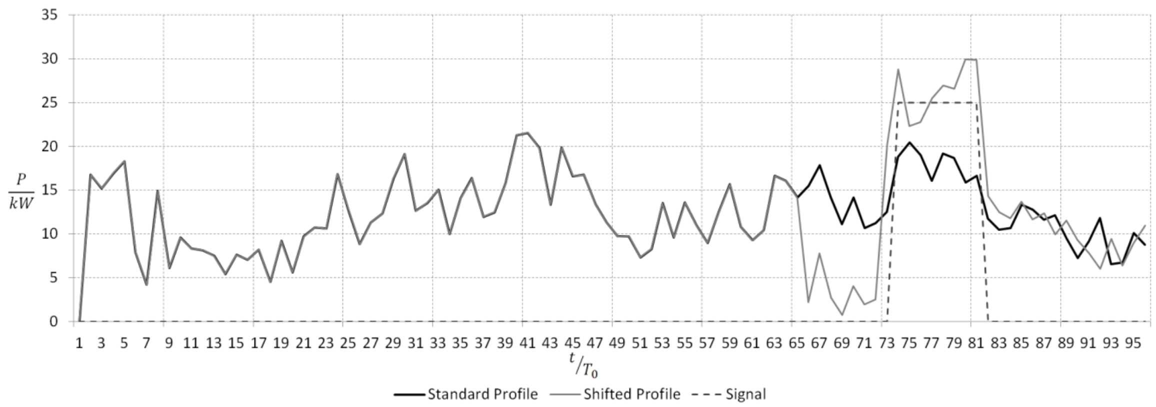


*Figure 4: Reaction of 100 households to a load-limited shifting signal*

It can be seen in Fig. 4 that the signal requests a limited shift of 25 kW for two hours from timestamp 74 to 82 which can be achieved by the dynamic devices. Due to thermal restrictions and runtime constraints of some devices, the average power of the shifted energy scheduling (grey line in Fig. 4) is slightly higher, because no more shifting potential was available.

## 5. Conclusion

In this paper a distributed, decentralized and scalable architecture for demand-side-optimization was described. The approach focuses the decentralized integration of the consumer side, using the capabilities of upcoming Energy Service Interfaces for offering energy services without the need of knowing the detailed configuration of the virtual network by the Energy Management System. Generating virtual networks provides a modular and scalable model for Smart Grid applications and energy services. The architecture was described according to the NIST Smart Grid Domain model. A prototypic implementation of the approach was built with JADEX, demonstrating the basic functionality of the approach, i.e. simulating a four hour shifting operation with 100 households. Although those shifting operations may be interesting for peak-clipping and peak-to-average reduction, the demonstration not yet features secondary or tertiary control.

Future work will cover detailed descriptions and reference implementations of the ESI components, as well as further simulations and tests. Field tests and integration of the architecture into common open-source Energy-Management-Systems are also planned.

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# An IT-architecture to support energy efficiency and the usage of flexible loads at a container terminal

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## Abstract

This paper presents a component-based software architecture that enables a container terminal to optimize their energy demand and the flexibility of this demand. This flexibility is gained from using energy-intensive battery-powered Automated Guided Vehicles (AGVs) for container transport within the terminal. While Demand Response strategies are known and already applied in some industrial branches, it is not yet common in the logistics domain due to highly dynamical and time-critical processes. In order to forecast the energy demand for the terminal and to be able to optimize it while having constantly changing logistic processes, the architecture includes modules to process a simulation based forecast of the power demand, optimize the demand by changing battery charging plans and to control the execution of the optimizations.

## 1. Introduction

In order to take part in new possibilities of the liberalised energy market and because of the growing influence of renewable energies, customers can adapt their energy consumption in regard to the variable price of their energy supply or they can adapt their consumption patterns in regard to the availability of renewable energies. They can even help to stabilize the grid by offering control reserve energy. New consumer behaviours are expected to emerge when E-Mobility is growing from only a few vehicles to a mass market. Software is needed to support the customer in optimizing their energy demand by reacting to different price or availability signals transmitted by the energy supplier.

In integrating flexible loads of the customer side, especially loads of large industrial and business enterprises, a high potential for supporting grid stability is seen. But not only from a grid point of view, but also from the sales perspective and from the customer side the possibility for new concepts is given. Using the terms “Demand Response” and “Demand Side Integration” the possibilities for influencing customer loads are discussed for quite some time and the first commercial contractors have entered the market to not only focus on large industries but also support small and medium enterprises to benefit from the liberalized power market. Pooling of different customers with flexible loads to one virtual customer (“virtual power plant”).

When E-Mobility is established flexible loads arise and can be used in industrial or commercial enterprises which are not a common part of the power market or known for their flexible energy demand. This is for example the case in a sea-side container terminal that is using automated

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guided vehicles (AGVs). At the Container Terminal Altenwerder (CTA) in Hamburg several AGVs are now equipped with battery-powered engines. The batteries introduce flexibility to parts of the power demand because the battery charging can be shifted in time. Since daily business at the terminal is very variable, a forecast of the terminals utilization and the respective energy demand is needed to determine potentials for load shifting and to use it effectively. A software system supports the use of the gained load shifting potential and supports the power demand forecast. The components of this software are described in the following chapters.

First, this paper provides a short introduction to the terms “Demand Response” and “Energy Demand Forecast” at container terminals, before the software architecture to support the energy demand forecast, the use of the flexibility in the power demand and the control of the power consumption at the terminal is introduced. The paper closes with a summary of the current implementation status and an outlook on future integration plans.

## 2. Demand Response and Energy Demand Forecast in a Container Terminal

Demand Side Management is defined as “[…] activities which involve actions on the demand- or customer-side of the electric meter, either directly caused or indirectly stimulated by the utility.” [1]. To be able to react in a flexible way to outside stimuli one needs a deep knowledge of the energy consumption patterns at the customer side. In an industrial enterprise with continuous and recurrent production cycles the energy demand can be forecasted with rather simple methods [2].

Optimization of the power demand can, besides others, include the following goals at the customer side:

- Load shifting and peak clipping
- Confirmation of the forecast to the supplier
- Offering balance energy
- Offering operating reserve

While the topics load shifting and peak clipping are not really new to applications of energy management, often described in the context of Demand Response [3], the other points are fairly new to the market, at least in Germany, and standards and processes for these use cases are still under development and are referred to in the context of Demand Side Integration [4]. Especially the communication from the consumer to the supplier lacks in standardized implementations. Some standards like IEC 61970/61968 might be a basis, but architectures for using it are rarely implemented [5]. Energy-related studies indicate that there is an overall potential for Demand Response and Demand Side Management of 60 GW in the European Union [6] and 8,5 GW in Germany [7].

While the studies also name some industry divisions with the highest potential, the division of logistics is never mentioned [7][8][9][10]. One reason for this might be that logistic processes are highly dynamical. For example, in a container terminal they are depending on the number of ships and containers to be handled. These numbers vary from day to day and do not follow any pattern. The energy demand is therefore highly dynamical as well. Also the potential for load shifting or other optimization goals seem rather low since the processes are not flexible in their time. This changes when E-Mobility is introduced. If battery-powered vehicles are used at a logistic enterprise the logistic processes are in parts decoupled from the corresponding energy consumption. At CTA, for example, ten AGVs are equipped with two battery systems; one is always used directly in the AGV, while the other one is charging in the battery-charging station. Since it takes less time for charging one battery system than the duration of AGVs operating time with a fully-charged battery system, flexibility is introduced to the power consumption of the battery-charging station.

# 3. An software architecture to support the use of flexible loads

Software to support Demand Side Management in a container terminal has to be aware of the logistic processes of the terminal. The battery usage in general and therefore the time of a battery exchange request of an AGV are highly dependent on the time points of ship arrivals and the number of containers to be handled. If the power consumptions of the AGVs as well as the entire terminal are known, the charging operations can be controlled in such a manner that the overall energy demand is affected in an optimized way. Battery exchange times and battery charging can be shifted in order to do so. Respective operating systems have to be informed of the change to their default behavior, the execution of the planned optimization has to be supervised and adaptation strategies in case of deviations must be applicable.

The proposed architecture is built up of the following three modules:

- The Logistics Simulation module
- The Energy Demand Optimization module
- The Energy Controller module

These three modules and their sub-components will be described in the following chapters.

## 3.1. The Logistics Simulation module

The Logistics Simulation module is responsible to forecast the container transport request which have to be dealt with the AGVs and the power demand of the entire terminal. The module includes components for the storage area, transport area and the quay area ("shipping"). The shipping component simulates the arrival and departure of the ships based on the list of sailings. In order to unload the container from the vessel a specific number of quay cranes is assigned to each ship. This number depends on the number of containers and the planned retention time of the respective ship at the terminal. The transport module simulates the AGVs, which transport the containers from the quay cranes to the storage/stacking area and also the other way around. They use a fixed layout of possible routes but find their way through the routes dynamically. AGVs without a current transport order drive to parking positions and wait for the next order. If a battery system of a battery-powered AGV drops below a certain charging level, the AGV drives to the battery-exchange station to switch the empty battery-system. The discharged battery system is automatically removed from vehicle and stored for charging. A charged battery system is entered into the AGV that is continuing operations after the exchange. The time point of a battery change is logged to have a starting point for load optimization later on. The Storage is divided into 26 yard stacking depots and one depot for refrigerated containers.

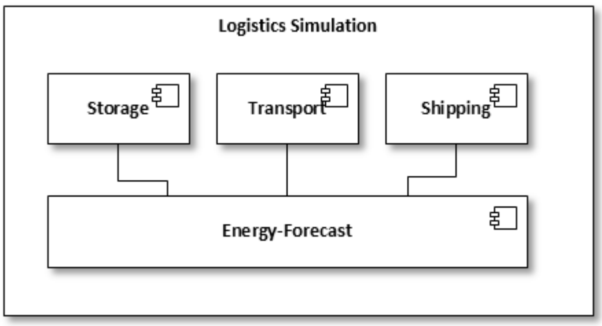


*Figure 1: Components of the Logistics Simulation*

While simulation of logistic processes in a container terminal is not really new (a literature review can be found in [11], for example), the focus has never been on the power demand. During a simulation run the power consumption is recorded for every involved actor, each having an individual energy usage model. For example, the lighting of the terminal has static power consumption depending on the time of sunrise and sundown, while the quay cranes have an energy consumption based on their current task like lifting a container, putting down a container or moving a container. From the power consumption of each consumer in the simulation an overall power consumption of the terminal can be calculated. A power demand forecast can be generated by starting the simulation the day before the processes are actually executed.

### 3.2. The Energy Demand Optimization module

The total energy consumption and the time points of battery exchanges from the simulation are input parameters for the Energy Demand Optimization module. Additionally, it uses processed price or priority signals from the Energy Controller module. Depending on the optimization goal the Energy Demand Optimization module optimizes two parameters:

- the charging of the battery: optimizing means to charge the battery in time slices when the energy price is low or when possible benefits are high
- change the time point of a battery exchange: in some cases it might even be useful to call an AGV to the exchange station earlier than waiting for the charging level to drop below the limit for a battery exchange

The module can use different strategies to optimize the demand regarding the use cases mentioned in the previous chapter. One rather simple strategy can be to charge the batteries at times when the spot price is low. Another strategy could be to charge the batteries primarily in times when the power generation from renewable energies is high. The optimization has to be done after the simulation, since the exit times of the batteries from the charging station are only known during runtime of the simulation and not a priori.

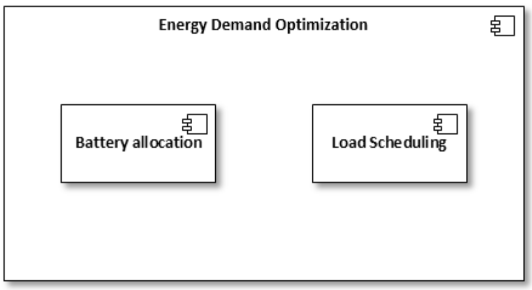


*Figure 2: Components of the Energy Demand Optimization module*

The result of the energy demand optimization is an operating schedule for the battery-powered AGVs and charging schedules for the batteries while they are stored in the charging station. It is important that the optimized operating and charging schedules have no impact on the logistic processes that have to be handled. One constraint is that the departure time of a ship must not be influenced. It has to be able to depart at the same time as it would do without any optimization. To check this constraint the simulation is executed a second time with the same sailing list as before but with the optimized schedules for the battery exchange and the charging of the batteries.

### 3.3. The Energy Controller module

The Energy Controller module is responsible for communication with external applications like the terminal ERP-system for ship arrival and departure plans (the so called sailing list), the AGV and Battery Management System for controlling the execution of the optimization and the external price signals. From the energy service provider it receives next day’s energy prices and prices for control reserve energy services. These are passed on to the Energy Demand Optimization so it can optimize the energy demand regarding these price signals. It is also possible to send a forecasted energy load curve to the energy service provider so that he can use it for his very own forecasting purposes. The unit controller is responsible to pass the calculated plan on to the Battery Management System (BMS) and the AGV Management System so that they are able to execute the battery changes and the battery charging according to the plan.

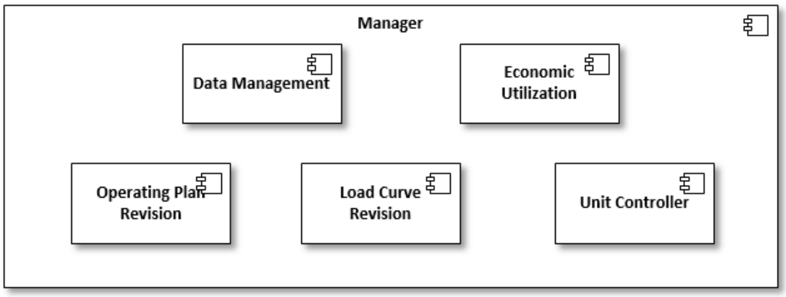


*Figure 3: Components of the Manager module*

The most challenging part of the Energy Controller is to observe the execution of the plan and to react to changes that affect the planning. Two components are responsible for this: the Load Curve Revision and the Operation Plan Revision. The first component is in contact with the energy management system where the currently metered data of the terminal is available. The metered data is constantly compared to the forecasted load curve. If the forecast is deviating from the current consumption, the plan might not be valid anymore. The same occurs when the Operation Plan Revision, which is contact with the AGV and the Battery Management System, recognizes that there are deviations between real world execution and the planning. Different strategies can be applied if a plan deviation is observed. The plan can be adapted to the new situation or the plan can be discarded. In the second case a defined default behavior of the AGV and the Battery Management System is required, which is used as back-up. This is also the behavior during the first run of the simulation before the optimization.

Figure 1 shows the single components of the architecture as well as the interfaces to the external systems.

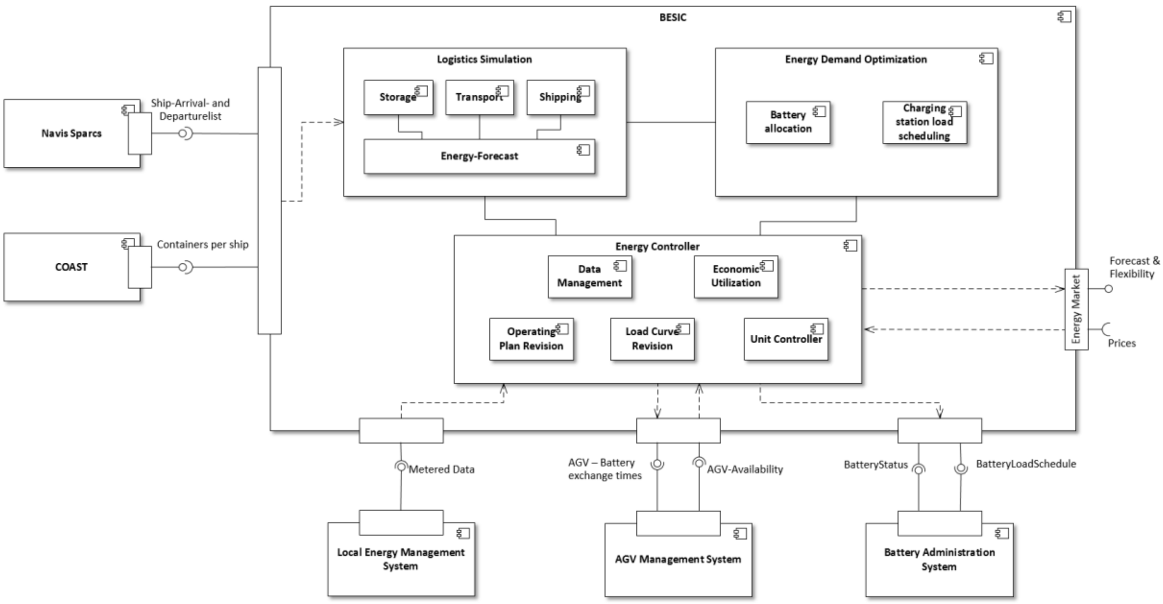


*Figure 4: Overall system structure with external components and interface*

### 3.4. Process flow of the application

The process usually starts the day before the actual logistic processes take place. At this time the ship arrival and departure list is quite reliable, energy prices for the day ahead spot market are known and the supplier has enough time to adapt to the forecast.

First all input data is gathered. Needed is the ship arrival and departure list including the number of containers to be handled per ship. This data is input for the simulation. Price signals, RTP-Prices or prices for control reserve energy offers are needed for the later optimization.

If the input data is available, the simulation is started. Result of the simulation is a forecast of the energy consumption for all consumer groups (including the battery charging station) as well as the overall energy consumption of the terminal. Additionally, the times of the battery entries and exits to the charging station are known. All this data is passed on to the Energy Demand Optimization module where the demand is shifted to provide an optimal energy supply. Optimization can include different entry and exit times of the batteries to the charging station. To verify that all logistic processes work with the different changing times as well as without, the simulation is executed one more time with the changed parameters. If the plan cannot be verified because the logistic processes are interfered the optimization is started one more time with a different goal or it is discarded and the initial timetable of battery exchanges from the first simulation run is used. The last option means that no optimization has occurred. A valid plan is passed to the AGV and the Battery Management System.

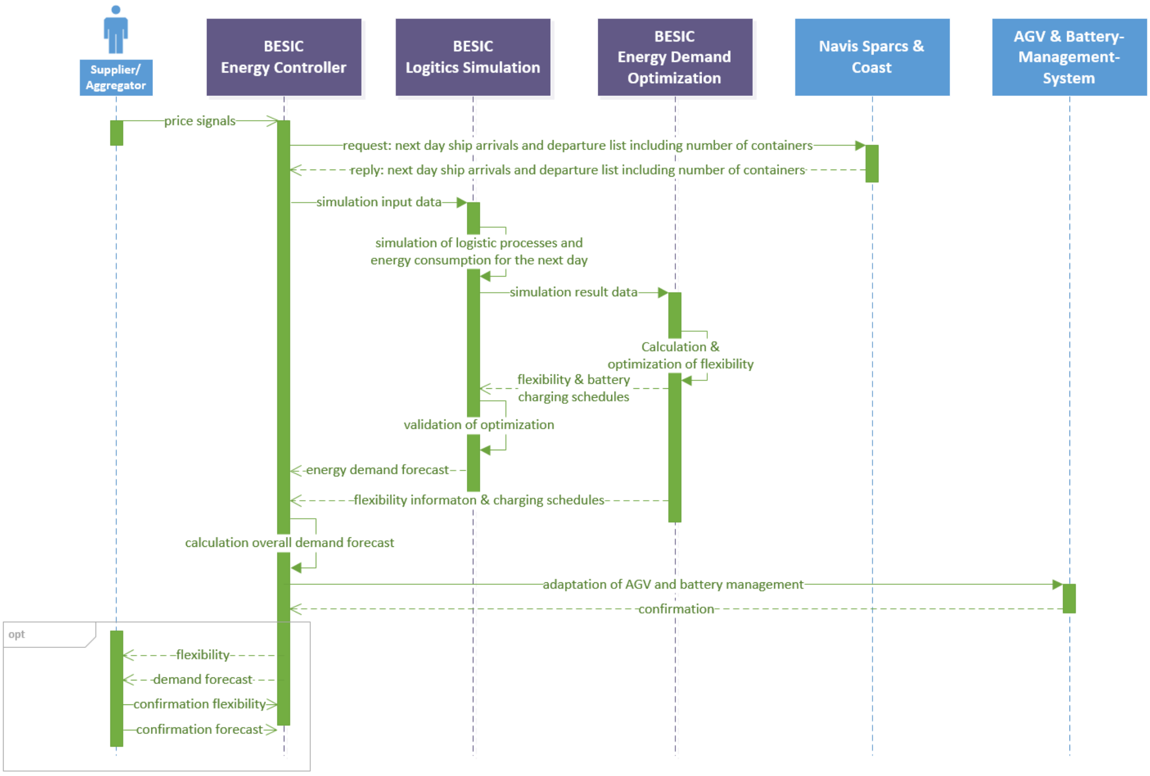


*Figure 5: Sequence diagram with the information flow during the forecast and optimization process*

At the time the forecasted logistic processes are actually taking place, the execution of the battery switching and the charging schedules is surveyed constantly. If a deviation of real world processes is recognized the planning is discarded and default behavior for AGVs and battery charging takes place. This way interference of the energy demand planning with changed logistic processes is avoided. Reasons for a deviation might be a delay of ship's arrival or the delay in processes due to weather conditions.

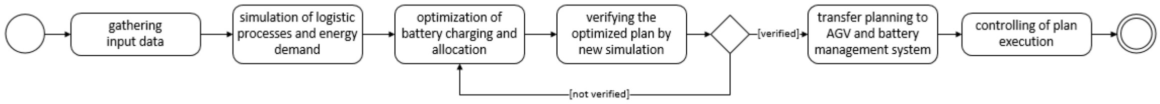


*Figure 6: Steps of the software including control*

### 3.5. Integration of the architecture into an energy management system

Since CTA has not implemented a complete energy management system (EMS) yet, the architecture is designed to be able work as stand-alone application with respective interfaces. At the time when an energy management system is fully installed at CTA, which is planned to be done soon, the architecture will be integrated into this system. Energy control and surveillance features can be executed and controlled by the energy management system itself. The EMS continuously meters the power consumption of all consumers at the terminal. One main function of the energy management system will be, besides collecting meter data, the avoidance of new power peaks during terminal operations. Besides the battery charging station, other switchable consumers, e.g. lighting or air conditioning, will be switched off when a new power peak is approaching within a 15 minute time range in order to avoid this peak. Parts of the Energy Control module could be executed directly from the energy management system since the metered data and some control functions will be available there. The Logistics Simulation and the Energy Demand Optimization module are not expected to be part of the energy management system, so further interfaces will be developed to integrate the simulation and the optimization as smooth as possible.

## 4. Current implementation and outlook

The Logistics Simulation module is fully implemented and in parts validated. First results of the energy demand forecast showed a need for modification of the energy consumption from some consumer groups. While the forecasted load curve relates to the load curve metered in real operations it was generally too low. Modifications have been applied to the static consumers of the terminal like lighting and offices. Additionally the hinterland connection was reworked to have a more realistic consumption pattern.

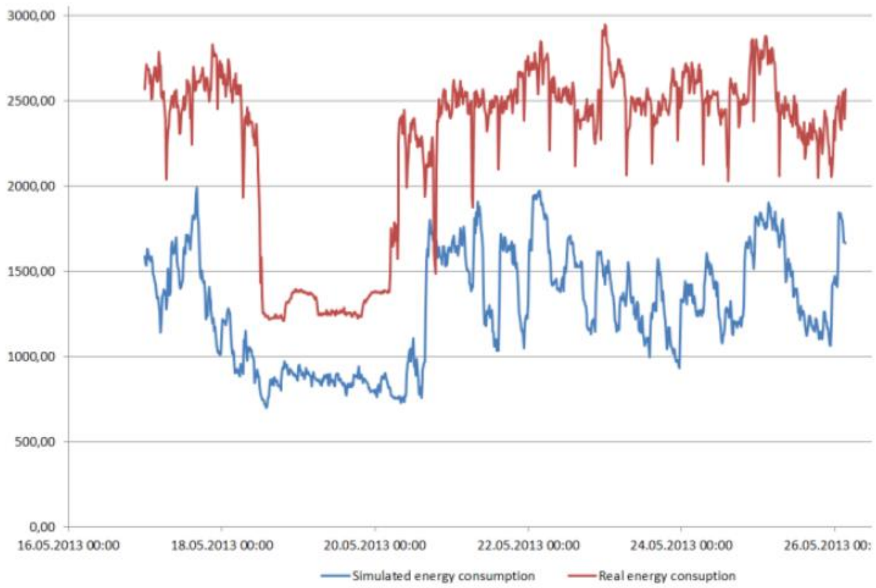


*Figure 7: Simulated and real energy consumption before modification*

The Energy Demand Optimization module is currently implemented. First optimized battery charging schedules have been calculated and could be verified by the simulation. A user interface for manual adaptations is available. Further optimization strategies still have to be implemented and tested. The Energy Controller module is not yet fully implement. A module to receive price signals from the stock exchange and from the control reserve energy platform is in place. A reading interface to the AGV management system will be available soon. The needed data is provided by the AGV and Battery Management System as XML-log data and just has to be read out. For the controlling of a Battery Management System the concept has been worked out in detail. The load curve revision and the operating revision still have to be implemented. Additionally, an overall application interface that assembles all the different modules and controls the process flow is currently developed. Future work is the direct integration into an energy management system. This has not yet accomplished since an energy management system is not yet in place at CTA.

Further research will be conducted to include strategies for integration of renewable energy generation. E.g., CTA is thinking of installing a wind turbine within the terminal. To use the generated power of this station would have the highest preference during optimization. Further parameters like wind prognosis data would have to be integrated.

Another research topic is the adaptation of generated plans and schedules to a changed real world situation. As described in chapter 3.4, a deviation from the forecasted processes to the execution in the real world leads to a cancellation of the charging schedules and to a return to default behaviour. Possibilities to adapt generated schedules in regard to unplanned events will help to have a higher probability that the energy consumption will follow an optimized planning.

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# Evaluation Guidelines for Asynchronous Distributed Heuristics in Smart Grid Applications

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## Abstract

In the context of Smart Grid applications, distributed control algorithms show advantageous properties over classical centralized approaches. Regarding their operation in a critical infrastructure, however, it is of utmost importance to validate the correct behavior of such approaches beforehand. In this paper, we give an overview on different aspects of evaluating Smart Grid applications, with a special focus on asynchronous distributed heuristics.

## 1. Introduction

A significant share of global $CO_2$ emissions can be explained by the combustion of fossil fuels for power production. Hence, it has become politically widely accepted in Europe, to reduce national shares of fossil fuels in power production significantly. Such a politically driven evolution of the power system faces not only economical and societal challenges, but it must also address several technological challenges of ensuring a highly reliable power supply, as described in e.g. [1]. In order to address these challenges, new concepts for power grid operation are needed. The notion of *Smart Grids* has been introduced for this purpose. The European Technology Platform for Electricity Networks of the Future defines a Smart Grid as an "electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies." [2] However, this implicates an increased computational complexity for optimizing the coordination of these individually configured, distributed actors. A significant body of research currently concentrates on this topic, see e.g. the research agenda proposed in [3].

In this context, the Smart Grid Algorithm Engineering (SGAE) process model introduces guidelines for application-oriented research and development in information and communication technology for power systems [4]. This envelops the phases Conceptualize, Design, Analyze, Implement, Experiment and Evaluate from a high-level perspective. In the contribution at hand, we focus on the "Analyze" and "Evaluate" parts in more detail. More specifically, we restrict our view to asynchronous distributed heuristics for solving optimization problems in Smart Grid applications. As the power supply system is a critical infrastructure, such approaches must be carefully evaluated in a secure environment before being implemented in the field. For gaining reliable results, however, this secure environment should reflect as many significant properties as possible of the targeted application area. Thus the objective of this contribution is to give an overview on the different aspects of evaluating asynchronous distributed heuristics for Smart Grid applications.

First of all, we will characterize the properties of asynchronous distributed approaches in section 2. From this, various evaluation criteria are derived in section 3, followed by a description of different methods for collecting and valuating these criteria in section 4. As a case study, section 5 then presents the evaluation coverage of an exemplary heuristic. Finally, section 6 concludes the paper.

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## 2. Asynchronous Distributed Heuristics

In centrally organized systems, a single entity with global knowledge about a given objective and all involved components is in charge of calculating an appropriate solution for the objective. For example, the traditional power supply system can be seen as a centralized system. It consists of only a small number of controllable power plants. A control center acts as a central component that knows the operational constraints of the plants and stipulates the plants' reactions when deviations from the original operating plans occur. However, as already indicated in the introduction, such a control paradigm is not suitable for future Smart Grids anymore. It is widely accepted that the power supply system of the future will be characterized by a distributed architecture comprising autonomous components with individual sub-objectives, see e.g. [5–8]. In order to orchestrate those components towards global stability and reliability of the system, appropriate control mechanisms are necessary.

An example of such a problem—which we will again refer to in section 5—is the schedule optimization problem for autonomous distributed energy units (DEU) like generators, flexible loads or electrical storages: Given a target power profile, the task is to find a schedule assignment for each participating DEU over a specified planning horizon, such that the aggregation of all selected schedules directly corresponds to the predefined target power profile. This problem is commonly present in the day-ahead planning of dynamic virtual power plants [9]. Due to the inherent computational complexity of such optimization problems, heuristic approaches are being used in order to obtain a good solution for a problem as quick as possible. Moreover, such problems naturally require using *distributed* approaches. In the described schedule optimization problem, the DEU are autonomous entities. Thus the search space of the optimization problem is naturally distributed over the system, with each unit initially knowing only its own set of feasible schedules. To find an optimized schedule assignment with respect to the global goal, communication and coordination has to take place between units. Note that, while parallelization is another reason for using distributed heuristics, in order to accelerate the process or to increase solution quality [10, 11], we focus on naturally distributed problems here.

In general, a distributed heuristic for such a task defines what, when and with whom to communicate, and what to do with received information, in order to efficiently solve the problem in a distributed manner. Depending on the communication structure, the approach can further be classified as decentralized, hierarchical, distributed or fully distributed, c.f. [12]. Moreover, we may distinguish *synchronous* from *asynchronous* approaches [13]. The former are characterized by the existence of synchronization points. These define algorithmic phases, such that the coordinating actions of all components within a specific phase (e.g. calculations and communication) have to be completed before the next phase can start. Moreover, if the actions do not depend on each other within a single phase, this leads to a strong robustness against irregularities in the underlying communication system. In turn, those approaches usually compensate such irregularities with a larger run-time. On the other hand, asynchronous approaches are characterized by the absence of synchronization points. In these approaches, communication irregularities can have a severe impact on the overall progress, because they may change the order of actions that exert influence on each other. See [14] for a study regarding such effects on synchronous vs. asynchronous approaches.

Hence, additional guidelines have to be followed when choosing or designing an asynchronous distributed heuristic for a specific problem. So besides performance and efficiency in terms of e.g. solution quality, run-time or communication complexity, further criteria are necessary. These include convergence properties, robustness analyses and scalability predictions with regard to different problem-specific parameters. In the following section, we give an overview on such criteria.

## 3. Evaluation Criteria

Before presenting our taxonomy of evaluation criteria, we have to define a few terms. In compliance with the SGAE process model [4], we understand a *scenario* as a specific collection of Smart Grid components, which then constitute the actors that the heuristic under evaluation operates on. These components may be configured using a set of *parameters*. Then an *instance* of such a scenario is a parameter assignment for all components within the scenario. Finally, an *experiment* comprises one or more computational executions of a scenario instance.

With respect to their dimensionality, we classify evaluation criteria into zeroth-, first- and higher-order criteria. In this context, a zeroth-order criterion yields a basic decision, i.e. a yes-no answer, which should generally be independent of any scenario configuration. On the other hand, a first-order criterion provides a scalar quantity, which is usually the outcome of an experiment, i.e. the interpretation of experimental data from a scenario instance. Finally, higher-order criteria allow quantifying effects that occur due to interdependencies between different scenario instances and first-order criteria, yielding higher-order quantities such as vectors or matrices as output values. For this, series of experiments are necessary, in which one or more dependent scenario parameters are varied from experiment to experiment. We will now describe these types of criteria in more detail.

### 3.1. Zeroth-Order Criteria

One of the most basic aspects to consider when dealing with heuristics that are targeted at the implementation in critical infrastructures is their *correctness* [15]. In the SGAE process model, this corresponds to the “Analyze” phase. First of all, showing correctness involves asserting that if the heuristic yields a solution, then this solution will satisfy a given specification, e.g. it is a valid solution for the given problem (partial correctness). An additional requirement is its termination, i.e. asserting that the heuristic terminates within a finite amount of time after it has been started (total correctness). In the field of distributed heuristics, this is also known as *guaranteed convergence*. Moreover, if this behavior additionally is independent of the system’s starting conditions, the heuristic is said to be *self-stabilizing* [16]. With respect to Smart Grid applications, one usually wants to show self-stabilization, as the involved autonomous components might be in arbitrary, unknown states when an optimization process is to be started. Moreover, as the occurrence of faults leads the system into arbitrary states, self-stabilization would allow such applications to recover from these faults autonomously.

### 3.2. First-Order Criteria

The probably most evaluated criterion, however, is *performance*. The performance of a heuristic describes a quantification of its ability to achieve its goal [11]. Typically, this is measured in terms of solution quality, e.g. a fitness value that is calculated using an objective function. Here it is important to maintain a defined frame of reference, such that the measured value can be interpreted properly. For example, an adequate approach would be to determine the theoretically best and the theoretically worst solution for a given optimization problem as upper and lower bounds, and to normalize the fitness value to the interval that is spanned by these bounds. Apart from such general measurements, Smart Grid specific performance indicators play an important role to assess the performance of a heuristic in this field. Such performance indicators are yet to be defined and will be subject to future work (c.f. the “Conceptualize” phase in the SGAE process model).

Besides performance, the *efficiency* of a heuristic is of interest, which describes the resource requirements of a heuristic [11]. Regarding centralized approaches, this is usually measured in terms of run-time, e.g. the amount of “steps” an algorithm takes for a given input, and memory, e.g. the amount of storage capacity an algorithm consumes while processing its input. For distributed approaches, determining the efficiency is more complicated: Regarding run-time, we have to distinguish the amount of time until the whole system terminates from the amount of "steps" the individual system components will take to reach this state. The former can be measured easily by means of real time, and will be an important information regarding the speed of the system in a specific hardware environment. The latter, however, is a more general measure as it determines the amount of work a system has to carry out. In this regard, a common practice is to count the number of calls to the objective function of the optimization problem, in each distributed component respectively. This way, both the individual work of the components as well as the overall effort can be determined in a hardware-independent manner. Finally, an additional evaluation criterion for distributed systems regarding the efficiency are communication expenses. As we are focusing on autonomous distributed components here, this leads to a message-passing paradigm (in contrast to a shared-memory model, in which multiple components possess a common working memory, c.f. [13]). Following, both the amount of exchanged messages as well as the size of these messages are significant factors for determining the efficiency of a heuristic.

### 3.3. Higher-Order Criteria

In this category, first-order criteria are evaluated against varying input parameters, i.e. changing scenario instances, in order to quantify correlation effects, or to perform a sensitivity analysis. In this regard, a prominent higher-order criterion is the *scalability* of an approach [17]. Here, the influence of a change in magnitude of input parameters on one or more relevant first-order criteria is determined. For example, given a centralized heuristic for calculating the schedule of energy resources for a future time horizon with respect to e.g. demand predictions, one could study the effects of the length of the considered planning horizon on the run-time of the heuristic. An example regarding distributed heuristics is the influence of the amount of autonomous components that are present in the system on communication expenses.

Another important higher-order criterion is *robustness* [17], which determines the influence of incidental disturbances from the environment on one or more first-order criteria. Such disturbances could be either "dynamic" incidents at run-time like e.g. varying message delays during the execution of a distributed system, or "static" perturbations that determine the sensitivity to changing starting conditions.

It is natural that higher-order criteria are rather difficult to analyze as they include lower-order criteria in different magnitudes. On the other hand, they are especially important when targeting critical infrastructures such as the power supply system.

## 4. Evaluation Methods

Each of the criteria introduced in the previous section can be valuated using different methods. Here, analytical methods are distinguished from empirical methods [10].

### 4.1. Analytical Methods

In an analytical approach, evaluation criteria are quantified by mathematical calculus, i.e. inspecting the inherent design of the heuristic formally. For this, the semantic of the heuristic has to be described rigorously. An overview in this regard is given in [18, p. 27]. For example, deterministic sequential algorithms can be described using a *denotational semantic*, which primarily relies on fixed-point iterations for modelling loops and recursions. For nondeterministic or distributed algorithms, however, the *operational semantic* (also called *transition systems*, see [19]) is more suitable, as it relies on formulating transitions between configurations, or states, of a system and thus eases the modeling of interactions between distinct components. A popular example in this context is the *I/O automata* formalization [13], which explicitly models the behavior of different components of a system through a standardized interface and thus allows for reasoning about the system's progress as a whole. Based on this, well-known proof techniques like e.g. *variant functions* or *convergence stairs* can be easily applied [16]. Another approach would be to employ automatic model checkers. Due to the numerous different semantic descriptions and methods that are available in this field, we refer to [20] for an introduction.

The above methods are particularly useful for zeroth-order evaluation criteria, e.g. for deriving convergence and termination properties. Recently, this has been adapted to first-order criteria as well. For example, in the context of self-organizing systems, [21] proposes quantitative definitions of the first-order criteria adaptivity, target orientation, homogeneity and resilience. These are based on an operational semantic in principle, which has been extended by *stochastic automatons* though. This allows for modeling the system's behavior not only in extreme cases (i.e. the best and worst cases as in the evaluation of zeroth-order criteria), but also in the average case, which is crucial for quantifying first-order criteria. The deduced average case behavior, however, directly depends on the chosen distribution functions for the stochastic parts of the model. As a consequence, special care must be taken in order to properly reflect the real behavior of the modeled system when employing such a method. Hence, if adequate distribution functions for a given system cannot be derived easily, an empirical study might be more appropriate in these cases. This approach is described in the following section.

### 4.2. Empirical Methods

In contrast to formal reasoning based on a rigorous semantic description of an algorithm, empirical methods are based on actually executing the algorithm, i.e. the heuristic in the scope of this paper, within a dedicated environment. From monitoring such executions, quantitative data can be recorded, whose dissection and interpretation then leads to the valuation of first- and higher-order criteria.

This involves a number of subsequent steps: As a single execution of a heuristic usually does not yield enough information to deduce general conclusions about the behavior of the system in the average case, an adequate *experiment design* has to be defined in the first step ("Design of Experiments" in the SGAE process model [4]). Primarily, this includes tactical decisions, such as the number of repetitions of the executions, in order to level out random effects from uncertain environments or uncontrollable parameters. This will increase the confidence level of the deduced insights later on. Especially for higher-order evaluation criteria, additional strategic decisions have to be made, such as defining a strategy for the intentional variation of input parameters in order to analyze the heuristic's behavior under varying conditions. A comprehensive overview on these topics from the perspective of simulation experiments can be found in [22]. In the context of heuristics, additional care has to be taken regarding the type of scenario instance that is to be solved by a heuristic in a series of experiments [10]. While parts of this, like e.g. the magnitude of input parameters, are usually already covered in the described tactical and strategic decisions, the inherent type of an underlying problem instance might be of interest as well. In the SGAE process model, this corresponds to the "Scenario design" phase. Here, on the one hand, synthetically crafted problem instances can be used. These do not reflect the targeted application field, but are constructed in such a way that specific properties are present in the problem to solve. For example, "deceptive" problem instances [23] are useful to analyze whether a given heuristic is able to overcome local optima in the search space. This way, a deep understanding of the observed effects can be gained. On the other hand, application-specific problem instances aim at reflecting the target application of a heuristic as close as possible, such that the heuristic's behavior can be observed directly in in its presumed environment.

In the second step, the experiment is actually carried out. This can either be done in a physical test bed, or by means of computer simulation. Again, a physical test bed—if built properly—can provide a higher degree of realism regarding the targeted application field. But as this may be inappropriate due to pragmatic reasons like e.g. implementation costs, computer simulations are often used as a substitute for physical experiments. Moreover, computer simulations offer greater flexibility regarding the system configuration. According to J. Kleijnen, the core of a simulation is a *simulation model*, which is defined as a "dynamic model that is meant to be solved by means of experimentation." [22] Regarding our focus on heuristic approaches for Smart Grid applications in this contribution, the simulation model for a computer simulation then comprises both the heuristic under evaluation and the environment this heuristic is executed in. Following, it is of utmost importance to build the model as realistic as needed, i.e. such that all relevant interdependencies between the (simulated) environment and the heuristic are incorporated into the model. For example, if a given distributed heuristic is said to be asynchronous based on message passing between components, possible flaws from the underlying communication technology such as message delays or buffer overflows should be anticipated. The other way around, if the outcome of a heuristic affects e.g. the power flow in an electricity grid, and the resulting effects are relevant for the evaluation, the grid must be modeled in such a way that those effects are properly accounted for. Again, [4] gives further suggestions regarding this topic. There, besides conceptual considerations, the modular Smart Grid simulation framework *mosaic* [24] is given as a tooling example in the SGAE process model. Moreover, we refer to textbooks such as [25, 26] for further reading.

Finally, in a third step, the preceding executions of the heuristic have to be analyzed with respect to the criteria of interest. Especially for higher-order criteria, specific metrics and suitable statistical methods can then be applied, in order to draw conclusions from the possibly vast amounts of recorded data. Examples for methods and metrics regarding various evaluation criteria can be found in [17, 10, 22].

## 5. Case Study

For an exemplification of the presented evaluation guidelines, we will in the following describe the evaluation process of the *Combinatorial Optimization Heuristic for Distributed Agents* (COHDA), which initially was published in [27] as a heuristic for the schedule optimization problem for autonomous DEUs that we introduced in section 2. Thus COHDA operates in a multi-agent system, where each agent represents a DEU with a private search space of feasible schedules. The goal is to select exactly one schedule for each DEU, such that a given target power profile is approximated by the sum of all selected schedules as close as possible. As the individual search spaces are to be kept private, the agents have to communicate via messages in order to coordinate towards a common solution. Basically, COHDA realizes an asynchronous iterative approximate best-response behavior, where each agent reacts to updated information from other agents, by adapting its own selected schedule with respect to the global target power profile.

The evaluation coverage for COHDA is depicted in figure 1. To prove the correctness of the heuristic in terms of convergence, termination and self-stabilization, a formal analysis has been conducted. For this, the approach has been described semantically in the I/O Automata framework [13], followed by formal reasoning using the convergence stairs method [16] (this proof will be published in a subsequent paper). As a side effect, the best case and worst case run-time could be determined in the process. Following, a simulation study has been conducted. Here, the performance of the heuristic was evaluated in two application specific scenarios: trading active power products in day-ahead electricity markets and load profile smoothing (these results are not published yet, but [9] and [28, sect. 3] provide more details on the respective tasks). Finally, the

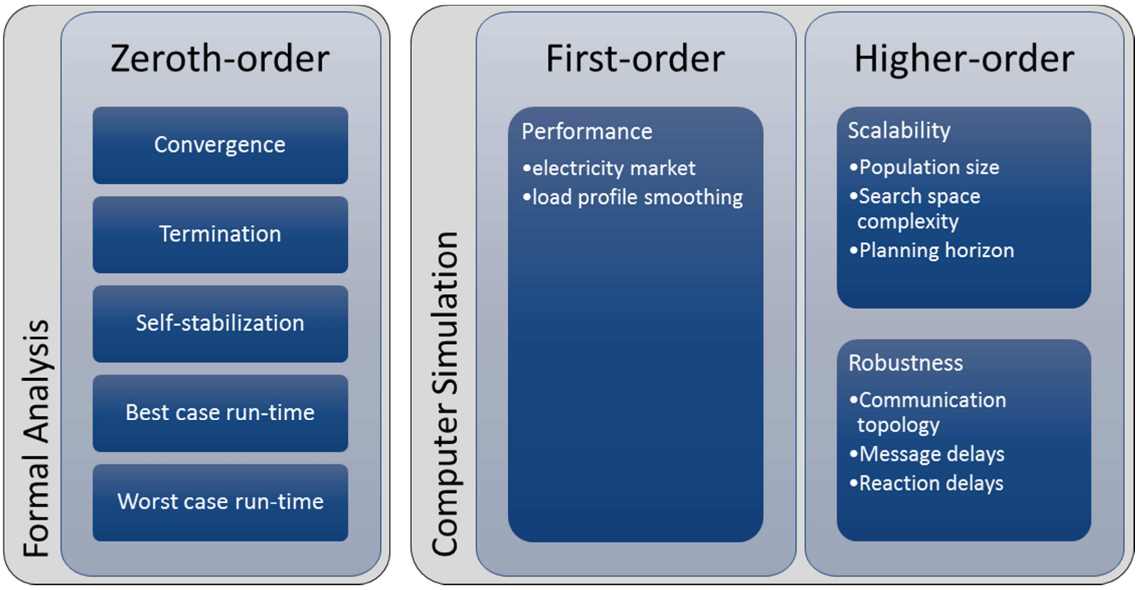


*Figure 1: Evaluation coverage of the COHDA heuristic*

higher-order criteria scalability and robustness were evaluated for various parameters (c.f. figure 1) with respect to the first-order criteria performance (solution quality) and efficiency (run-time, computational expenses, communication expenses). Here, both synthetic and application specific scenarios have been employed, see [29, 30, 14].

## 6. Conclusion

The Smart Grid Algorithm Engineering (SGAE) process model [4] provides a foundation for the structured development of Smart Grid application algorithms. In the paper at hand, we explicate the "Analyze" and "Evaluate" phases of the model in more detail, with a specific focus on asynchronous distributed heuristics for solving optimization problems in Smart Grid applications. The main contribution of this paper is a taxonomy of evaluation criteria, followed by an overview of methods for valuating these criteria. Finally, we presented a case study regarding the evaluation of an exemplary heuristic for the schedule optimization problem for autonomous distributed energy units.

Future work in this context will be to define application specific performance indicators, such that Smart Grid application algorithms, especially distributed control approaches, can be developed and evaluated using standardized and accepted criteria from the problem domain.

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# Using Information Security as a Facet of Trustworthiness for Self-Organizing Agents in Energy Coalition Formation Processes

Christine Rosinger[1], Mathias Uslar[1], Jürgen Sauer[2]


## Abstract

Trustworthiness - besides other decision making factors like technical or regulatory requirements - can be one key aspect for the decision making in coalition formation processes with agents in the energy domain. In this paper the trustworthiness facet information security is used to describe the realized security measures and standards of the systems for coalising energy agents as one trust building factor. These realized security measures are assessed and used for the decision making in the coalition formation process. This contribution shows also some of the results for developing a trust model for a multi-agent-based energy management system in the "*Smart Nord*" project.


## 1. Introduction and motivation

There are different issues for the motivation of using a trust model/system as one security measure for an agent-based energy management system.

The reorganization from a monopolistic electricity market to a distributed smart grid and also the liberalization of this market with its unbundling induces the need of more information and communication technologies (ICT). The increasing ICT leads to a higher threat potential, as a result of new and more intelligent actors and additional interfaces and data exchange that are introduced in the energy domain. Thus, the energy domain requires more revised and in some cases even new security measures because of the special requirements of the energy domain [1].

The increased usage of decentralized power plants results in a distributed structure of the power grid. To control, organize, and act at markets in an economic way and even to reach a higher automation level, one possible solution is to use multi-agent-systems, as it is actually realized in the project "*Smart Nord*"[3] [2]. In this project, producers, consumers, and storages of energy are represented as agents who form coalitions to act at an energy marketplace.

The main motivation using a trust model is the occurrence of malicious agents. Different attack motivations [3] like e.g. achieve economic advantages can mislead malicious agents to misuse the system for their own advantage. In a worst case scenario, malicious agents can create a system blackout if they cooperate as a botnet. To thwart such attacks, the application of a reputation or a trust system [4] shall prevent this. Additionally, such a trust model should restrict the actions of the malicious agents and acts as one security measure, respectively, increases information security.

### 1.1. Outline

This paper provides an overview of first results of a distributed trust model which is developed in the project *"Smart Nord"*. This contribution focusses at the trustworthiness facet information security which will be used as a trust building factor for the coalition formation process of self-

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[3]The homepage of the "*Smart Nord*" project can be found at www.smartnord.de/.

organizing energy agents. After this introduction, Section 2 gives a short definition of the terms reputation, trust and trustworthiness, and their use in the project *"Smart Nord"* where this trust model is applied. In Section 3, related work of this security assessment approach is described and Section 4 shows an overview of the trust model. Section 5 illustrates the ontology-based concept of assessing security measures of a computational system of an energy agent. Afterwards in Section 6, a preliminary use case is applied to show this approach exemplarily. Finally, the paper ends with conclusions and an outlook in Section 7.

## 2. Terms: Reputation, trust and trustworthiness

To get a consolidated understanding of the terms reputation, trust and trustworthiness; first, the difference between the terms reputation and trust and the relationship of trust and trustworthiness needs to be explained. After that, the terms are classified in the project "*Smart Nord"*.

### 2.1. Difference of reputation and trust

In common understanding, the terms reputation and trust are frequently applied with the same meaning. The difference of the terms is defined as follows [5]:

The term *reputation* means that a group or a community of entities (agents) has a common opinion or understanding about another entity. This reputation or reputation value was built up by the community and they, altogether, have only one common value about this other entity (as shown in Figure 1, left side): The group of the entities *A, B, C, and D* as community has one reputation value about entity *E*. Within a reputation system every entity uses the same reputation value about one entity, which means that a reputation system is a kind of a centralized approach.

In difference to reputation, the concept of *trust* describes a local meaning or understanding and represents the subjective opinion or feeling from one entity towards another entity. Additionally, trust can be distinguished into direct and indirect trust like in the trust model "Web-of-Trust" [6]. This is further described in Figure 1 on the right side: *Entity A* wants to get into a trust relationship with *entity B*. *A* has no former direct experience with *B* but *A* has a direct trust relationship with entity *C*, which furthermore has a direct trust relationship with *entity B*. In this way, *A* can get some indirect information or referral trust about *B* over its direct relationship with *C*. Within a trust system, every entity has its own trust value to another entity. Thus, each entity can have a different trust value towards another entity which represents a kind of decentralized approach.

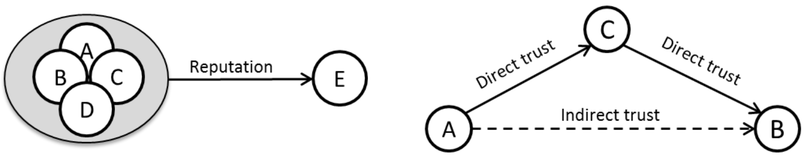


*Figure 1: Difference of reputation and trust*

### 2.2. Relationship of trust and trustworthiness

Trust and trustworthiness will be considered and used if one entity has to rely on another entity. The difference of trust and trustworthiness depends on the viewpoint. Trust is a property of entity A in relation to Entity B; Entity A has trust in entity B. In distinction to trust, trustworthiness is a property of entity B but has also a relation to entity A; Entity B represents its trustworthiness (in front of other entities), e.g. from the view of entity A [7]. In this paper, both terms are used for the trust model depending on the viewpoint.

### 2.3. The context of the project *"Smart Nord"*

Within the project *"Smart Nord"*, a trust system for a decentralized and self-organizing multi agent system will be designed. The decentralized approach of trust in comparison of the centralized approach of reputation is applied because it is similar to the decentralized energy supply design which is realized in the project and this decentralized approach is more adaptive. Additionally, the distributed storage of the trust values should prevent a single-point-of-failure of the trust system.

## 3. Related work

This contribution should show an approach to assess security measures of a computational system and – especially in the context of the *"Smart Nord"* project – of a computational system of an energy agent. Generally, for the assessment of security realizations, security metrics are used to improve the security in a system or architecture [8]. But this is not really an assessment of security measures; it is rather assessing the impact or barely counting the attacks. To realize an improvement over existing systems or even in the development of architectures, risk analyses [9], [10] and principles like security by design [1] or security standards [11] are applied. These described techniques are a kind of top-down approach.

The assessment of the security measures in the approach of this paper is rather a bottom-up approach. The energy agents negotiate and use the assessment of the security measures to decide to go into cooperation with the potential partners. But this assessment approach, described in Section 5, bases on how risk analyses are executed for security improvement.

## 4. Trust model for self-organizing MAS in the energy domain

The trust model which is developed in the *"Smart Nord"* project supports the trustworthy coalition formation of time-table-based active power provision. It consists of two parts: the structure and the application of the trust model.

### 4.1. Structure of the trust model

The structure of the trust model is shown in Figure 2. One main component of this structure is the integration of different facets of trustworthiness [12] and combining these facets to one trust value [3], [4]. Trustworthiness facets defined in the project *"Smart Nord"* are for example:

- *Credibility* represents the former behavior of an agent.
- *Reliability* forms a prediction value of technical data from the plant for the product delivery performance.
- *Information security* assesses realized security measures of the agent/plant system.

Figure 2 shows an illustration of the trust model. Besides the described facets, there are different ones that will not be considered in the project *"Smart Nord"* but can still affect trustworthiness. Generally, the facets are distinguished into trust building a priori and at runtime. Additionally, the trust value of an agent $A_j$ from the viewpoint of $A_i$ always refers to a context and is also time-dependent. Hence, the trust value $tv$ can be expressed as quintuple:

$$Trust\ value\ tv = \left[Trustor\ A_i, Trustee\ A_j, Context\ c, trustworthiness\ tw, timeframe\ t\right].$$

Furthermore the trustworthiness $tw$ can be expressed as the following hextuple:

$$trustworthiness\ tw = [Functional\ correctness\ fc, safety\ saf, informations\ security\ sec,\\ usability\ u, credibility\ cre, reliability\ r].$$

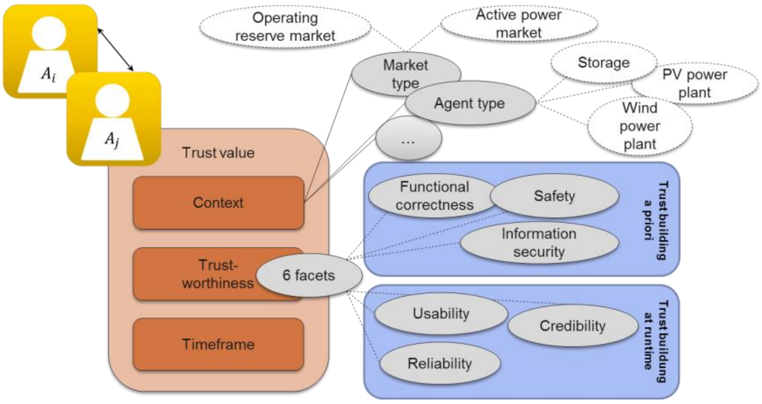


*Figure 2: Illustration of Trust Model*

### 4.2. Application of the trust model

The second main part of the trust model is the consideration of different phases a trust value has to go through during its lifecycle which is shown in Figure 3. The first appearance of a trust value is in the *initial trust* phase. This occurs when an agent is generated or joins the community. In this phase it has to be decided and determined which value the trustworthiness will be. Facets that have a trust building a priori can be applied in this *initial trust* phase. After this, the *calculation* or *update* phase takes place where e.g. the former behavior of an agent is regarded. This behavior is then included into the value or the value is updated. The *storage* phase considers where and how the different facets are stored and how tampering can be prevented. After a value was stored, there is a relationship back to the *calculation* and *update* phase because this is the main life circle of the value. After *storage* there are different other possibilities what happens next with the value. The *exchange/distribution* phase is concerned with the method how the values are exchanged and distributed between the agents and also a secure transfer of the values is considered. In the *utilization* phase, the different facets of the trust value are combined, goal functions are applied and guidance recommendations are given. If a value is compromised by malicious agents, revocation of the value has to be initiated.

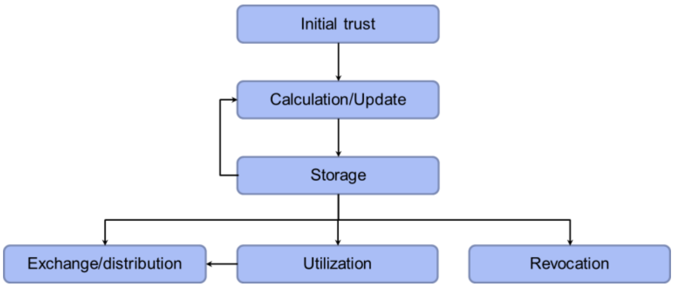


*Figure 3: Phase model of the trust model*

One of the main purposes of this paper is the presentation of how the trustworthiness facet information security for the agent-based energy management can be realized. This will be shown in the following Section 5.

## 5. Information security as a trustworthiness facet

Trustworthiness, as used here for the trust model in the intelligent energy management with self-organizing agents, is a value of one agent which represents its actual trustworthiness in a specific context. Trustworthiness in common consists of multi facets [12] – as shortly described in the previous section. One of these trustworthiness facets is information security, which takes into account that the more security measures a system of an agent applies, the higher is the assumed trustworthiness of the agent. Additionally, for this information security facet it is expected that if an agent realizes its security measures in a standard-based way, the agent is considered more trustworthy. In the following, the *basic security assessment model* and the *security value assessment method* are described which are necessary for the information security facet.

## 5.1. Basic security assessment model

In Figure 4, an overview of the basic security assessment model as ontology is depicted. The solid lines represent hierarchical relationships between the concepts shown in blue and red-striped boxes and the dashed lines are object-property relationships, which can be reasoned. The green oval shows the security value which is calculated by the security assessment model and which represents the result of the assessment phase.

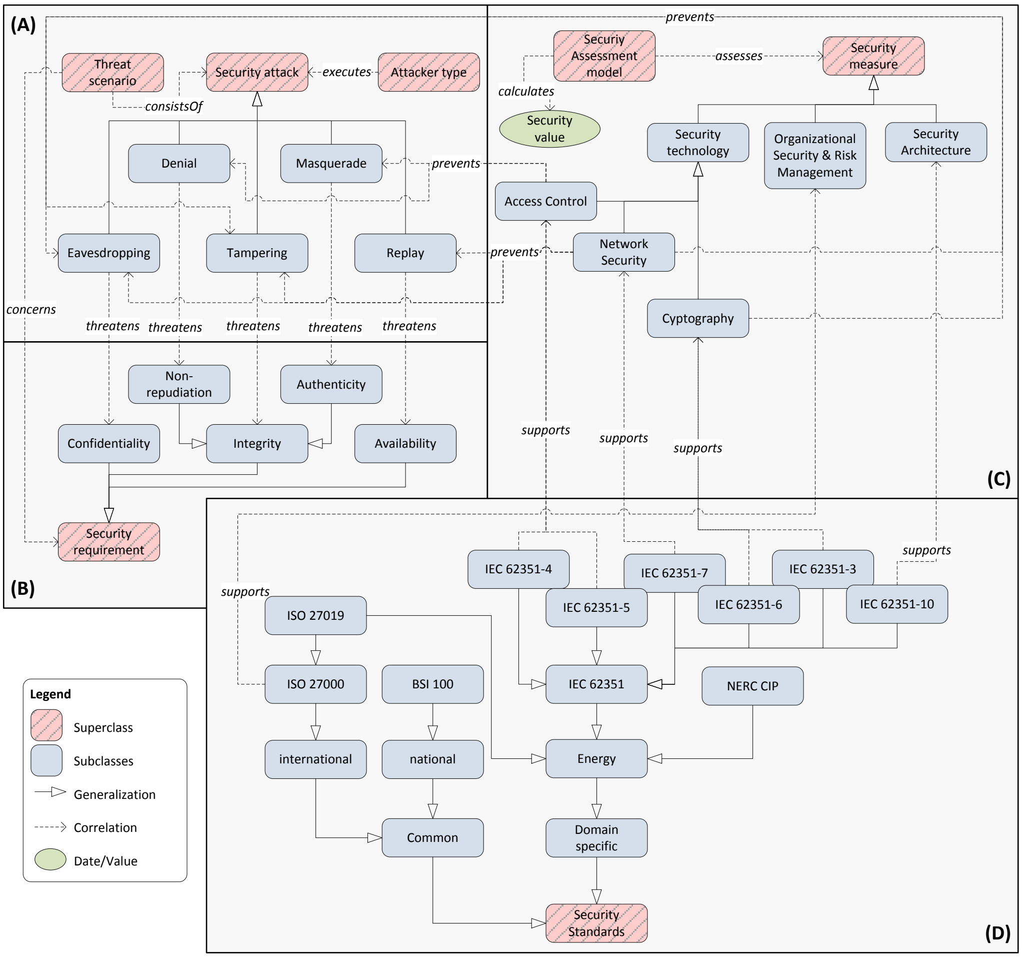


*Figure 4: Assessment of implemented information security measures*

The basic security assessment model in Figure 4 is segmented into four parts. Part (A) on the left upper side shows the concept *security attack* which consists of *threat scenarios* and is executed by an *attacker type*. Additionally, the corresponding concepts *eavesdropping*, *denial*, *masquerade*, *tampering* and *replay* are depicted. In part (B), on the left lower side in Figure 4, *security requirements* are illustrated which have to be guarded. Furthermore, the derived concepts *confidentiality*, *non-repudiation*, *integrity*, *authenticity*, and *availability* are shown. These concepts are pairwise threatened by *security attacks*. Part (C) shows the *security measures* with its sub-concepts *security technology* (*access control*, *network security*, *and cryptography*), *organizational security & risk management*, and *security architecture*. These *security measure* concepts are also pairwise associated over object-properties with their corresponding *security attack* concepts.

Additionally, they are related with the appropriate *security standards* which support the security measures. The security standards are depicted in part (D). Even in part (C) – the most relevant concept for this assessment – the *security assessment model* concept is associated with the *security measure* concept over the object property *assesses*. Finally, this *security assessment model* concept with its assessment functions realizes the overall *security value*.

Figure 5 gives a deeper insight into the *security measure* and *security assessment model* concepts of the ontology from part (C). On the right side, the concept *security measure* is separated in the three concepts *security techniques* – which shows different exemplarily realizations of the concepts *access control*, *network security* and *cryptography* – *organizational security & risk management* and *security architecture*. On the left side, the *security assessment model* concept is depicted which calculates the *security value*. For this calculation the *assessment model* has different *consideration* concepts with various *functions*, which are formed on the basis of assumptions. Additionally, for the *assessment* the *consideration* concepts support each other.

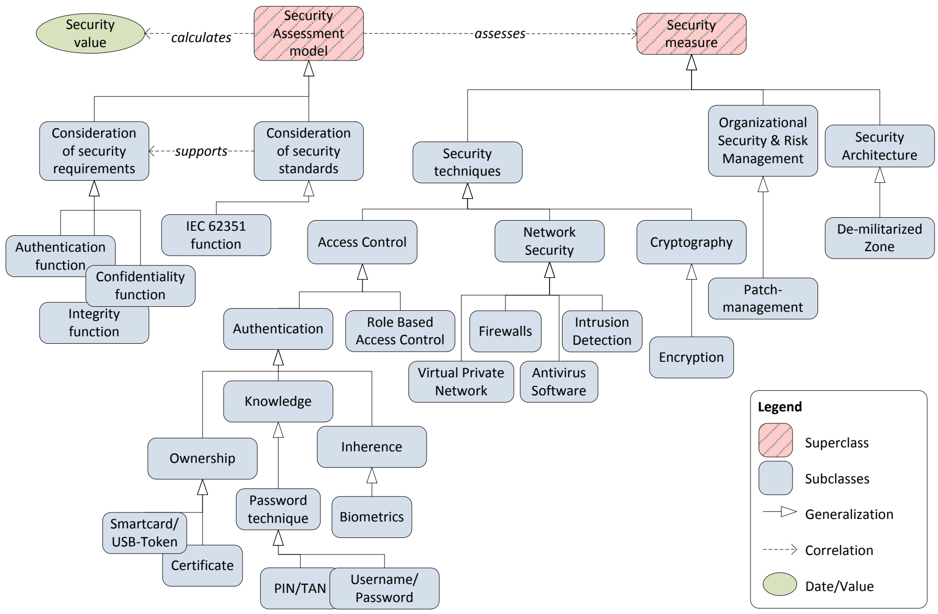


*Figure 5: Assessment of information security measures*

The approach of the assessment is based on the described ontology. Every agent of the energy management system realizes its security in a different way. Thus, for every agent instances from the ontology of its security realization are created. After the instantiation, over the *security measures* concept can be reasoned which *security requirements* have been protected for securing the system and whether useful and appropriate combinations of security measure are implemented. With that process, the *security assessment model* concept supported by reasoning and the *consider functions* calculates the *security value*.

### 5.2. Security value assessment method

Security assessment consists of assumptions because there are always different requirements and every user has to decide on his own which security requirements are the most important for his particular use case.

The presented security assessment method is based on a regular risk analysis [9],[10] with the assumption that the more security requirements are covered the more trustworthiness can be expected. Thus, the security assessment per agent consists of three parts. First, the *consideration of security requirements* concept of the ontology recognizes which security measures are realized and infers which security requirements are protected with these measures. This results in an assessment value $A$ per security requirement $secreq$. Second, the *consideration of security standards* infers which standards are used for the realization and which security requirements are covered with them. This results in a 20 percent improvement of the assessment per security requirement $secreq$ if this security requirement is realized with a security standard ($St$); if there is no standard-based realization no improvement is obtained. Thirdly, there is a priority between 1 (low) and 4 (high) – which is based on the protection demand categories of the German "Federal Office on Information Security (BSI)[4]" – to get a weighted factor $Prio$ for the security requirements $secreq$. This priority has to be determined by the operator of this assessment on behalf of the appropriate use case.

For the final security assessment per agent $Sec(Agent)$ a weighted average with the single assessment per security requirement $A(i)$, the assessment of standard-based realization per security requirement $St(i)$, and the priority per security requirement $Prio(i)$ can be built which can be seen in formula (1). $\#secreq$ implies in this case the number of security requirements.

$$Sec(Agent) = \frac{\sum_{i=1}^{\#secreq} A(i) * St(i) * Prio(i)}{\sum_{j=1}^{\#secreq} Prio(j)} \quad (1)$$

## 6. Preliminary use case example

In this section a use case example of a coalition formation process with the trustworthiness facet information security between three energy agents will be described. This facet and also all the other trustworthiness facets (see Section 3) should function as trust building factor and support the decision making process of finding the right coalition partners.

Agent $A_1$ which initiates the coalition is called *initiator*; all other agents are the *responders*, in this use case these are the agents $A_2$ and $A_3$. Before starting the process with the call for proposal the initiator $A_1$ requests the trust values of the responder agents $A_2$ and $A_3$. This trust value consists normally, as described before, of different facets but this use case example is limited to the facet information security which calculation is described in the following paragraph.

| | Security requirements: Agent $A_2$ | | | | | Security requirements: Agent $A_3$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Authenticity | Integrity | Confidentiality | Availability | Non-repudiation | Authenticity | Integrity | Confidentiality | Availability | Non-repudiation |
| Single assessment | 0.8 | 0.6 | 0.5 | 0 | 0 | 0.5 | 0.4 | 0.8 | 0 | 0 |
| Standard-based (y/n) | n | y | y | - | - | n | n | y | - | - |
| Priority | 4 | 3 | 3 | 1 | 2 | 4 | 3 | 3 | 1 | 2 |
| Product | 3.2 | 2.16 | 1.8 | 0 | 0 | 2.0 | 1.2 | 2.88 | 0 | 0 |
| Total assessment | $\frac{3.2 + 2.16 + 1.8 + 0 + 0}{4 + 3 + 3 + 1 + 2} = 0.55$ | | | | | $\frac{2.0 + 1.2 + 2.88 + 0 + 0}{4 + 3 + 3 + 1 + 2} = 0.47$ | | | | |

*Table 1: Example of security assessment calculation*

Agent $A_2$ gets for its authentication a value of 0.8 in contrast to Agent $A_3$ who has a value of 0.5. For example, Agent $A_2$ realizes its authentication via 2-factor authentication (password and USB-token), and agent $A_3$ realizes its authentication only with a simple authentication (only with a password). Both agents have no standard-based realization of the measure. If they would have a standard-based realization in any of the measures, we assume an improvement of 20% for the

[4] The homepage of the BSI can be found at: https://www.bsi.bund.de/EN/Home/home_node.html.

trustworthiness, limited to an upper bound of 1. Furthermore, Agent $A_2$ and $A_3$ have the following values that can be seen in Table 1 in row *"single assessment"* for the other security requirements. In row *"standard-based (y/n)"* it can be seen, if these measures are realized in a standard-based way or not. Row *Priority* shows the assumed priorities for the different security requirements in this agent-based use case example. After that, in row *product* the three factors are multiplied – remember: standard-based realization gives 20% improvement limited to an upper bound of 1. Finally, the last row shows the calculation of the total assessment derived from formula (1).
For this use case this means that the initiator agent $A_1$ has the choice between agent $A_2$ who has a security value of 0.55 and agent $A_3$ who has a value of 0.47. Hence, $A_1$ takes $A_2$ for the coalition because of its better security realization. In a real scenario, the initiator agent has to include into this decision at first of course the contribution of energy the agent wants to provide and – as described before – the different facets of trustworthiness.

## 7. Conclusion and outlook

This contribution provides an overview of a trust model that is applied in the context of negotiating energy agents. The focus of this paper is the trustworthiness facet information security. Thus, an ontology-based approach of assessing security measures is described and examined, on the basis of a use case example.

For future work, the different factors of the information security facet in the context of the *"Smart Nord"* project needs to be estimated and evaluated. After the finalization of the different facets, the combination of the different facets has to be considered and examined.

## Acknowledgement

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# Modeling of power consumption in a small microgrid

Weronika Radziszewska[1], Zbigniew Nahorski[2]

## Abstract

Development of energy management systems and models of power grids are popular topics of many research projects. Unfortunately, quite often the behavioral tests with load data are not present. It is due to the difficulty of representing and collecting data about the power usage. To obtain such data it is required to deeply analyze operation lifecycle of certain devices and information about statistics of human behavior, as well as the patterns of people actions. Although many devices time profiles have been published, they lack characterization of variability of behavior and uncertainty. The paper presents some alternative ways to model power usage: probability profiles, rules and a mix of them. The purpose is to create a simulator for testing performance of energy management systems in a small microgrid.

## 1. Introduction

With the development of new technologies and with the digitalization of many areas of life, the number and variety of electrical devices grows. In larger grids, the influence of single device activity is limited, as the total grid is aggregated so much that small fluctuations often do not appear in the aggregated result. But in smaller ones, like microgrids, this effect becomes much more prominent. This implies that there are more dynamically changing conditions, to which small power grids should preferably adjust. This can be done by introducing intelligent methods of power management. Development of such methods requires appropriate models, as experiments usually cannot be run on existing structures. The models should possibly resemble the real world situations, which requires a thorough understanding of what the consumers do. Some aspects of consumer behavior can be described by patterns (e.g. day/night), but influence of random human behavior is always profound.

With the development of smart grids, there appeared systems that allow gathering on-line information about the amount of power usage. This can help users to smartly save power by shifting its usage towards the time when it is cheaper due to a time of a day or a better availability of power from renewable power sources. This idea is called Demand Response approach to power management [6]. Many studies have been started recently to profit from measurements provided by smart meters, particularly in the residential sector, see e.g. [3]. Within them intensive research have been conducted to identify periods when different devices are active during the measurement time. For this, the measured power is disaggregated to the devices that are generating it. Presentation of these methods can be found in [3, 8, 10]. Simulators described there perfectly reproduce the power usage of the chosen devices, when their activity times are known [3]. But very little is known on patterns of using devices by people. Here, we focus more on human aspect – on modeling how people switch on or of a device. This is connected with creating a simple simulator to represent operations of chosen devices by rules.

Supplementary results of the mentioned above studies are energy consumption profiles of different devices [1, 7, 9]. They were used to categorize devices. [8] classify them as resistive, inductive, capacitive, and non-linear. Zeifman et. al. [15] divide them to permanent, on/off, multistate, and

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variable. None of these classifications suits good enough a simulation of human patterns of using electrical appliances.

The problem addressed in this paper pertains to simulation of the electric energy loads in a research and educational center which is now under construction. It was needed to examine an energy management system proposed to be tested in the center. This task is different from those considered in the literature mentioned. First of all, it is not a residential sector and patterns of devices usage depend on many persons and on events taking place in the center. In particular, a considerable part of energy usage in the center is due to intensive computations, see e.g. [11]. Moreover, the center was only in a design stage, so no measurements have been available to help in simulation. Finally, to better test the management system, simulation of the electric energy load with a random behaviors is needed. In this paper data structures that can store characteristic power consumption of different devices are outlined. An idea of a simulator is presented.

## 2. Modeling power consumption

The power consumption is triggered by human actions. Very often people do not know how much power is used for their activities. A good example of that is power usage in the stand-by mode of the devices: people think it is negligible, but in reality such usage can reach up to 50% of actual usage of this appliance [13]. Recent studies described in [5] show that average user is underestimating power usage of some of his appliances while overestimating others. During that study the power usage of electric clothes dryer was severely underestimated, whereas the power usage of a laptop was slightly overestimated.

Modeling of users behavior regarding the use of electric equipment is especially difficult due to some obstacles that have to be overcome:

- there is a great variety of peoples' actions due to personal differences in habits, location, time, etc. — a research made in one location may be not useful in others. This forces to make research on a larger scale, categorized by social group, place, time, etc.;
- people do not like to be interrogated — questions about how they use electric equipment during the day would reveal their daily activities, in such case it is unlikely to obtain honest and exact replies;
- behavior of people might be extremely erratic — group of people might have a tight schedule, but their detailed actions will be different each day, that suggest a probabilistic or fuzzy models of such actions;
- constant evolution — change of technology is extremely fast, even when people behavior would be predictable, the devices they use are constantly being modernized, in the area of computers and cell phones changes are introduced every few months; as a consequence measured and described usage of power can be outdated soon enough to be unusable.

The power usage of a device can be measured, which gives a lot of information about change of its operating point in time. That would allow making a detailed description of the power consumption. Such description can well define devices which operating cycle is not changeable: for example a toaster. In this case small changes, like the length of toasting, can occur, but that would be just small prolongation of the operation time. But such devices are in minority, usually the conditions of the environment are introducing significant changes in the operation cycle. For example operation of washing machine depends not only on the program, but also on the weight and dirtiness of the laundry and softness of the water. What is more important, it is difficult to measure the frequency when and in what conditions the device is being switched on. That requires long term observations of different users to derive typical patterns and deviations from the patterns of using the device.

Correlations between operation of different devices also exist. People often act in sequences, for example switch on a television set and make popcorn. The problem of finding this correlations is that people do not think about them, they just do it because it is their custom or a desire of the moment. Description of such relations is difficult and little research is done to discover and formalize them.

Another aspect that has to be considered while describing the consumption is the aggregation level of the power usage. When a city is modeled, the profile of its usage is a sum of all sectors, like commercial, residential, industrial and others. Such data are dominated by daily and weekly cycles. When a village is considered, the aggregated profile encompasses private houses, farms and small factories, characterized by much bigger variability. To model power usage of a household, single devices are considered. In such low level modeling each day is usually different. All of this examples have different aggregation level and their properties and dynamics are distinct, so the method of description has to be different. The big aggregates tend to have less variability between the same times and days of the week during the year, in such case their consumption can be described by profiles. When a single device is considered, the description has to be more detailed, also the distribution of device usage and its operating point must be properly simulated, to achieve useful operation rules or probability profiles. In the next section some methods of describing the power consumption for simulation purpose are presented. Fig. 1 presents a simplified schema of the described methods.

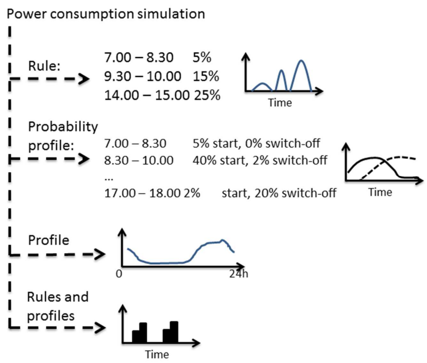


*Figure 1: A diagram of different descriptions of energy consumption*

## 3. Profiles

Usage of energy by some devices can be modeled as a profile, which is an approximation of a device energy usage in time. In the digital technology, profiles are defined in a certain time period. The shorter the period, the more exact the representation is. Discrete-time real measurements are divided into time periods ($t_1, t_2, \dots, t_n \in T$) and then the values that have been measured within this time period are averaged to give one value representing this period of the operational cycle of the device, for period $t_i$ the value is $x_i$.

Profile can be describes as: $p(x) = [x_1, x_2, x_3, \dots, x_n]^T$ . Examples of devices, for which profile modeling can be applied may be a dishwasher, a fridge, heat pumps, a meteorological station or a freezer. Profiles can be also used to represent the sum of small power consumption of devices, for example a set of light bulbs in a large corridor. In this case the small changes in operation of single element does not create big deviation from the profile and with a large number of devices the deviations can level out. Some examples of profiles are presented in Fig. 2.

Profiles describe the typical, average behavior and should not be used when power usage dynamics has to be considered or when a device has very erratic behavior. For example, a weekly profile of a washing machine would be extremely not accurate, as the times and frequency of switching it on vary during the week. The main limitation of the profiles is that their resolution of data is limited. Often half an hour or one hour time periods is assumed, which is often not enough when a quasi real time processing is considered. On the other hand, for some purposes such information can be sufficient and then it is very effective structure to work with. Usual lack of information about the variance within the time period makes it difficult for a simulator to add some randomization in the profile.

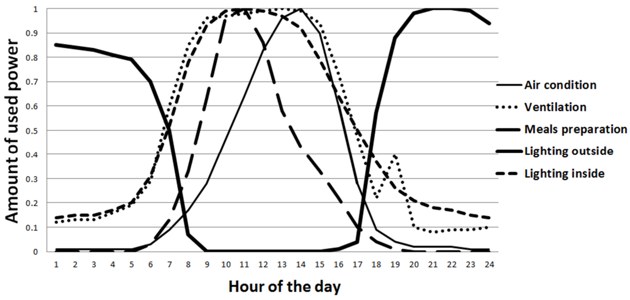


*Figure 2: Examples of profiles for chosen categories of devices*

## 4. Probability profiles

Profiles are very suitable and adequate to represent devices which are dependent on time of the day (e.g. light, ventilation). When the power consumption of a device is very volatile during the operation time, the profiles become imprecise and not useful. The main example of a device that should not be described by a profile is a computer — it is a device that once switched on usually stays on for a long time, even when it is not used. This is caused by long starting and stopping time; long time needed for switching on and off the programs; and the false assumption that the components of the computer get used more quickly during the switch on and off phase [1]. When computer is not occupied by the tasks it can enter an idle mode in which it uses around one third of the average power consumption. Users tend to switch on the computer when they come to work and switch it off in the afternoon when they go home, but some groups of people would schedule time consuming operations for night time and then do not switch computer off at all. During short breaks at work people often do not bother to switch off the monitor or printer, not mentioning the computer. So, operation of a computer can vary a lot among different people and different jobs.

For such devices deterministic profiles are not adequate. A proposed solution, that can be used in consumption simulation, is to use probability profiles. In this case, the profile does not present the total power consumption at certain time of the day, but a probability of switching the device on and off, i.e. a probability of incrementing or decrementing the total power used. During the device operation, some random fluctuation of power may be also introduced, if it better corresponds to the device work patterns. It is convenient to use at least two profiles, one describing probability for switching the device on ($p_{on,i}$) and one for switching it off ($p_{off,1}$). Such profile can be describes as: $p_p(x) = \begin{bmatrix} p_{on,1}, p_{on,2}, p_{on,3}, \cdots, p_{on,n} \\ p_{off,1}, p_{off,2}, p_{off,3}, \cdots, p_{off,n} \end{bmatrix}^T$. Examples of profiles for a device are presented in Fig. 3. As can be noticed, at 4 pm the device considered there can be switched on with 5% probability (if at the time it is inactive) and can be switched off with 20% probability (if it is active). There might be multiple profiles for a single type of device, conditioned on different situations or days of the week.

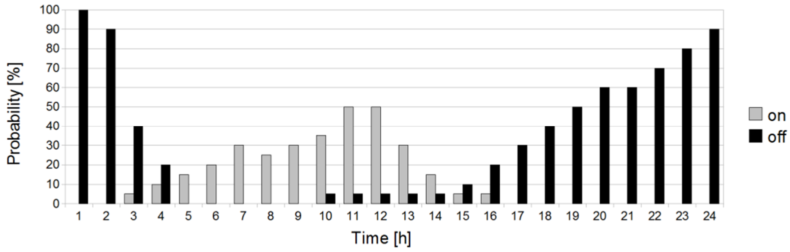


*Figure 3: Examples of probability profiles for switching on and off of the device*

## 5. Rules

The power consumption of the devices that do not have typical profiles and do not usually operate for a long time, has to be described differently. An example of such device is a microwave. It is switched on for short moments, maximum few times per day, usually in the afternoon or evening. The time period when the device is working, is called here an activity period. The most exhaustive research results concerning power consumption were presented in [4]. Authors described distributions of devices operation. The power usage in Spain are divided on sectors. Then typical devices which consume powers are defined and their typical operation cycles described. In the residential sector the devices were home appliances like oven, washing machine, television set, etc. The description is focused on typical times when devices are active (e.g. electric kitchen is usually used around 9:00, 13:00 and 21:00 o'clock), probability of using them (e.g. 20%, 10% and 2%, respectively). In our system, to simulate consumption data, a random generator has been used to ensure that each generation will be different, with the expected operation time within some defined limits. This type of description gives large variability in consumption generation. To obtain such rules, detailed studies on a large enough sample has to be done, which is rather complicated and costly to conduct.

A rule is defined by a set of parameters:

- duration – a value describing the average duration of the activity period of a given device,
- time from – the earliest time of the day that the device can work,
- time to – the latest time of the day that the device can work,
- amount – amount of power that device uses during the activity period,
- number of times – a value describing how many times the device is active in a given time frame,
- deviation of duration – deviation of the length of the activity period of the device,
- deviation of time – deviation of the switch on time of the device,
- deviation of amount – deviation of the amount of power used by the device,
- deviation of number of times – deviation of the number of times the device is activated during a given time frame.

An example of simulation using the above rules is presented in Fig. 4. There are four projectors connected to this node, all defined by the same rule:

- duration: 120 [min];
- time from: 09:00:00,
- time to: 17:00:00,
- amount: 0.1,
- number of times: 5,
- deviation of duration: 20 [min],

- deviation of time: 20 [min],
- deviation of amount: 0.1,
- deviation of number of times: 2.

An algorithm simulating such device has to resolve one complication: the device might be switched on multiple times, but the activity periods should not overlap. In this example it is preferred that projector is switched on for two hours, but the situation when it has to be on for twice as much is also possible. To realize that requirement the algorithm uses heuristic method of choosing the time period, by shifting the activity time of the device in such a way that it starts immediately after the overlapping activity period (in case of a forward shift) or that it ends immediately before the activity period (in case of a backward shift). This algorithm is not guaranteed to simulate requested number of activity periods, but it prevents overlapping and distributes the activity periods not uniformly.

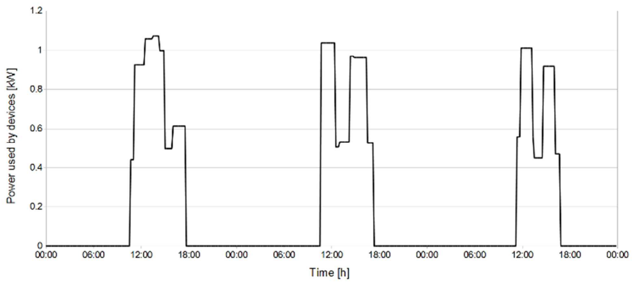


*Figure 4: Examples of simulated power consumption in a node when using rules*

## 6. Combination of rules and profiles

Profiles and rules are suitable to represent only a subset of power consuming devices. There also exist devices for which simulation of power usage can benefit from both such descriptions. These are the appliances that are started by humans, but once switched on, they have a fixed operation cycle. An example is a coffee machine. An user switches it on, but the cycle of coffee making is almost the same for all types of coffees. Rules can define a probability of starting an action at certain time. When a device is active, the power consumption during its activity time is described by its profile.

Profiles here are by default short, contrary to profiles from section 2.1, so they are described as a list of couples containing a minute and a value. The minutes represent moments of changes. Starting from an initial time (in this case from 0), the next minutes show how much time later the change in power occurs. Value may represent the percentage of the maximum power usage or absolute power usage of the device.

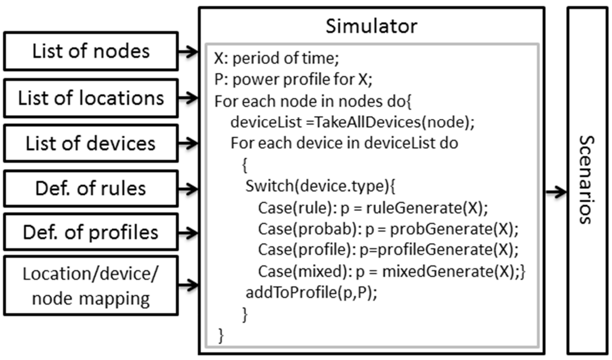


*Figure 5: A general schema of a consumption simulator showing data sources, outcome and general description of the algorithm*

## 7. Simulator of power consumption

Using the above presented methods of modeling the power usage, a power consumption simulator intended for a research and training center has been implemented. The simulator is designed to generate load data in a microgrid for a certain period of time, with a given start date and time. Generated data are stored as a test scenario. Multiple repetition of scenarios with random variations of the loads are possible, to allow for evaluation of different statistics of the microgrid performance. The schema of the system is presented in Fig. 5.

A description of the microgrid considered can be found in [14]. The grid consists of nodes that aggregate some group of devices. A node can supply power to few locations, e.g. few rooms, a corridor, few laboratories, hotel rooms etc. A device is connected to a certain node and to a location. Location is important, as power usage depends on the events that happen in it, like a conference in a conference hall. In the microgrid the power usage is considered at nodes, so the power from all devices has to be aggregated in the nodes. The simulator processes each node separately in the order of their numbering by querying all the devices connected to the node. Then the loads of all connected devices are generated in the requested time period and summed up to form the power consumption in the node for each moment. The loads are generated using profiles, probability profiles, rules, or rules and short profiles, depending on device types. The outcome is the power usage profile with required resolution, e.g. one minute. The example outcome is presented in Fig. 6 where 3 nodes were merged. In the presented example the first node has 24 computers and 2 projectors connected to it, the second aggregates 3 general devices and the third one has 4 printers connected.

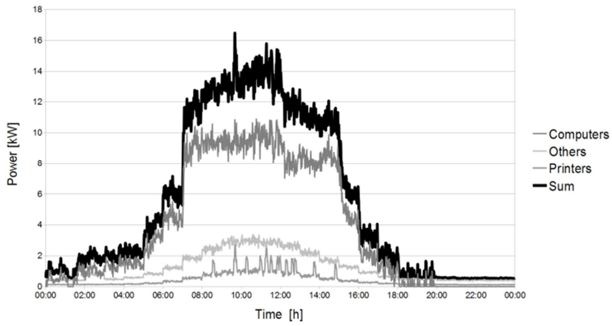


*Figure 6: Example of the generated power usage for 3 nodes.*

## 8. Conclusions

Power consumption and human behavior are very erratic and influenced by many factors. There are only scarce studies on typical usage of electric equipment or habits of using such devices. This makes it difficult to simulate consumption precisely enough. That is why simplified methods have to be used. There is no one unique way to model power consumption: profiles, probability profiles, rules, distributions, etc. were used for this purpose. A simulator of energy consumption ought to mimic consumers behavior with all its impreciseness and unpredictability, which requires using probabilistic or possibilistic distributions, possibly combined with fixed profiles. The presented energy consumption simulator is an attempt to look for a system that can describe the full range of behaviors and characteristic of electric devices. To improve the system, it is required to insert real world data of how the power is used by a single device, as well as categories of the devices. There are many different types and brands of devices with different power patterns. Concerning the rules of usage, many people do not want to participate in a study that requires revealing certain aspects of their private life. Thereby, approximations seem to be inherent parts of the approach presented.

Consumption is changing according to influences of different people, social and environmental factors. There is a number of unknown connections and correlations between operation of devices, which are not included as far in our simulator. For example, in some countries switching on a toaster is positively correlated with switching on a coffee machine. Such knowledge would improve the forecast of power usage, allow making more exact models of power consumption and show where energy is pointlessly wasted. Moreover, having included advanced user behaviors it can be possible to test different demand-side management policies.

However, even such simplified modeling of consumers' behavior is sufficient in testing energy management systems and microgrids models, and the presented simulator gives enough varied power usage data to test energy management system, like the one described in [12], and actually applied in the considered case.

## Acknowledgments

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# Green IS Management Framework Verification: Explicating the Enabling Capabilities of Green IS

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## Abstract

The first objective of the paper is to expose the Green Information Systems (Green IS) management framework comprising the enabling capabilities of Green IS, moderating concepts, and relationships to environmental sustainability. The second objective is to demonstrate the framework's verification using the focus group method and member checking. The achievement of these objectives establishes that the framework successfully captured the essential Green IS concepts and interrelationships to be relevant for environmental sustainability and that it was trustworthy, credible, relevant, and an original contribution to the academic body of knowledge. The research was empirical, confirmatory, and qualitative. The evidence indicated that the enabling capability of Green IS was prevalent, while there was no significant evidence of a transforming capability. The framework presents verified and salient management focal points for environmental sustainability in the South African banking sector.

*Environmental sustainability, Green computing, Green Information Systems (Green IS), Green Information Technology (Green IT), Green IS framework, Focus group, Member checking.*

## 1. Introduction

### 1.1. Background and context

People are entirely dependent on the Earth's natural resources for their existence. Nevertheless, human activities are degrading and depleting these resources and this threatens human well-being and possibly long-term human survival [10, 24, 40, 38]. In reaction, the concept of environmental sustainability confronts this problem. Environmental sustainability aims to maintain the environment in order to support human well-being and life into the far future [12].

Specifically, there are four degrees of environmental sustainability, namely very weak, weak, strong, and very strong [13, 9]. Very weak and very strong environmental sustainability are not feasible and weak promotes sustained capitalism and business at the expense of the environment [20, 22, 17]. However, strong environmental sustainability demonstrates the non-substitutability of manufactured capital for all natural capital [8] and its necessity is substantiated by the indisputable scientific evidence on environmental resource depletion and degradation.

The unit of analysis and focus in the paper is the organisation. Organisations are the drivers of the world's economies [43] and are responsible for considerable natural resource degradation and depletion [29, 14]. Still, it is organisations that present significant opportunities for environmental sustainability [36]. In particular, banking organisations offer an opportunity, through their

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widespread investment and financing activities, to address extensive environmental resource degradation and depletion [1, 11].

Importantly, Information Systems (IS) have been prominent in transforming the world's organisations [30, 19, 25, 3] and have fulfilled a critical enabling role [35, 5, 2, 31, 7]. Thus, IS present an essential mechanism for addressing environmental resource degradation and depletion. Nonetheless, prior research has not exposed the enabling and transforming capabilities of Green IS for environmental sustainability [23, 16]. Subsequently, an empirical Green IS management framework was developed using a grounded theory approach in the South African (SA) banking sector. Thereafter, the framework was verified and it is this verification that is the main focus of the paper.

### 1.2. Research problem, objectives, and question

The paper has two objectives. The first is to expose the Green IS management framework comprising the enabling capabilities of Green IS, moderating concepts, and relationships to environmental sustainability. The second objective is to demonstrate the framework's verification using the focus group method and member checking. These objectives address the problem of an unverified framework and show that the framework was trustworthy, credible, and relevant. These objectives provide an answer to the research question: according to experts, does the framework successfully capture the essential Green IS concepts and interrelationships to be relevant for environmental sustainability?

## 2. Literature review

There are numerous terminology debates concerning the definitions and boundaries of IS and Information Technology (IT). Nonetheless, the paper adheres to the view that IT is a component of IS [41]. Thus, IT focuses on the technological systems comprising physical devices and associated software that are used to retrieve, transmit, process, and store data and information [41]. In comparison, IS are the systems comprising social systems that include people and processes and the aforementioned IT in support of individual, organisational, or societal goals [40, 21]. Consequently, Green IT involves environmental sustainability throughout the IT lifecycle [26, 27] focusing on energy efficiency maximisation and e-waste minimisation [41]. In comparison, Green IS are specialised IS that address the problem of environmental resource depletion and degradation attributable to all organisational activities [41].

Green IS provide the information processing, knowledge, and response capabilities for organisations relating to the environment and facilitate environmental decision-making based on complex and large-scale environmental information [15]. Green IS are appropriate for addressing the substantial cognitive load of environmental information and help to embed sustainability into an organisation's operations and culture [39]. Green IS facilitate sustainability by the provision of accurate, timely, and useful information concerning the flows of energy, materials, and water, and the corresponding monetary effects on costs, savings, and earnings [6]. The generation of digital data by Green IS motivates sustainability changes that produce operational efficiencies and improvements, maintenance cost and emission reductions, and improved profitability [42]. Particularly, Green IS promote the measurement of complex environmental measures in order to reduce risk and uncertainty in environmental sustainability decision-making [44].

## 3. Methodology

### 3.1. Focus group

In order to verify the framework, which was developed using a grounded theory approach in the SA banking sector, a focus group was conducted with expert informants. Such a focus group provides conclusive evidence from knowledgeable and professional practitioners in the field for verification [32]. The focus group approach is consistent with the purpose of interpretivism and appropriate for IS research [37] and for testing frameworks [28, 32, 34].

To locate experts, Internet searches were done for SA-based sustainability experts, leaders, and management. Importantly, no experts that had already participated in the study were invited to the focus group. The necessary criteria for an expert were relevant and expert knowledge and experience with regards to environmental sustainability and related IS, time, willingness, capacity to participate, and effective communication skills [4].

During the focus group, the researcher did not participate in the discussions in any way, either verbally or non-verbally. He was present only to do the necessary administration, personally thank the participants, and perform an observer and note-taker role. The session was moderated entirely by a university lecturer who was not involved in any type of sustainability research; this prevented any content bias on the part of the moderator. The focus group took place in a private corporate boardroom located in Johannesburg, SA during February 2014.

The expert status of the nine focus group participants was justified in terms of formal qualifications and experience. In terms of highest relevant qualification, three had PhDs, two had master's degrees, two had SA professional chartered accountancy registrations, one had a postgraduate honours degree, and one did not provide qualification information. All had between 5 and 20 years of direct relevant experience, with an average of over 9 years.

The direct relevant experience was evident in the participants' occupations, namely a recently retired company partner and director and leader for Integrated Reporting, a sustainability professional and sustainability reporting standard council member, an IS research professor not related to the study in any way, a consultant in sustainability and Integrated Reporting, a consultant and advisor to multinational and domestic companies on legal, tax and sustainability compliance, governance and risk management, a consultant and author on sustainability and Integrated Reporting, an environmental specialist who was also a portfolio planner and environmental analyst, a sustainability consultant, who was also an adjunct faculty member at a leading business school and advisory committee member on a United Nations sustainability body, and a consultant evaluating and promoting the role of business in global sustainable development, who was also a researcher, writer, and strategy consultant.

In addition, the participants were from relevant SA organisations, namely a large and prominent auditing firm, a large financial services company, a large university, a large bank, a consulting firm providing a variety of environmental legal services, a leading accountancy body, a government banking organisation, an independent consultant, and a sustainability strategy and management systems company.

### 3.2. Member checking

Member checking is considered one of the most important provisions for a study's credibility and also provides verification of the researcher's emerging theories and inferences [33]. Member checking involves presenting the research findings to key informants to determine whether they can recognise their experiences in the findings [18]. The member checking took place during March 2014.

The key informants for the member checking were the original key informants or interviewees from the initial framework development. During the initial framework development there was one key informant from each sampled organisation except the SA sustainability software vendor that had two key informants. The number of people managing what is termed sustainability in these organisations was small. Thus, a single high-level key informant from each organisation was appropriate. All the key informants were specialist management, senior level management, or directors who had the necessary strategic, management, and operational sustainability knowledge. The corresponding sampled organisations were the five largest SA corporate banks, a large SA retail bank, a SA banking industry body, and a leading SA sustainability software vendor.

These sampled organisations made up 100% of the corporate banks in the JSE's top 100 companies list by market capitalisation (the JSE is SA's Johannesburg Stock Exchange and it is the African continent's premier stock exchange) or 70% of all the banking organisations, not just corporate banks, in that list or 58% of all the SA registered banking organisations that are under SA control, not just corporate banks and not just those on that list. This represented a significant proportion of the SA banking sector and of the influence of the sector on the SA economy and natural environment. Of all the original interviewees, only one of the corporate banks and the industry body did not provide feedback due to work pressures. Furthermore, an additional corporate sustainability software vendor was approached for member checking because of its particular prominence in the SA market relating to sustainability software.

## 4. Research findings

### 4.1. Initial framework

During the initial framework development a high-level concept that emerged from the data was environmental sustainability transformation. This was demonstrated by the SA banks that were undergoing a process of transformation relating to environmental sustainability, albeit to varying degrees. This transformation related to each bank's own or internal transformation and to the transformation of other organisations throughout the economy or external transformation as a result of financing and investment by the banks. The dominant type of transformation was a combination of economic, environmental, and social, where the environmental competed against both social and economic sustainability, of which economic had the highest priority. This equated to a weak form of environmental sustainability. Nonetheless, there was also evidence of a strong form of environmental sustainability transformation although to a far lesser degree.

Another high-level concept that emerged from the data was the enabling capability of Green IS, which is the intangible characteristic of Green IS that provides the means for environmental sustainability. Significantly, there was only evidence of the enabling capability of Green IS and no evidence of the transforming capability of Green IS, which is the intangible characteristic of Green IS that drives organisational transformation for environmental sustainability. The enabling capability of Green IS had six definite aspects and each was a manifestation or evidence of the enabling capability of Green IS or a Green IS enabled management function. These aspects were business process efficiencies, environmental data management, environmental analysis, environmental information disclosure, carbon footprint management, and environmental risk management.

The first aspect, business process efficiencies, was IS that were not explicitly designed for environmental sustainability purposes, this aspect was implicitly Green IS because its implementations affected environmental sustainability, e.g. IS-enabled automation of paper-based processes resulting in decreased resource waste and/or usage. The second aspect, environmental data management, was Green IS that enabled the management of organisations' environmental data, e.g. kilowatt-hours, which were significantly different to the organisations' financial and transactional data. The third aspect, environmental analysis, was Green IS that enabled analysis of the effect of business activities on the environment and exposed meaningful patterns, e.g. environmental dashboards. The fourth aspect, environmental information disclosure, was Green IS that enabled the disclosure of an organisation's environmental information, e.g. specialised environmental reports.

The fifth aspect, carbon footprint management, was Green IS that enabled the management of an organisation's greenhouse gas (GHG) emissions and was primarily internal in focus. The sixth aspect, environmental risk management, was Green IS that enabled the management of the risks to a bank arising from financing and investment activities and was primarily external in focus, e.g. credit risk and reputational risk. In addition, business process efficiencies, environmental data management, environmental analysis, and environmental information disclosure were considered lower level aspects, while carbon footprint management and environmental risk management were regarded as higher-level aspects because, in many instances, these higher-level aspects subsumed the lower level aspects.

Importantly, there were three concepts that moderated the relationship between the enabling capability of Green IS and environmental sustainability transformation, namely Green IS integration, environmental data quality, and environmental-financial translation. It was evident that a lack of integration of Green IS into organisational systems and processes resulted in the exclusion of environmental considerations which negatively affected environmental sustainability. It was also evident that environmental data quality had a substantial effect on environmental sustainability transformation. In addition, evidence showed that without environmental-financial translation, the transformation could not be controlled or managed, which had a material effect on environmental sustainability transformation.

### 4.2. Focus group

The aim of the focus group method was to provide conclusive evidence from knowledgeable and professional experts in the field for verification of the developed framework. Interaction effects were evident during the focus group session, especially in terms of group learning. On several occasions, an initial opinion was expressed and as participants joined that particular discussion, the initial opinion was developed into a more complete group opinion. Furthermore, initial opinions seemed to become more considered, in terms of the overall group discussion, as the discussions unfolded and other perspectives, experience, and information were provided.

The focus group did not result in significant changes to and provided support for the framework's core concepts and their interrelationships. The modifications to the framework as required by the focus group related mostly to contextual detail additions to enhance its usefulness for practitioners. In addition, there was a terminology change request relating to the enabling capability of Green IS aspect called carbon footprint management. The group indicated that ecological footprint management provided a more holistic concept for application to all organisations. Therefore, this concept's name was changed to carbon (and ecological) footprint management. Given that carbon footprint management is still a primary priority in the banking industry and prevalent in comparison to the other ecological footprint items, the term carbon footprint management remains central to this aspect. Thus, with confirmation of and without changes to the framework's core concepts and their interrelationships, the framework was verified and was regarded as relevant through expert evaluation, which is competent research evidence.

### 4.3. Member checking

The aim of the member checking was to provide credibility to the study and further verify the framework. The member checking provided support for the framework's core concepts and their interrelationships and did not significantly change it. The modifications to the framework as required by the members related to more contextual detail to enhance its usefulness for practitioners. The main feedback that was received was that the framework would be useful in practice for its purpose and that it conceptualised the role of Green IS in the domain. Thus, the framework was regarded as credible and the framework's core concepts and their interrelationships were regarded as verified.

### 4.4. The verified Green IS management framework

Following the focus group and member checking below in Figure 1 is the verified Green IS management framework.

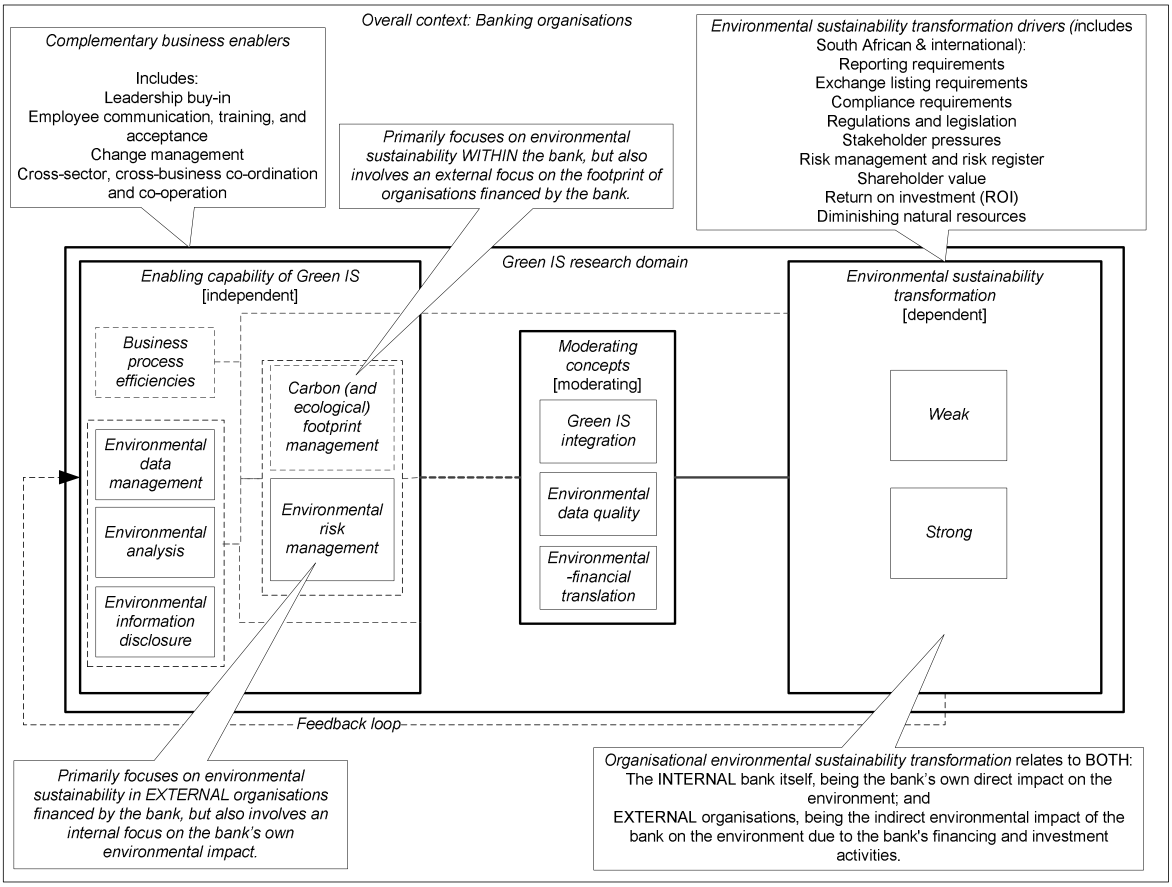


*Figure 1: The Verified Green IS Management Framework*

## 5. Conclusion

The paper has addressed the research problem of an unverified framework. The paper met the research objectives and answered the research question. The paper exposed the Green IS management framework, both the initial framework and the verified framework. In addition, the paper demonstrated the framework's verification by detailing the focus group method and member checking. The achievement of these objectives establishes that the framework successfully captured the essential Green IS concepts and interrelationships to be relevant for environmental sustainability and that it was trustworthy, credible, relevant, and an original contribution to the academic body of knowledge.

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# What constitutes EMIS for sustainability reporting? A classification approach, using a systematic literature review

Hendrik Hilpert[1], Matthias Schumann[2]

## Abstract

Due to an extensive amount of environmental impacts by industrial processes, the demand for information about firm's caused environmental impacts increases by different stakeholder groups. An uprising and sophisticated form of environmental performance information distribution is sustainability reporting (SR), although it is a complex task. Information and communication technologies (ICT) are supposed to support and enable SR, however the adoption and diffusion of specific EMIS for the task of SR is rather low. One reason may be that scholars missed their chance to provide tangible and precise definitions for EMIS as well as features and characteristics of this class of IS. In order to understand and define what really constitutes EMIS for SR, we first use a well-known IS classification pattern to find general features of IS. We then use this classification pattern in a systematic literature review and analyze present knowledge for characteristics of EMIS for SR. The outcome is twofold. First we derive an EMIS for SR specific classification pattern. Second, we point out what is already known about EMIS for SR and which topics should be addressed in further research.

## 1. Introduction

Due to an extensive amount of environmental impacts by industrial processes, the demand for information about firm's caused environmental impacts increases by different stakeholder groups [1]. A sophisticated form of environmental performance information distribution is sustainability reporting (SR), which includes information about the environmental, economic and social performance of a firm [3]. „Sustainability reporting is the practice of measuring, disclosing, and being accountable to internal and external stakeholders for organizational performance towards the goal of sustainable development" [7]. As sustainability reporting is a complex task, information and communication technologies (ICT) are considered to be able to support the process of sustainability reporting in a comprehensive manner [5]. An information system class which is discussed to support the process of sustainability reporting is environmental management information systems (EMIS) [12; 9]. EMIS have the objective to obtain, process and make environmental relevant information available in a systematic manner [12] to enable decision-making and knowledge creation within and outside of organizations [15]. While IS scholars conducted research on EMIS since the early 1990s, the adoption and usage of EMIS in general and also for sustainability reporting purposes in practice is rather low. One reason for this situation is that the field misses its chance to provide tangible and precise definitions for EMIS as well as characteristics of this class of IS [8], wherefore other scholars call for action [10; 17; 15]. First attempts have been made to gather more detailed characteristics of the general class of EMIS [6]. However, EMIS for SR are still understudied, undefined, and uncharacterized while representing an important subclass of EMIS. For this reason, we intent to reach two goals with this paper: First,

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we want to know what are the relevant features and characteristics that represent and describe EMIS for the task of sustainability reporting comprehensively. Second, we intent to point out what is already known about EMIS for SR and which topics should be addressed in further research.

In this paper, we first provide a short overview of the used methodology in section two and proceed to the results of our systematic literature review. Ongoing, we discuss the results and propose a classification pattern according to the results. Finally, we provide a short conclusion.

## 2. Methodology

To characterize EMIS for sustainability reporting in more detail, we draw on an IS systematization pattern by Schumann [13] and Mertens [11]. The used pattern (Figure 1) defines relevant aspects of information systems in general and comprises seven IS features to be analysed. These features are the supported processes, the subject-specific methods, the comprising capabilities and its implemented algorithms. Furthermore, the necessary data as well as the degree of automation and integration are relevant to describe information systems.

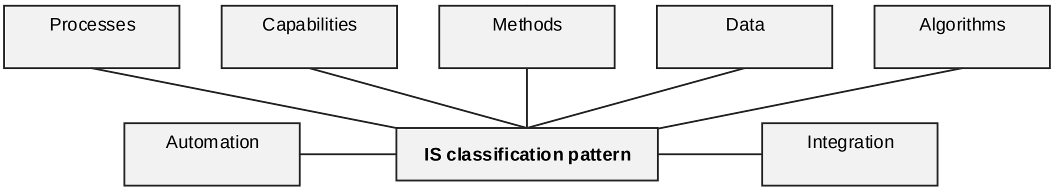


*Figure 1: IS classification scheme [13, p. 10]*

To classify EMIS for SR, we linked this basic schema with EMIS for SR domain specific features and characteristics that are known from prior literature on environmental informatics and the uprising field of Green IS. To provide a complete overview as well as detailed insights into present knowledge, we further conducted a systematic literature review according to [18] and [16]. Therefore, we used search terms comprising of “sustainability reporting” and “(environmental management) information systems”, their abbreviations as well as their German equivalents. Within the search process we used the search engines EbscoHost, SpringerLink, ScienceDirect, EconBiz, the AIS library and the “Gemeinsamer Verbundkatalog” (GUV).

## 3. Results of systematic literature review

The systematic literature review revealed 993 articles in the first search process iteration. After an initial inspection of titles and abstract, we were able to reduce the amount of articles to 84 (available in online appendix; http://www2.as.wiwi.uni-goettingen.de/getfile?DateiID=725) that found to be relevant for describing features and characteristics of EMIS for SR. We classified the provided content of these articles according to the proposed pattern and analysed them topic-centred according to Webster and Watson [18]. The resulting analysis framework, which comprises the basic pattern by Schumann [13] and known literature from the field of EMIS is shown in Figure 1. Furthermore, the framework draws on knowledge from [2] and [14], describing the reasons of SR by institutional theory as well as the perceived usage of SR by knowing organization theory [4].

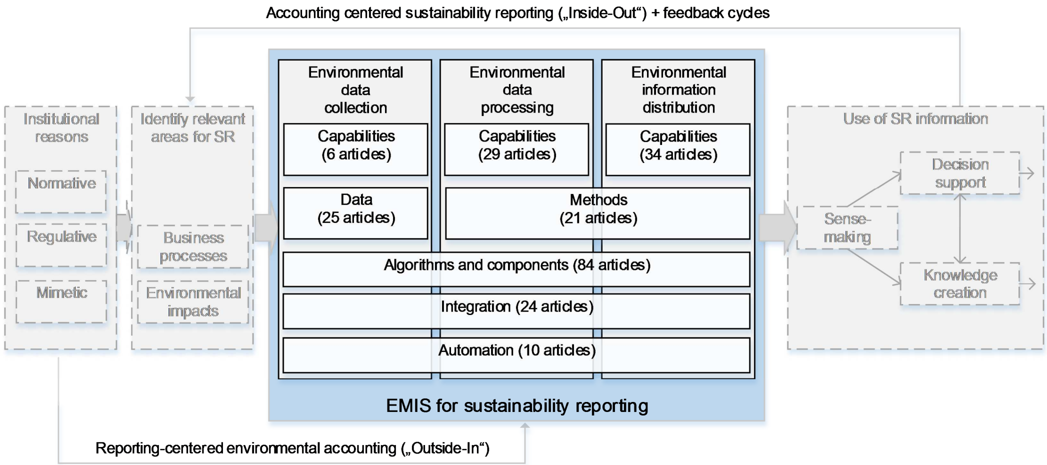


*Figure 2: Analysis framework and topic-related results*

The topic-related amount of relevant literature that resulted from the analysis can be depicted as follows: We captured knowledge about relevant capabilities in terms of environmental data collection (6 articles), processing (29 articles), and the subsequent information distribution (34 articles). Knowledge about algorithms and components has been described by 84 articles. Moreover, we were able to gather knowledge about the necessary data (25 articles), sustainability and environmental accounting methods (21 articles), the degree of automation (10 articles), and integration (24 articles). According to these results, the identified papers will be discussed and ordered by aspects of IS classification pattern. Due to coherence of capabilities and algorithms these aspects will be discussed together. Furthermore, we will connect the aspect of automation and integration as they are connected by horizontal and vertical integration.

## 3.1. Capabilities and algorithms

We found 69 papers in our systematic literature review that discuss capabilities of EMIS for SR and 84 papers that provide specific algorithms and components that implement functionalities. First, SR requires *environmental data collection* [101], [41] and [65]. For instance, Gösling et al. [41] discuss that EMIS for SR need a structured data collection of in- and output data in order to enable environmental reporting, while Jensen & Norup [65] point out that comprehensive monitoring is especially necessary for regulative purposes, e.g. for the GHG emission trading act. In the field, the environmental data collection is supposed to be fulfilled by *interfaces* with other business IS [102], [40], [99] and [59]. Wohlgemuth & Page [102] connect the LCA tool Umberto to an environmental simulation tool, Gomez & Amelang [40] propose an interface that is capable to read out environmental data by XML (Extended Markup Language). Wohlgemuth et al. [99] use the standardised data exchange format PAS 1025 in order to read out environmental data from business IS. According to Watson et al. [17], *sensor networks* can be used to obtain environmental data. In literature, only few scholars provide solutions that actually use sensors for data collection. Wohlgemuth et al. [101] suggest to use sensor networks, while Hentz et al. [45] propose a system design, where sensors within the operative machine logging system are used to collect environmental information in production processes. Collected data need to be stored in *databases*. Isenmann et al. [59] use MySQL to store environmental data in order to provide a persistent data storage. Petrini & Pozzebom [84] propose to use a data warehouses for this task. Bischof & Winkler [25] conceptualize a system, using a data warehouse, which is implemented by Thies [96] with a SAP BW system.

Furthermore, environmental data *aggregation* is a relevant capability of EMIS for SR [12]. Gräuler et al. [6] for instance found this requirement in the context of Green IS, stating that the level of abstraction has to be selectable. In order to enable (dis-)aggregation of environmental data, *models* of activity and environmental data flow are necessary, as this capability also enables life cycle analysis [39], [85] and [75]. Additionally, *calculation algorithms* are used to compile environmental indicators [19], [21] and [41]. Ahmed & Sundaram [19] present a prototype that is able to calculate environmental data, Arco et al. [21] use algorithms in case of missing data based on neuronal networks and case based reasoning. Gösling et al. [41] propose a calculation algorithm that is able to provide environmental indicators. Another algorithmic component that is found to be necessary in literature are *workflow mechanisms* as they supports the process of SR [46] and [91]. Hrebieciek et al. [19] argue that the workflow of persons that collect data should be supported as well as auditing processes.

*Document management* has been revealed as another important capability of EMIS for IS [23], [46] and [53]. For instance, Arndt et al. [23] developed a document management system for environmental related content. Hribicek et al. [46] use XML-based document management systems and XSLT (Extended Stylesheet Language) for the distribution of SR in different formats, e.g. PDF. The usage of XML and XLST has also been shown by several publications of Isenmann. In this context, the *historization* of sustainability reports is also an important feature of EMIS for SR [39] and [68]. Kuryazov et al. [68] conceive a revision and historization control for IS for SR, using delta calculations.

According to literature EMIS for SR also need to be capable of the *visualization* of environmental data in terms of graphs or sankey diagrams [39] and [40]. Cencic & Ruchberger [32] point out that environmental indicators in time series or in relation to source of origin enable decision-making in SR. *Simulation* also has been analysed extensive in prior literature [12], [100], [82] and [71]. Wohlgemuth [100] simulates environmental impacts in case of missing data in time series, Pawleski & Otamendi [82] propose the use of suitable programming frameworks (e.g. EcoSimPro; DESMO-J) and software products (JADE). Lee et al. [71] developed a simulation prototype, using DES (discrete event simulation) for determine the environmental impacts of production programs.

Finally, EMIS for SR need to be able to provide sustainability *reports* in different distribution forms [93], [44], [74], [56] and [92]. While reports can be provided as classical PDFs, they can be distributed on *web portals*, which have *interactive* features. Solsbach and Gomez propose the use of web portals for SR distribution, which has been shown by Grünwald [44] in terms of a prototype. Also Lopez Abad & Meyerholt [74] showed the development of a portal for SR as a prototype. Isenmann and Kim [56] propose a concept of interactive sustainability reporting, having feedback mechanisms. Solsbach et al. [92] developed a prototype called "iStorm" that uses a shopping cart-feature to enable stakeholders choosing information according to their needs. The usage of XML and XSL enables to *export* sustainability reports in a desired format [26]. The characteristics for capabilities and algorithms / components are summarized in Table 1.

| Feature | Characteristics (n) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Capability** | Data collection (6) | Aggregation (2) | Modelling (13) | Analyze (5) | Visualize (7) | Historize (1) | Simulate (7) | Report (30) | Interact (3) |
| **Algorithm / components** | Sensor networks (1) | Import interfaces (18) | Databases (6) | Calculation algorithms (6) | Workflow algorithms (10) | Document management algorithms (10) | | GUI (31) | Export interfaces (25) |

*Table 1: Features and characteristics of capabilities and algorithms / components*

### 3.2. Data

The aspect of data integration has been addressed by 25 papers. While 21 mentioned the type of data, 14 papers reflect on data collection methods and 15 papers consider data quality. Funk et al.

[34] use material flow data from ERP systems for SR and calculate resulting environmental impacts. Also Wohlgemuth et al. [100] use *activity flow data* from existing business IS for environmental impact determination. Lee et al. [72] analyse the occurrence of environmental impact data at a Korean car manufacturer, finding that *resource consumptions* can be determined only by hand as this data is not available in present IS. Grünwald [44] developed a prototype of a reporting system and found that environmental data sources at a German car manufacturer can only be found rarely. Cencin & Rechberger [32] conclude that environmental data calculations result in high uncertainties, wherefore decision support is not possible. Hentz et al. [45] propose a concept on how to use sensor data in production processes, gathering primary *environmental impact* data. Schlund et al. [89] claim that environmental data should be gathered directly, using sensor systems in order to increase data quality. However, the literature shows that environmental data is often *calculated* or *estimated*. We found only two papers that address *direct measurements* of environmental impacts, while seven papers propose to calculate and six papers to estimate data. Also Melville & Whisnant [77] conclude that necessary data for SR is often 'not digitzed' wherefore *primary data* is missing. Thus, external databases are used that provide *secondary data* sources. Solsbach et al. [91] and Gräuler et al. [6] state that data sources and the collection of environmental data is a major problem in SR. The identified characteristics of EMIS for SR are summarized in Table 2.

<table>
<tr><th>Feature</th><th colspan="6">Characteristics (n)</th></tr>
<tr><td>Type of data</td><td colspan="2">Resource consumptions (14)</td><td colspan="2">Environmental impacts (1)</td><td colspan="2">Process activity data (5)</td></tr>
<tr><td>Collection method</td><td colspan="2">Directly measured (2)</td><td colspan="2">Calculated (7)</td><td colspan="2">Estimated (6)</td></tr>
<tr><td>Data quality</td><td colspan="3">Primary data (6)</td><td colspan="3">Secondary data (7)</td></tr>
</table>

*Table 2: Features and characteristics of environmental data*

## 3.3. Methods

In terms of adequate methods for SR, we found 21 papers that address this issue, mainly proposing environmental accounting methods. Konrad [66] shows in an empirical study that *environmental indicators* and LCA (*life cycle analysis)* are suitable methods for SR. Möller & Viere [80] point out that physical and monetary representations of environmental impacts should be considered, wherefore also *environmental cost accounting* needs to be considered. Funk et al. [35] analyse carbon footprints on product level as an adequate method for environmental impact information distribution. Eun et al. [33] also point out the importance of a product level view in SR. Petrini & Pozzebom [84] analysed the integrated usage of environmental indicators, which is determined as the most suitable method for SR by Löschner [75]. Specific solutions have been shown by Wohlgemuth & Page [102], Gomez et al. [40], Cencic & Rechberger [32], Personn et al. [83] and Gösling et al. [41]. Wohlgemuth & Page [102] showed how IS can be used to provide LCAs, while Gomez & Amelung [40] used Umberto for demonstration. Cencic & Rechberger [32] developed a prototype called STAN (substance flow ANalysis) that uses environmental accounting methods to calculate environmental impacts in production processes. Personn et al. [83] use the material stream method as a derivate of value material flow method to determine material and resource consumption flows. Table 3 shows the identified characteristics.

| Feature | Characteristics (n) | | |
|---|---|---|---|
| Methods | Life cycle analysis (13) | Environmental indicators (8) | Environmental cost accounting (3) |
| Related object | Environmental impact of products (10) | Environmental impact of processes (7) | Environmental impact of company (11) |

*Table 3: Features and characteristics of method*

### 3.4. Automation and integration

The systematic literature review revealed ten papers about the degree of automation and 24 papers about the integration. In terms of automation, Rapp & Bremer [87] analysed current EMIS for IS and found that the degree of automation is low, as most of these IS do not support an automated data collection, but rather are *partly automated* IS. These IS only support the environmental data collection by hand or by using Excel imports. According to Scheide et al. [88] these manual tasks increase the chance of errors in data collection. Also Hrebicek et al. [46] conclude that the current state of EMIS for SR does not feature automated tasks in the process of SR. However, they state that EMIS for SR should support automated data collection from existing business IS. Bracher [27] provides a concept for *automated* ad-hoc reports, using a RESTful (Representational State Transfer) web service, gathering the necessary data from existing IS.

In terms of a vertical integration the distribution of environmental relevant data in *real-time* is stated by Isenmann & Lenz [57] and Thies [96] as an important requirement. However, due to the rather low availability of data most IS work with *batch processing*. Petrini et al. [84] show empirically that there is a lack in real-time environmental reporting, Eun et al. [33] and Schlund et al. [89] state this topic as a research gap. Bischof & Winkler [25] point out that a continuous data flow from operative to top decision-making IS is necessary for a real-time integration, showing this vertical integration by a SAP business intelligence concept. The vertical integration of EMIS for SR is also analysed by existing research. According to Möller & Viere [80] EMIS are stand-alone or integrated IS. However, Isenmann & Rautenstrauch [58], Möller et al. [78] and Möller & Michelsen [79] describe that a vertical integration with other IS is important. For instance, Möller & Michelsen [79] show the necessity of vertical integration of IS for flow management with production planning systems *within the company*. Gräuler et al. [6] found empirical evidence for a vertical integration, which has also been stated by Freundlieb & Teuteberg [37]. Funk et al. [35], Isenmann [53] and Bublitz et al. [29] point out the relevance of *inter-company* integration, especially in terms of supply chain integration. Bublitz et al. [29] integrate environmental impacts from supply chain partners, using estimated values from an external life-cycle database. The characteristics of automation and integration are summarized in Table 4.

| Feature | Characteristics (n) | |
|---|---|---|
| Automation | Partly automated (9) | Automated (1) |
| Vertical integration | Real-time processing (6) | Batch processing (13) |
| Horizontal integration | In-company (21) | Inter-company (4) |

*Table 4: Features and characteristics of automation and integration*

## 4. Classification of EMIS for SR

A qualitative analysis of the relevant literature has been used to reveal detailed characteristics of the analysed features in the previous chapter. We use this knowledge to systemize the characteristics of EMIS for SR. The results of this classification are shown in Table 1. Understudied characteristics and thus research gaps are highlighted in Table 1 and will be discussed in the following.

The analysis of literature revealed research gaps in the field of primary data sourcing and collecting of environmental impacts as well as for IS capabilities in supporting this task (e. g. by using sensor networks). While several articles treat data collection topics, they do not provide comprehensive solutions for this task. Import interfaces are defined but further analysis shows that data are not present in an adequate quality in current IS. Therefore, secondary average data from life cycle inventory databases is used, resulting in high uncertainties of environmental information. Thus, knowledge about relevant environmental data types and adequate data collection methods is missing as well as their support by information systems [17]. Furthermore, the aggregation and analysis of gathered data as a basis for decision making and knowledge creation hasn't been investigated in detail by prior research. Our analysis reveals that this is influenced by the quality of environmental data. As secondary data sources provide average values with high uncertainties, further detailed aggregation and analysis has not been possible in the past. Thus, data aggregation and disaggregation also hasn't been investigated in detail so far. The automation and real time data supply hasn't been studied sufficiently too, while found to be relevant to improve decision making processes, enable process and behavioural changes, and subsequently contribute to sustainable development. The horizontal integration has been discussed in literature for intra- and inter-organisational sustainability reporting. However, comprehensive artefacts are missing for the integration of supplier's and other network partner's information about environmental impacts.

| **Feature** | **Characteristics** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Data type | Resource inputs | Environmental impacts | Activities | | | | | | |
| Data collection method | Measurement | Calculation | Estimation | | | | | | |
| Data quality | Primary data | Secondary data | | | | | | | |
| Methods | Environmental life cycle assessments | Environmental performance indicators | Environmental cost calculations | | | | | | |
| Scope | Product impacts | Process impacts | Company impacts | | | | | | |
| Functionalities | Collect | Aggregate | Model | Analyze | Visualize | Historize | Simulate | Report | Interact |
| Algorithms and components | Sensor-networks | Import interfaces | Data-base | Calculation algorithms | Workflow algorithms | Document management algorithms | GUI | Export interfaces | |
| Automation | Partly automated | Fully automated | | | | | | | |
| Vertical integration | "Real time" supply | „Batch" supply | | | | | | | |
| Horizontal integration | Intra-company | Inter-company | | | | | | | |

*Table 5: Systematization of EMIS for SR*

Based on the gained knowledge about features and characteristics of EMIS for SR, we propose a research agenda according to [16] based on the identified research gaps as the second outcome of this study (see Table 2).

| **Research agenda** | |
|---|---|
| Data sources | (1) What is an adequate level of data granularity for sustainability reporting?<br>(2) Which primary environmental data sources can be used to decrease uncertainties in sustainability reporting? |
| Capabilities / algorithms and components | (3) How can innovative information systems and technologies be used to gather environmental impacts at the causing business entities?<br>(4) How can environmental impact analysis and aggregation functionalities be designed to enable improved decision-making and knowledge-creation? |
| Automation / Integration | (5) How can EMIS for SR be designed to enable real-time data collection, processing and distribution of environmental impact information? |
| | (6) How can supply chain partner's IS be integrated with EMIS for SR to enable environmental impact data collection from up- and downstream partners? |

*Table 6: Research agenda*

## 5. Conclusion

In conclusion we sought to seek a more detailed, precise and improved systematization of EMIS for SR than provided by prior research. Furthermore, we aimed to understand the state of current knowledge about EMIS for SR. Therefore, we used an IS classification pattern which was adapted to the field of investigation. A systematic literature review has been used to gather relevant characteristics for the subclass of EMIS of SR and revealed research gaps. Finally, we provided an agenda for further research, paving the way for more relevance and rigor in the field of environmental informatics and Green IS, especially for the class of EMIS for SR.

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# The Use of Social Media as an Enabler to Create Environmental Awareness of Staff in Higher Education

Masive Zita[1], Clayton Burger[2], Brenda Scholtz[3]

## Abstract

This paper examines the environmental awareness of staff members in a higher education institution through the use of social media and an environmental awareness campaign. The key question raised is whether the use of social media is an effective tool to run an environmental campaign to raise awareness and evaluate knowledge of the green initiatives that are happening with in the organisation as well as in popular media. The sample used for the campaign consists of academic, professional and support staff at the Nelson Mandela Metropolitan University which boasts an environmentally-friendly core value and has driven a significant amount of research in renewable energy, environmental management, estuarine protection and biodiversity protection, amongst other fields. The campaign was conducted through a centralised website which provided information about environmental management and challenges. The content was provided three times a week with the goal of raising awareness between the start of the campaign and the end, where knowledge interventions were performed to determine a difference in knowledge and social media usage for environmental awareness. The qualitative findings of the campaign through surveys and questionnaires indicate that, despite typical time restrictions, Facebook is the most effective social media platform used use to spread information and initiate “green practices”. Participants indicated an increase of knowledge which was validated through assessment. Coupled with increased knowledge, participants indicated a positive attitude to the subject matter in encouraging them to play a role in the environment. This attitude is thus beneficial in a tertiary learning environment as educators can encourage students to be responsible custodians for the next generation.

*Keywords: environment awareness, sustainable practices, social media*

## 1. Introduction

There are many environmental issues that are increasingly becoming of concern to each country as well as to the global community [1]. There is thus societal pressure to create environmental awareness which is essential for informing people about the effects of global warming and other environmental hazards. Despite a finite amount of natural resources, pressure is placed on these resources through the rapid increase in the world’s population which is amplified by the increase in average living standards and industrialisation. These issues have led to the concept of Earth Stewardship where individuals, as well as organisations, are responsible for being environmentally responsible and promoting sustainable practices [2].

The increase of environmental awareness has risen relatively in proportion to the demand for sustainable practices [3]. Environmental responsibility is accepted by United Nations Education, Science and Cultural Organisation (UNESCO) as each person’s choice and basis towards

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sustainability [1], therefore the decision to mitigate waste, minimise reliance on fossil fuels and other environmental decisions and factors must be initiated at a personal level to affect change.

Education is the foundation for skills development, knowledge generation and personal development [4]. The education system is responsible for guiding the norms, values and attitudes of individuals to be global citizens, part of which is having respect for the natural environment. The higher education system, comprised of universities, colleges and training institution is also responsible for equipping students with skills and preparation for their trade [5]. Higher education institutions play a critical role in the development of their graduates, which can be coupled with environmental awareness and responsibility by encouraging educators and stakeholders to lead by example [6].

This paper investigates the usage of social media platforms by educational stakeholders in the Nelson Mandela Metropolitan University (NMMU) and analyses how these stakeholders interact within a digital campaign which aims to raise environmental awareness by means of social media. The context of environmental awareness and social media (Section 2) are critical for the creation of an informed campaign that supports social media platforms in raising environmental awareness. The methods employed in this study to construct, guide and study the campaign are outlined in Section 3. This is followed by a discussion of the results obtained (Section 4). Finally, recommendations for institutions and subsequent campaigns are outlined to provide a tangible contribution from the implemented campaign (Section 5).

## 2. Literature Review

### 2.1. Environmental Awareness, Attitudes and Action

The intention of environmental sustainability is to maintain and protect natural resources. There are three aspects to sustainability, namely: *knowledge*, *affect* and *behaviour* [7]. These individual aspects affect an individual's attitudes and manner of thinking towards the environment. A fundamental change in the way individuals think plays a key part in the realisation of sustainability, collectively referred to as an individual's mindset. The mindset of the individual motivates and guides others to play a role in the Earth's stewardship. The role of the mindset is a key driver in mitigating the effects of environmental issues.

Sustainability is traditionally supported by three pillars, namely the social, environmental and financial pillars. These pillars are applicable at both the personal and organisational level, but each pillar brings its own challenges and approaches to realising sustainability. Focusing on the environmental pillar of sustainability, two key concepts are critical, namely *awareness and environmental responsibility*. Awareness is defined as an introduction to informed action [1], while environmental awareness focuses on knowledge of the environmental concerns happening globally and how to positively impact these concerns. This concept extends to public awareness which helps individuals understand and drive other individuals to participate effectively in activities towards achieving sustainable practices [3]. A simple example of this concept is being aware of the natural cost of generating paper when printing a document. An environmentally aware individual will question whether the document should be printed. If the document must be printed, the individual will encourage the use of duplex printing to minimise paper usage, thus minimising the natural impact of the action. Individuals that are interacted with in this process are exposed to the rationale of minimising paper usage which thus drives environmental responsibility.

To produce sustainable practices, awareness must be coupled with existing environmental attitudes and exhibited behaviour while being affected by societal norms and values (Figure 1). Yahya and Hashim [8] observe that societal norms and values form an important context for strategies of raising awareness of the natural environment. The existing attitudes that individuals have and their current behavioural patterns similarly contribute to how they adopt sustainable practices when exposed to public awareness initiatives, such as campaigns.

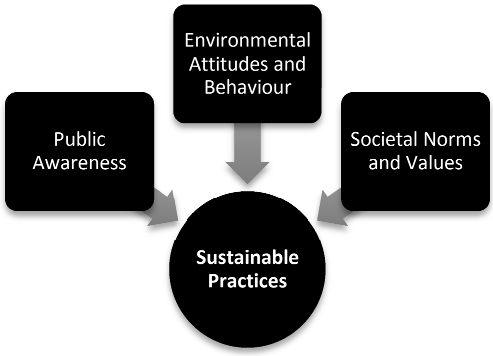


*Figure 1: Framework for contributions to sustainable practices* [3,8,9]

The key factor for the improvement of environmental awareness is the access to insightful and well-presented information [3, 9, 10]. Information is often packaged in communication campaigns that reach larger audiences [9]. Environmental awareness is seen as a component to the education process and helps with creating change [9]. The greater the number of aware and informed individuals; the more likely societies will take some form of action to affect environmental change. In higher educational institutions it has been proven that students have a basic awareness of environmental issues but are ignorant on strategies to address these issues [10].

### 2.2. Environmental Education

Various policies and international requirements, such as the King III report [11], have mandated that organisations not only focus on the financial bottom line, but on the triple bottom line principle of sustainability, thus also addressing social and environmental action [6]. There are two different types of opportunities for higher educational institutions in engaging in sustainable development according to the UNESCO [6]. The first opportunity is the direct transfer of knowledge while the second is societal development. Both strategies can be adopted by institutions to generate graduates with environmentally responsible attitudes and values by informing them of environmental issues together with a means of addressing these issues on various levels. Traditionally, higher educational institutions bear the responsibility of providing a tertiary education to students while providing leadership skills and support for resources to create sustainable practices in their environment [12].

Institutions appoint academics who serve to educate the students of institutions by sharing their knowledge in courses, assessing students and imparting cultural lessons in responsibility and leadership. This approach seeks to create students with responsibility and knowledge that are capable of becoming the leaders and experts of the next generation. This underpins the role that staff members of these institutions play, which forms a crucial context for the delivery of environmental awareness and responsibility in their students [10]. There are barriers in encouraging staff of higher educational institutions to impart environmental awareness to their students, specifically a lack of training, limited organisational support, limited resources, and cultural resistance. These issues cannot be isolated, so a unified approach to training and supporting these staff must be applied, such as through institutional policy and knowledge awareness campaigns.

### 2.3. Effectiveness of Social Media for Information Sharing

The term *social media* is defined as "a group of Internet-based applications that build on the ideological and technological foundations of Web 2.0, and that allow the creation and exchange of user-generated content" [13]. There are a plethora of Internet services that can be classified as social media, with Facebook and Twitter being two of the most common platforms [9]. Twitter encourages word-of-mouth and discussion through short messages which are tied to events and/or people. Facebook encourages social networking and accessing of aggregated social network information through a personalised dashboard. Facebook provides the facilities for users to share content to their network of contacts of various types of content, such as text, links, images and videos. Conversely, Twitter provides limited facilities for sending short messages and embedding images [14].

Social media platforms have been shown to be effective tools to communicate and support interaction[14]. To determine the effectiveness of a platform, or proliferation of specific content, various measuring tools have been developed, such as Google Analytics, Sprout Social and social media tracking buttons (Figure 2). These tools help monitor and assess the usage of the social media networks. When assessing campaigns that are driven by social media, these services provide key insights, such as Facebook *likes* and *shares* and Twitter *tweets*, *retweets* and *followers* [14]. Social Sprout allows the analysis of demographics of geographically distributed content, while social media tracking buttons provide an aggregated summary of social media interactions for a specific piece of content. Finally, Google Analytics tracks the number of unique visits to external content from social media sources.

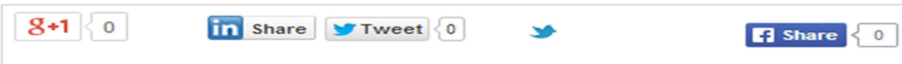


*Figure 2: Example of a social media tracking button bar including one-click-sharing and tracking on Google Plus, LinkedIn, Twitter, and Facebook*

## 3. Research Methodology

This study investigates a social media driven campaign for raising awareness of environmental issues at the NMMU. The campaign was conducted over a period of six weeks using an action research approach to providing content to participants. As the focus of the campaign was to raise awareness in a higher education context, a purposive sample was employed to attract participants that are currently employed by the institution. In addition to the initial sample (n=12), participants were encouraged to share information from the centralised project website which would expose the content to additional participants for the continuous response surveys, which was done through an informal snowball sampling approach. The sample included academic, professional and support staff from the spectrum of departments at the institution, drawing from Computing Sciences, Engineering, Student Governance, Media Studies, Journalism, Mathematics, Development Studies, Finance and Examinations departments.

The structure of the EcoSafe Campaign Model is illustrated in Figure 3. At the commencement of the campaign the *pre-campaign questionnaire* was administered to determine the social media usage and environmental awareness of participants prior to the commencement of the campaign. During the campaign, a *continuous feedback survey* was made available whereby participants could provide feedback about the campaign conduct and suggestions. Various *polls* were provided as part of the content to determine participation levels. Finally, *a post-campaign questionnaire* was provided to determine if the participants had shared the content provided through their social media networks, which networks were preferred and if their environmental awareness had been improved. A limited number of *semi-structured interviews* were conducted with participants to discuss the campaign structure and content at the end of the campaign. All data gathered was anonymous to protect the identities of participants. Similarly, the actual proliferation of the content was not measured as this pose an ethical issue to the participants as their social media profiles would need to be tracked.

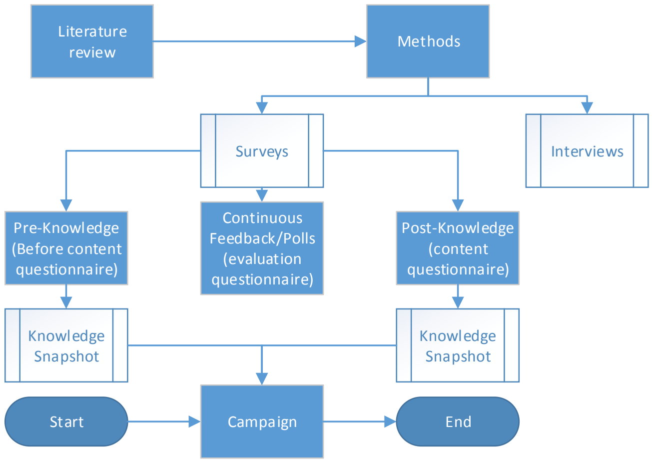


*Figure 3: EcoSafe Campaign Model*

The campaign was driven through shareable content that was posted on the central campaign website three times weekly. Participants were required to visit the website regularly to ensure exposure to the provided content. All content was peer-reviewed prior to posting to ensure relevance to the campaign and accuracy of content.

Examples of some of the posted content themes are:

1) NMMU sustainability initiatives and projects, such as renewable energy initiatives;
2) Recycling facts and tips; and
3) Popular sustainability initiatives, such as Earth Hour.

## 4. Analysis of Results

### 4.1. Participant Profile

The sample was drawn from employees at the NMMU and consisted of twelve monitored participants. Additional participants engaged with the content throughout the campaign, but their awareness and social media usage was not monitored. The length of employment for most participations (n=7) was considered short as the typical length was between one and five years which could suggest limited knowledge of the institutions environmental initiatives. The age distribution and gender distribution (Figure 4) indicate a roughly even distribution of age groups but a skewed gender sample of female participants.

### 4.2. Awareness Assessment

To determine the level of awareness of participants before and after the campaign, a *pre-campaign questionnaire* and *post-campaign questionnaire* was administered to each participant. The questions focused on general environmental awareness as well as awareness of institutional specific environmental initiatives. Examples of some of the multiple-choice questions posed are: "*What different types of environmental policies can be employed by companies?*" "*Which NMMU Campus is known as the Green Campus?*"; "*Which diseases can indoor pollution cause?*" Examples of participant responses include *"Developing an environmental policy statement"*, *"George Campus"*, and *"Lung Cancer"*.

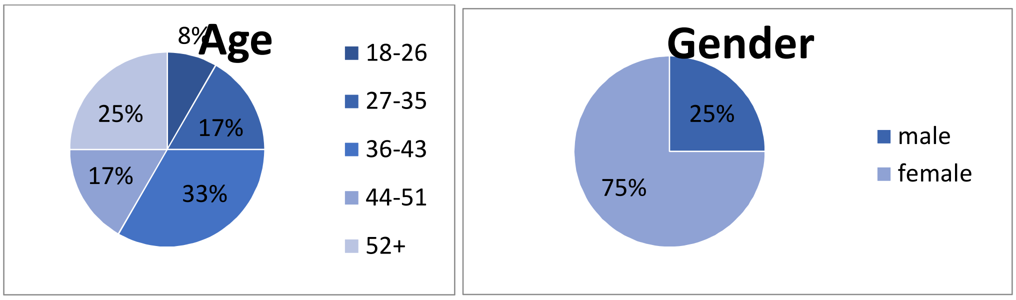


*Figure 4: Gender and age distributions of participants (n=10)*

A total of 17 questions were presented in each of the awareness questionnaires posed. The comparative results (Figure 5) indicate an increase in awareness overall of 27.4% over the course of the campaign.

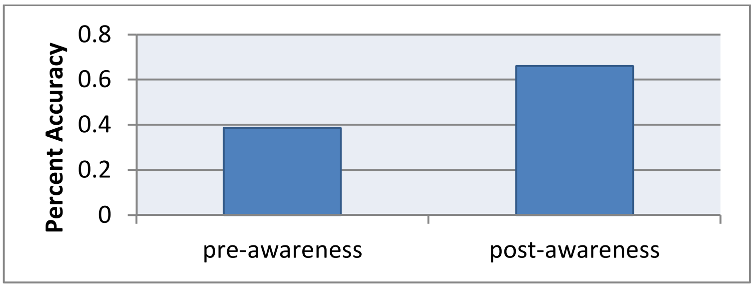


*Figure 5: Assessment of environmental awareness before and after the campaign*

Throughout the course of the campaign, participants were requested to complete *continuous feedback surveys* and *polls*. The role of the continuous feedback surveys was to assess the awareness gradient over the course of the campaign. Examples of questions that were presented in the surveys include:

1) What are some of the ways to save electricity at university?
2) Which sources of energy and electricity is renewable (if harvested)?
3) What actions are you willing to take to reduce global warming? Please describe.

Some of the questions posed were multiple-choice and some were open-ended to gain some insight into the perceptions of participants. Three continuous feedback surveys were presented over the course of the campaign. These surveys were informally assessed to determine if the participants were engaging with the subject matter provided on the campaign website. The general observation made is that participants were more aware of global environmental issues than of the NMMU's environmental initiatives.

The open ended questions asked on the surveys allowed the researcher to change the type of content published to align with the media that the participants preferred the most. The participants indicated that they prefer fresher content comprised of current topics and visual media, such as images and video. Examples of some of the quotes from participants are: *"To see the new discussed topics on Ecological factors."*, *"To see the different content, such as the videos"*, and *"To be kept informed"*. The participants indicated that they were surprised at many of the statistics shown on the website and that they had gained an appreciation of topical environmental factors, such as rhino poaching in South Africa. Using the informally scored surveys of the evaluation of content, a difference from 13% to 70% can be noted for the participants' awareness of institutional initiatives, which serves to highlight that the campaign successfully emphasised the existence of these initiatives.

Semi-structured interviews were conducted with three of the participants to determine their reactions to the campaign. The prevailing opinion voiced by the participants was that both the environmental and NMMU content was relevant and interesting, but that there was not an institutional culture for sustainability. They emphasised the manner in which they would share some of their environmental responsibilities and values with their students in order to strengthen the graduate profile of the students while encouraging Earth stewardship.

Participants indicated that to instil and create sustainable development, as an organisation more sustainability awareness was needed, training and responsive action taken. Examples of direct quotes from participants are: *"Modernise the campus by raising finance to make the infrastructure more sustainable and construct new infrastructure to reduce car use (inter campus shared transport options); bonus schemes for departments that eliminate waste"*, and *"Have a professional lecture/presentation on a topic about environmentally friendly systems and activities which would lead to promoting ecologic platforms and systems."*

### 4.3. Social Media Usage and Proliferation

A *social media usage questionnaire* was administered to all participants. The questionnaire contained questions on which social media platforms were used by each participant and how they accessed the platforms. The participants were given a set of options for the some of the most widely used social media platforms to indicate their preference. The distribution of social media platform usage (Figure 6) indicates that Facebook is the most popular platform used by the participants for the campaign with all participants indicating at least "neutral" with 80% indicating "agree" or "strongly agree". The least popular platforms considered by the participants are Instagram, Blogs and Twitter.

The participants were asked how much time they spend on their preferred social media platform and what hampers their access to the platform. The majority of the participants (n=7) indicated that they spend between one and two hours daily on their platform to network with peers and engage with media. The constraints to usage of social media platforms listed were time (43%), Internet access (35%) and knowledge (22%).

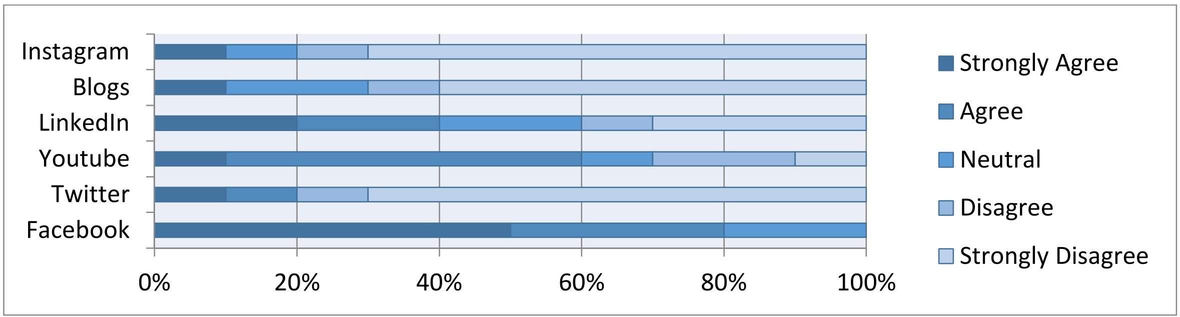


*Figure 6: Social media platform preferences. Strongly agree indicates that the social media platform is preferred*

The sharing analytics gathered during the website indicates that there was a mean of 82 hits per day throughout the course of the campaign. Many of these hits could be due to external search engine hits or web crawlers, but many were from IP addresses that belong to the institution. Through the semi-structured interviews, the three participants interviewed indicated that they regularly shared content that appeared in the campaign with the social network of peers when they felt that it would be appreciated by their peers. The most popular shared content amongst the interviewees was video content as it can be easily accessed.

## 5. Recommendations and Conclusion

The results of this study suggest that the staff participants of the higher educational institution used in the study felt that they benefited from the campaign and that they had engaged with the content provided. There was an increase evident in the environmental awareness of the participants. Key findings indicate that institutions, such as the university investigated, should invest marketing efforts into their environmental initiatives, while endeavoring to make them accessible to as many staff members in these institutions that are not aware. This is a shortcoming as these initiatives can assist in drawing in student numbers and staff that are aware of them and can foster environmental values into their students. The limitation of this study is in the small sample size. However, it is a qualitative study which forms part of a larger, ongoing study. In spite of this limitation, the theoretical model proposed and initial findings provide a valuable contribution to the research field of environmental awareness and the use of social media for promoting these campaigns. Social media were shown to be a valid means of conducting an environmental awareness campaign but would need governance to maintain momentum, much like the action research approach employed in this study. Future research is required which could implement the model in other educational institutions in order to provide further empirical evidence.

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# Application of Software and Web-Based Tools for Sustainability Management in Small and Medium-Sized Enterprises

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## Abstract

Recently, new approaches to organizational level sustainability management and reporting have emerged in the form of software and web-based applications. At first glance, it appears that such software and web-tools are applicable in small and medium-sized enterprises since they offer user-friendly and cost-effective alternatives to implement, manage and report on company-wide sustainability activities. Nevertheless, it remains academically and practically uncertain if such technologies will be adopted by a great number of SMEs. Using the Technology-Organization-Environment (TOE) model as a theoretical framework and empirical data from a recent survey with 1,250 German SMEs, this paper investigates various firm-internal and external factors that might influence managers' decisions to adopt or reject this new technology. As a result, this paper can help determine which factors play a role in the adoption of sustainability management software and web-tools in SMEs.

***Keywords***: *Sustainability Management; Small and medium-sized enterprises; Software; Technology-Organization-Environment (TOE) framework; Web-based tools*

## 1. Introduction

Large and small businesses are increasingly confronted with sustainability issues, such a rising energy costs and health and safety issues of employees. At the same time, companies of all sizes are challenged by regulations, public scrutiny, and changing consumer preferences to take responsibility for their company endeavors and the linked effects to environment and society. Such responsibility can be taken as company-led initiatives and proactive sustainability strategies, such as improved energy efficiency, company-wide environmental management, integrative sustainability reporting, etc. Depending on the particular industry and challenges an enterprises faces, various management tools have been developed to support managers assess, measure and communicate these sustainability activities.

While large multi-national corporations development and implement a range of sustainability management strategies and tools, small and medium-sized enterprises (SMEs) are oftentimes lacking the necessary resources, personnel and know-how to effectively management growing environmental and social concerns relating to their business [10]. Many formal and complex management tools, such as the Sustainability Balanced Scorecard or life cycle assessment, find little practical application in SMEs [12]. With few exceptions [15], relatively few developments and academic attention has focused on SME-specific solutions for sustainability management.

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In addition, it remains uncertain which tools will find widespread application in SMEs. For example, an environmental management system (EMS) according to ISO 14001 or the Eco-Management and Audit Scheme are witnessing a period of stagnation in new German company members [5]. Most companies remain unaware und disinterested in the subject environmental and sustainability management. However, a recent study by Johnson [12] showed that the rate of application for sustainability management tools is strongly related with the rate of awareness. In other words, the higher the awareness of a tool (e.g. an EMS), the more likely that SMEs will adopt it. Therefore, a conclusion is to promote awareness-raising programs for such tools in SMEs through governmental initiatives and business network meetings.

More recently, new approaches to sustainability management have emerged in the form of software and web-based applications to support companies of all sizes assess, coordinate and communicate their sustainability activities [6, 20]. Organization-wide software and web-tools have been designed to facilitate various management tasks related to sustainability, such as self-assessment and strategy formation on sustainability aspects (e.g. N-Kompass – www.n-kompass.de; KIM Software - www.sustainum.de/index.html), sustainability controlling and benchmarking (e.g. EPM-Kompass) [8]; sustainability reporting (e.g. CR-Kompass – www.crkompass.de/; 360Report - www.360report.org/de/) [11, 20] as well as administration of occupational safety and environmental management (e.g. EcoTra).

However, an all-embracing software and web-tools containing all these sustainability management features is currently available [13], but few SMEs adopt it mostly due to high implementation and maintenance costs.

With very limited exceptions [1, 8], research has not yet investigated the adoption of sustainability management software and web-tools in SMEs. Furthermore, a research gap has emerged on the firm-level factors that influence the decision to adopt or reject such software and web-tools. This paper attempts to fill the gap by providing initial insights on the main influential factors that might affect the adoption of software and web-tools in SMEs.

## 2. Theoretical Background

Sustainability management entails a simultaneous organization of economical, ecological and social aspects regarding business activities in a conscious effort to improve environmental and social performance while remaining competitive and economically viable [3, 18]. In this light, a company should steer its activities in such a way to reduce negative effects and/or achieve positive outcomes for the environment while contributing to the sustainable development of society and the economy [19]. Visions and strategies of corporate sustainability in turn aim to integrate all these activities into the core business of a company. To support this integration, companies are now provided with a wide set of options, including sustainability management tools and software applications. A wide range of tools can facilitate managerial tasks across many business functions, including accounting, research and development, procurement and production, supply chain management as well as cross-functional activities [22].

Similarly to tools, software applications and web-tools for sustainability management can facilitate various management tasks including the assessment, planning, control, communication and reporting of sustainability activities. Commercialized software applications are increasingly emerging, promising to enable the overall coordination and communication of sustainability-related tasks shared between various functions and employees within the company. While it is understood that software is in no way a substitute for the human factor – from strategic visions and planning to the manual input and coordination of data – it appears that software can offer many promising advantages once the strategies and responsibilities have been properly assigned.

At first glance, it appears that sustainability management software and web-tools are applicable to SMEs. These applications offer a cost-effective approach to dealing with sustainability activities. They can be tailored to an enterprise's particular structure and provide user-friendly features so that additional training is not required to input and retrieve the necessary data. While several authors promote the applicability of such software [8], there is a lack of empirical evidence on the adoption of such software in SMEs. It remains unclear if firm-level software and web-based tools for sustainability management will be applied by a great number of SMEs. Previous research has not investigate which firm-internal and external factors play a role in decision-making to adopt such technologies. Therefore, these practical and scientific uncertainties have lead us to propose the following research question:

*Which firm-level factors influence the adoption of software and web-based tools for sustainability management in SMEs?*

Instead of examine the current success and failure rates of individual software application and web-tools, this paper examines organizational factors that might influence adoption rates from a wider perspective. It is interesting to see how particular factors influence the rate of adoption for these new technologies for an enterprise's sustainability management. The next section will explain how the research question was addressed from a theoretical standpoint.

## 3. TOE Framework

In order to address this question, the Technology-Organization-Environment (TOE) framework [21] was chosen to examine various firm-internal and external factors that might influence decision-making for new technologies in SMEs. The TOE framework can be very useful in explaining the adoption and implementation of technologies at the organizational level. It combines factors in three contexts, including technological factors, firm-internal or organizational factors, and firm-external or environmental factors. An additional fourth context, individual factors, may be included into this framework.

The TOE has been applied frequently in SME research, especially with Enterprise Resource Planning (ERP) software [2, 16, 17], and e-business solutions [14, 23]. These papers' conclusions then reveal which and how various factors, such as prior IT-knowledge, attitude towards new software, top management support and external IT-support, play a role in decision-making of such software. For example, Ramdani et al. [16] illustrate how the adoption of ERP software in SMEs is mostly influenced by top management support since the primary decision-maker in SMEs is typically the owner-manager.

However, no account was found for the TOE framework in context of environmental or sustainability software. Therefore, we have adapted the TOE framework to sustainability management software in SMEs. Figure 1 below shows the overall research model as well as the various factors among the four contexts that were taken into consideration for this paper.

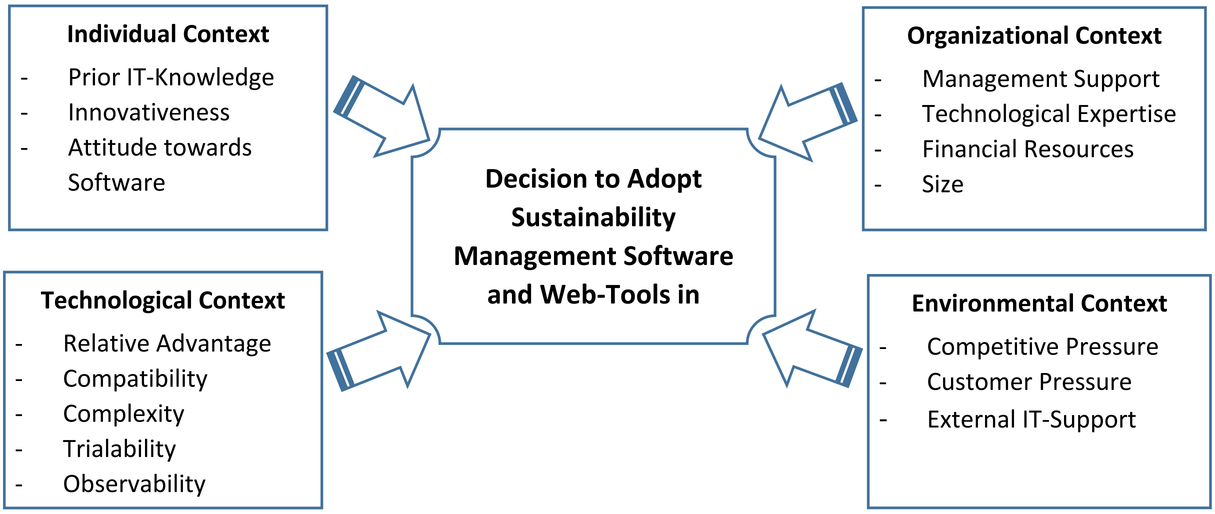


*Figure 1 – Adaptation of Technology-Organization-Environment (TOE) Framework from Tornatzky and Fleischer [21]*

Within the individual context, three factors were selected, including prior IT-knowledge, innovativeness and attitude. Prior IT-knowledge explains an individual's beliefs about level of competency with IT, which in this case is the perceived ability to use the computer and related software applications. Innovativeness refers to the managers' willingness to take risks and try something new through experimentation. Attitude refers to a managers' positive or negative feelings about a new technology [4].

From the technological context, relative advantage refers to the degree in which a manager perceives the software or web-tool to be superior to the previous method of operation. This factor is considered a key factor in improving the rate of new technology adoption to the extent that the innovation is perceived as advantageous [9]. However, it might not be as relevant in the case of sustainability management software and web-tools as most SMEs have not previously have had a formal approach to sustainability up till now [7]. Compatibility explains the degree in which software is perceived to be well-matched with existing organizational structure and software usage. Complexity is the perceived extent to which a new technology is difficult to understand and use. This would be reflected as a negative value in comparison to rate of adoption. Trialability and observability focus on the degree in which software can be experimented on a limited basis and can be visible to others.

Most organizational and environmental factors are self-explanatory so they will not be covered in great depth in this paper. For starters, support from top management can highly affect if such software will be implemented [9, 17]. Furthermore, the availability of in-house software support (technological expertise) and ample financial resources may play a role in decision-making. Company size has been revealed as a major determinant for the rate of new technology adoption [9]. From the environmental context, competitive pressure measures the perceived intensity level of competition and resulting pressure to adopt new technologies to remain competitive. Customer pressure is the perceived feeling of demands from customers to adopt software. In the case of SMEs, this may occur through large companies demanding their suppliers to adopt a certain software. Finally, external IT-support examines the perceived availability of external support from software companies and from state-funded programs. The next section will explain how these factors were are brought together in a quantitative analysis and provide the results.

## 4. Method and Results

In order to address this paper's research question, an online survey was conducted with top managers in German small, medium and large-sized enterprises from February to June 2014. In order to gain a suitable representation of German SMEs in all industry sectors, enterprises have been selected and classified according to two main criteria. First, companies were evenly distributed into four groups in accordance with the European definition of SMEs:

(1) small – enterprises up to 50 employees;

(2) mid-sized – enterprises with 51 to 100 employees;

(3) medium – enterprises with 101 to 250 employees; and

(4) large – enterprises with more than 250 employees.

Second, companies were selected according to various industry sectors. In total, enterprises from 10 main industries were included in the survey, for example manufacturing, construction, wholesale and retail and various service sectors. The number of companies selected from each industry was based on percentages of enterprises in each sector [5].

A total of 1,250 enterprises were sent an e-mail invitation to the online survey. However, 96 of these invitations were sent back as "not deliverable". In total, the survey produced 145 usable questionnaires from the 1,154 e-mails received. The response rate is 12.6%, which is comparable with other surveys with similar focus of sustainability management in SMEs [12].

The online survey consisted of questions with mostly closed-form responses using a 7-point Likert scale. The dependent variable was a simple yes or no question "Does your company currently use or plan to adopt sustainability management software within the next two years?" Questions on the relevant factors were organized according to the four contexts - individual, technological, organizational and environmental. For every individual factor (e.g. "top management support"), three to eight questions were provided, which were then averaged in the analysis stage.

An initial evaluation of the results looked into the descriptive statistics of the data including mean values (Avg.) and standard deviations (S.D.) of studied factors of the TOE framework. These factors can be separated and categorized into two groups: 1 = "decision to adopt" – managers who currently use sustainability management software and/or who intend to adopt such software within the next two years; and 0 = "decision to reject" – managers who neither use nor plan to adopt such software. As expected, the group "decision to reject" was much greater (110 enterprises) than the group "decision to adopt" (35 enterprises). Table 1 below shows the descriptive statistics of mean values and standard deviations from the various influential factors between the two groups of respondents.

From Table 1 we observe significant differences between both groups with the factors personal attitude, trialability, observability, top management support and competitive pressures. From these preliminary results, we can deduce that managers' perceived awareness of commercialized software is a major determinant for adoption, where they are able to test it on a limited basis (trialability) and see others using it (observability). Furthermore, the overall positive attitude towards software combined with added support from top management also positively influence the chances that such software will be used.

Other factors had also similar results, including prior IT-knowledge, innovativeness, complexity and customer pressure. In fact, the non-users actually had a slight edge on prior IT-knowledge, but it is not substantial to argue that commercialized software might be perceived as boosting such knowledge. From the environmental context, the results were below average for both groups. In the context of SMEs, these factors are not positively related to managers' decision-making in adoption of software.

| Factors | Decision to Adopt | | Decision to Reject | | Difference |
|---|---|---|---|---|---|
| *Individual Factors* | *Avg.* | *S.D.* | *Avg.* | *S.D.* | *Avg.* |
| Prior IT-Knowledge | 4.43 | 1.06 | 4.55 | 1.39 | - 0,12 |
| Innovativeness | 6.01 | 0.85 | 5.85 | 0.91 | 0.16 |
| Attitude | 4.80 | 1.41 | 2.93 | 1.35 | 1.87 |
| *Technological Factors* | | | | | |
| Relative Advantage | 4.59 | 1.23 | 3.91 | 1.27 | 0.68 |
| Compatibility | 4.47 | 1.29 | 3.67 | 1.24 | 0.80 |
| Complexity | 4.18 | 1.42 | 3.86 | 1.21 | 0.32 |
| Trialability | 4.02 | 1.61 | 2.33 | 1.48 | 1.69 |
| Observability | 4.90 | 1.61 | 2.02 | 1.52 | 2.88 |
| *Organizational Factors* | | | | | |
| Top Management Support | 4.36 | 1.44 | 2.92 | 1.51 | 1.44 |
| Financial Resources | 4.93 | 1.67 | 4.31 | 1.79 | 0.62 |
| Technological Expertise | 5.47 | 1.20 | 4.54 | 1.65 | 0.93 |
| *Environmental Factors* | | | | | |
| Competitive Pressure | 3.87 | 1.52 | 2.80 | 1.37 | 1.07 |
| Customer Pressure | 3.23 | 1.51 | 2.95 | 1.56 | 0.28 |
| External IT-Support | 3.65 | 1.29 | 2.76 | 1.18 | 0.89 |

*Table 1. Averages and Differences between Factors in the Decision-Making of Software Adoption*

In a second step, a logistic regression analysis was conducted on those variables that had the greatest difference in mean values between the two groups (adopt and reject). These included variables are attitude, trialability, top management support, competitive pressure and external IT-support. Company size according to employee amounts was included as a control variable. The variable ‘observability’ was removed because it too strongly predicts adoption. The problem of multicollineartiy arose with observability in the regression model, as the variance inflation factor (VIF) was above 4. From another point of view, it could be argued that the other variables first influence observability and then the latter strongly influences adoption. Table 2 below shows the results of the regression analysis.

| Independent variables | B | Wald | Sig. | Exp(B) |
|---|---|---|---|---|
| Constant | -7.801 | 24.07 | 0.000 | 0.00 |
| Attitude | 0.496 | 2.87 | *0.090** | 1.64 |
| Top Management Support | 0.421 | 3.56 | *0.059** | 1.52 |
| Trialability | 0.590 | 5.72 | *0.017*** | 1.80 |
| Competitive Pressure | -0.171 | 0.39 | 0.534 | 0.84 |
| External IT-Support | 0.000 | 0.000 | 0.999 | 1.00 |
| Company Size | 0.697 | 6.71 | *0.010**** | 2.01 |

Notes: * = $p < 0.10$; ** = $p < 0.05$; *** $p < 0.01$; N = 112

*Table 2. Logistic regression model for the adoption of sustainability management software*

The most significant variable is company size (0.697), followed by trialability (0.590), personal attitude (0.496; only significant at the 0.10 level), and top management support (0.421; only significant at the 0.10 level). While other studies confirm that size plays a significant role [2, 16], these presented individual (attitude) and internal factors (trialability and top management support) are key determinants for the decision to adopt sustainability management software. Competitive pressure and external IT-support were both not significant, confirming the descriptive analysis that environmental factors do not influence managers' decision making on sustainability management software.

## 5. Conclusion and Outlook

Besides the strong influence of company size, the results show that the decision to adopt sustainability management software mainly depends on the observability or in other words awareness that sustainability management software exists, that an SME managers have been able to try it out and that managers have an overall positive attitude towards the software. In addition, it is important that top management supports the decision to adopt it. Future research could further investigate these influential factors in qualitative interviews to better understand why companies should to adopt or reject such software.

While these results provide new insights on influential factors for the adoption of sustainability management software, several concerns remain. On one hand, it remains uncertain if companies with existing environmental and sustainability management systems have less of a need for commercialized software, as they have probably some IT-solution already, for example self-made Excel spreadsheets and Word documents. On the other hand, companies that are not interested in sustainability management in the first place will not perceive any benefit for related software.

Nevertheless, this paper was able to gain greater insights on the factors that influence the adoption of sustainability software in SMEs. It opens the discussion and offers new find pathways to consider in the adoption by highlighting the main factors that might encourage further adoption in SMEs. From a practical standpoint, it should help software developers understand their target market and position the product more effectively toward the end-user. In this way, the results can make a considerable contribution for future research to build from as well as support the further development of software in SMEs.

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# Towards Green ERP Systems: The selection driven perspective

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## Abstract

Enterprise Resource Planning (ERP) system has become a vital strategic tool in today's competitive business environment. Recently, a high demand is emerging for computer-based information systems that better support corporate sustainability management. In this regard ERP systems are supposed to contribute for these demands such that they can be considered under the categories of Corporate Environmental Management Information Systems (CEMIS). Such ERP systems are considered as Green ERP systems and there are several efforts towards such systems. These efforts also contribute to the realization of the concepts behind the project IT-for-Green, which is running at University of Oldenburg. One of the modules in this project, which is named Green IT, emphasis on effective system utilization under efficient power consumption. Therefore the effort towards Green ERP systems will also add up to the efforts of the project IT-for-Green. For the instrumentation of this concept, companies should be aware of Green ERP systems and should also consider and emphasis on dimensions in evaluating the greenness of ERP systems. At this junction, one of the major issues to be addressed is the determination of the dimensions to evaluate the greenness of ERP systems. This study is, therefore, motivated to determine the dimensions in evaluating the greenness of ERP systems. In determining these dimensions the study first identified general ERP selection criteria and further refined them and come up with suitable criteria for the assessment of the greenness of ERP solutions. Based on this result, companies are expected to emphasis on such criteria to identify a Green ERP alternative and this will also enforce vendors towards the manufacturing of Green ERP systems.


*Keywords: Green ERP Systems, ERP selection criteria, Dimensions for Green ERP systems, Sustainability, CEMIS, IT-for-Green*

## 1. Introduction

Enterprise Resource Planning (ERP) system has become a vital strategic tool in today's competitive business environment [1]. It facilitates the smooth flow of common functional information and practices across the entire organization. In addition, it also improves the performance of the supply chain and reduces cycle times. In general, an ERP system is expected to improve both backbone and front-end functions, simultaneously resulting in to low operating cost and improved customer service. Accordingly, organizations are choosing and deploying ERP systems for such and many other tangible and intangible benefits and strategic reasons. However, recently, a high demand is emerging for computer-based information systems that better support corporate sustainability management and this initiate the need for special type of information systems called Corporate Environmental Management Information Systems (CEMIS) [2]. These systems are supposed to fit for new administrative approaches, e.g. in the field of emission trading, and recommendations, for instance regarding carbon footprints of products [3].

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In this regard, an ERP system is supposed to provide the required information for environmental or sustainability management such that it can be considered under the categories of CEMIS systems. This leads to the realization of the concepts behind the project IT-for Green, which is running at University of Oldenburg. The project has several modules and one of them, which is named Green IT, emphasis on effective system utilization under efficient power consumption. Therefore, since the motive behind Green ERP system is also energy efficiency, the effort towards Green ERP systems adds up to the efforts of the project IT-for-Green.

In order to get the best out of ERP systems, companies should be aware of Green ERP concepts and should also consider and emphasis on dimensions in evaluating the greenness of ERP systems, such that, vendors will gear towards manufacturing of such systems. At this junction, one of the major issues to be addressed is the determination of the dimensions to evaluate the greenness of ERP systems. This study, therefore, determined the dimensions in evaluating the greenness of ERP systems. In reporting the works carried out when determining the dimensions, the paper is organised in to five parts. The second part addressed how Green ERP can contribute for the efforts in IT-for-Green project. The extraction of general ERP selection criteria to evaluate ERP alternatives is addressed in the third section. Having the identified criteria list, the fourth part discussed the determination of the criteria for the evaluation of the greenness of ERP systems. Finally summary and conclusion of the study is provided in the last section.

## 2. Green ERP as an Enabler in IT-for-Green

### 2.1. IT-for-Green

IT-for-Green aims at increasing the environmental friendliness of companies and their processes by means of ICT. In this context, ERP systems can play a significance role if they are designed to address the requirement sets for CEMIS. Such ERP systems can be considered as Green ERP systems and their role is discussed in the next section.

### 2.2. Green ERP in IT-for-Green

ERP systems, which are environmentally friendly and allow organizations to cut costs while benefitting the planet, are termed as Green ERP systems [4]. The concept Green ERP system is a more environmentally responsible initiative to reduce carbon emissions and concerned with people and the planet in addition to profit [5]. This philosophy has been dubbed the "triple bottom line", which is an expanded version of the business concept of the bottom line that includes social, environmental and financial results [6]. As Green ERP systems are concerned with addressing the" triple bottom lines" (social, economic, and environmental dimensions), this coincides with the objectives and concerns of the project IT-for-Green. Therefore such ERP systems that can provide the required information for environmental or sustainability management can be considered as enablers of IT-for-Green as they can lead to the realization of the concepts behind the project. The corresponding benefit can also extend to companies adopting ERP systems.

In this regard companies should be aware of Green ERP concepts and should also consider and emphasis on dimensions in evaluating the greenness of ERP systems, such that, vendors will gear towards manufacturing of Green ERP systems. At this junction, one of the major issues to be addressed is the determination of the dimensions to evaluate the greenness of ERP systems. However, a depth evaluation on existing ERP selection trends revealed that there is lack of research in determining ERP selection dimensions even for the evaluation of common ERP systems [7]. As an emerging concept, the lack of dimensions in determining the greenness of ERP systems is also quite expected. Therefore the general ERP selection criteria, which are the basis for the criteria to evaluate the greenness of ERP systems, are first determined in the next section.

## 3. Criteria for ERP Evaluation

The implementation of an ERP system is an important investment for an organization and for a successful implementation of such systems selecting the most appropriate software is a necessary condition [8, 9]. In selecting the most appropriate solution, the available alternatives should be evaluated against standard criteria such that the new software capabilities and needs should not be mismatched with organization's business process and procedures [10]. Although a considerable amount of articles contribute towards analyzing the value of information systems, packaged software solutions or commercial off the shelf (COTS) products in general, only a few have focused on the special case of ERP systems [11, 12].

This study, therefore, combines the theoretical approach to ERP selection with ERP practical recommendations to determine the dominant set of criteria that would provide maximum support for ERP implementation. The process encompasses several activities starting from extraction of the criteria from journal articles and then matching the criteria based on their similarity. The unified criteria are then ranked based on their frequency of occurrence and the most frequent ones formulate the suitable criteria list. Finally standardization has been made through ISO9126 software quality model to determine the categorical representation of the criteria.

### 3.1. Extracting

The extraction of ERP selection criteria has been made from journal articles covered in Web of Science. Articles which were considered as the most relevant are those which topics include strings "enterprise resource planning" and "selection" or "selecting". Similar strings were also used in the study of [7]. 25 articles, which fulfil the criteria, out of 2971 articles on enterprise resource planning were found on web of science. Only 16 out of these 25 articles mention selection criteria. The remaining 9 articles discussed ERP system selection in general or as a part of implementation process or terms selection and ERP were not related.

### 3.2. Matching

Although the total list indicate as there are 226 criteria, it is not to mean that all of them are unique, rather the counting considered redundancies and this should be managed to get the real figure. In addition to this, there are also criteria, which seem unique but similar in their effect with some other criteria. Therefore, the matching process addressed synonymy and also similarity in effect. In managing this process the matching has been made first within an article and then followed by the matching between articles. The matching with in an article has been made for synonymy and effect as illustrated in Table 1 below.

| Criteria | Terms | Article |
|---|---|---|
| Cost | Software Costs | [13] |
| | Consultation Costs | |
| | Maintenance Costs | |
| | Price | [14] |
| | Value (Total implementation cost versus total value tithe company) | |
| | Average cost of packages | [15] |
| | Support fees | |
| | Training fees | |
| Reliability | Trust in the ERP System | [13] |
| | Credibility of the System | |

*Table 1: Matching ERP Selection Criteria*
*Source: [16]*

The table gives two exemplar criteria which are redundantly expressed and represented in different terms in a given article. “Price” and “Value” in Umbel et al. [14] are cost aspects represented by synonymous terms and have similar effect. “Trust in the ERP system” and “Credibility of the system” in Bueno and Salmeron [13] are other dimensions expressing the reliability of the software but represented redundantly in a given article. The matching has been made within all articles and the total criteria list shrinks to 81 based on this intra article matching process.

The matching process has then further applied for criteria in different articles and as depicted in table 1 different articles represent the criteria “cost” in synonymous terms and also with terms having similar effects. This process has been applied to all criteria between articles and when accounted for synonyms in a wide sense of the word, it was possible to identify 30 uniquely expressible criteria out of the eighty one criteria. Therefore this inter-article matching process concludes the matching phase and the 30 criteria are taken to the ranking phase to determine the most important and suitable criteria.

### 3.3. Ranking

The identified 30 criteria are ranked based on their frequency of occurrence in different articles. The occurrence of the criteria ranges between a maximum of 10 articles and minimum of a single article. This study, therefore, considered those criteria which occurred in 3 and more articles and the rarely occurred criteria are rejected from the list. Accordingly the top 21 criteria are considered as important ones and the criteria together with the corresponding articles are depicted in Table 3 below.

| Criteria | Articles |
|---|---|
| Vendor Support | [14, 15, 17–24] |
| Administration Cost | [7, 13–15, 17, 20, 25] |
| System Cost | [7, 13-15, 17, 20- 22] |
| Vendor Reputation | [7, 23,19, 21, 24, 25, 17, 20] |
| Ease/Speed of Implementation | [7, 13-15, 17, 21-22, 25] |
| Time to go live | [7, 14-15, 17, 21-22, 25] |
| Training | [15, 22, 25] |
| Organizational fit | [14, 19, 21, 23, 24, 26, 27] |
| Customization/Parameterization | [7, 13, 19, 22, 23, 25, 28] |
| Accuracy | [7, 17-19, 23-24] |
| Recoverability | [18, 13, 7, 25, 17, 22] |
| Compatibility | [7, 13, 17-19, 23] |
| Ease of use | [7, 13, 17-18, 22, 25] |
| Latest Technology | [18-20, 23, 27] |
| Flexibility | [14, 17-18, 27] |
| Upgrades | [14, 19, 20, 23] |
| Modularity | [13, 19, 23] |
| Information Needs | [ 13, 27-28] |
| Scalability | [19-20, 23] |
| Security | [14, 17-18] |
| High Performance | [13, 27-28] |

*Table 3: Important ERP Selection Criteria List*
*Source: [16]*

Representative terms are selected out of existing criteria list and domain experts are also consulted for expert based consensus on the naming of the 21 criteria. Accordingly “Ease/ speed of

Implementation" is represented by "Implementation" and in the definition of the criterion the intention of the term is further explained. In a similar way "Time to go live" is also tuned as "preparation", "organizational fit" as "Suitability"; "Customization/ Parameterization" as "Customization" , "latest technology" as "technology", and "High performance" is represented as "Performance". Based on this labelling, the most important criteria are depicted in Figure 3 below.

### 3.4. Standardization

The standardization process is mainly concerned with the comparison of the identified ERP selection criteria with the criteria in ISO9126 software quality model to check whether all the dimensions in the software quality model are also reflected in the identified criteria list. In addition, the process is also concerned with the categorical representation of the criteria. In doing so ISO9126 software quality model, which is depicted in Figure 1 below, is employed in the process through its 22 software quality sub-criteria and 6 criteria categories

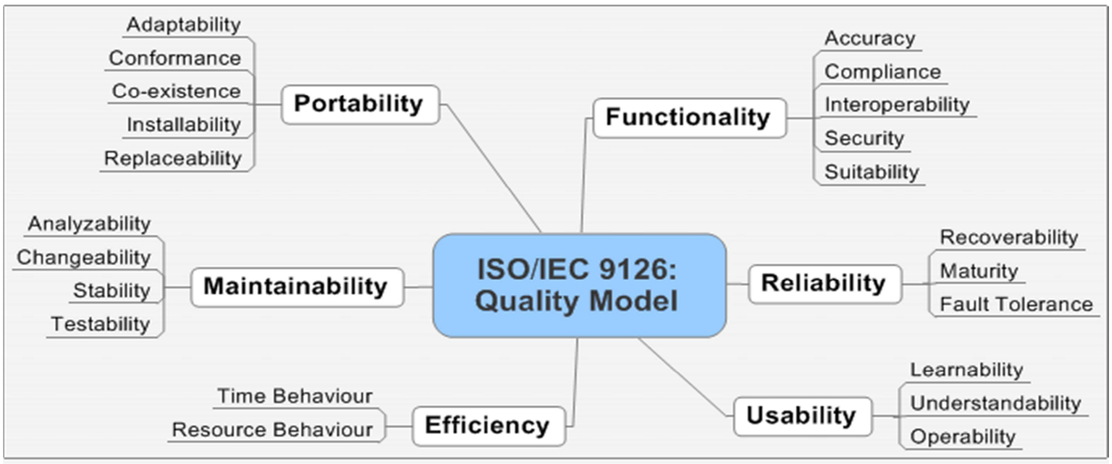


*Figure 1: ISO9126 Software Quality Model*
*Source: [29]*

The result of the comparison revealed that the identified ERP selection criteria are matching with the sub-criteria in ISO9126 software quality model. But, since the identified ERP selection criteria have no categorical representation, the representation inISO9126 software quality model is adopted to the identified ERP selection criteria. Categorical representation of the criteria is quite important to simplify the management of the criteria [30]. However the categorical representation in ISO9126 software quality model can only address 14 of the identified ERP selection criteria and the remaining criteria are not stated in ISO9126 software quality model. This initiates the need for further assessment on the categorical representation of ERP selection criteria.

According to Ayaug and Özdemir [18], ERP selection criteria can be classified in three dimensions: competitive advantage, productivity, and profitability. Bueno and Salmeron [13] identified six ERP selection criteria and stated that four of them involve criteria related to ERP software, whereas the last two are related to the organization. Wei et al. [17] draws a clear boundary between ERP selection factors related to ERP system itself and factors related to ERP vendors. From these arguments, it is evident that the diversity of ERP selection factors complicates their classification into standard groups.

However by considering the nature of the identified criteria, this study split ERP selection criteria into two groups: the first group consists of ERP software quality-related criteria and comprises those criteria related to software quality aspects. The other category comprises software cost, time factors, and vendor related criteria under the category of management aspects of ERP implementation. The categories for quality aspect criteria are determined from ISO9126 software quality model and the management aspect categorization is customized from the work of Lien and Chan [8]. In their work, they represent the criteria related to management issues of ERP system in to three major categories: vender factors, cost factors and time factors. Accordingly, the 7 management aspect criteria have been categorized under these 3 major categories. This categorical representation of the criteria is depicted in Figure 2 below.

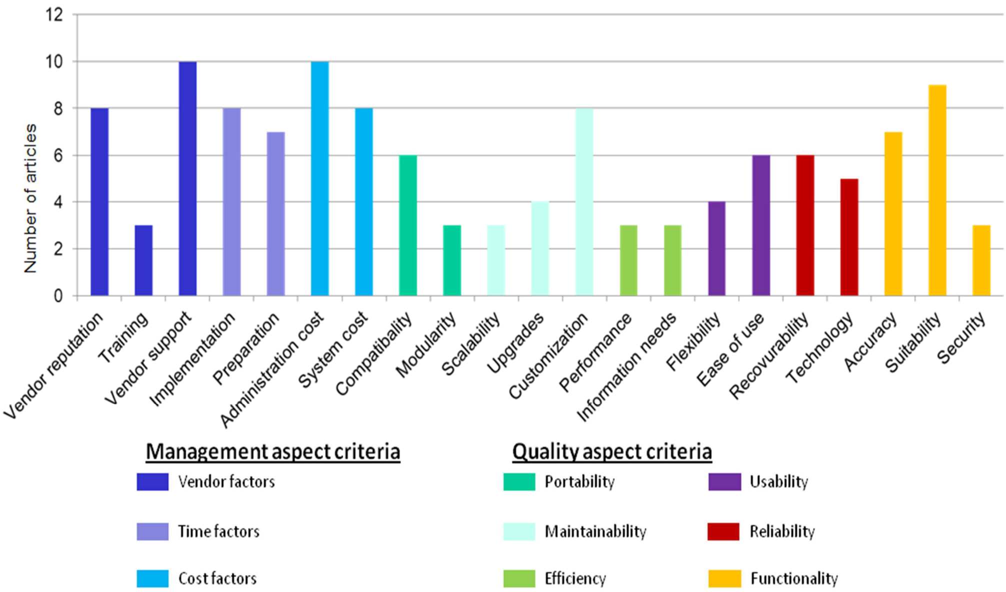


*Figure 2: Categorical Representation of Important ERP Selection Criteria List*
*Source:[16]*

The study further refined the above listed criteria through literature and consultation with CEMIS experts, and accordingly determined the criteria for the evaluation of the greenness of ERP systems as discussed in the next section.

## 4. Determining the greenness of ERP systems

### 4.1. The general dimensions in IT-for-Green

IT-for-Green project basis on the three pillars of sustainability (social, economic and environmental), which are currently unequally addressed by the project. The three modules Green IT (focusing on energy efficiency in data centre), Green Production & Logistics (aiming on life-cycle assessment over a product life cycle including production and transportation), and Sustainability Reporting and Dialogue (focusing on reporting the activities and impacts towards the three sustainability dimensions) are currently focussing to determine and optimize material and energy flows and to point out possible improvements. Therefore, energy optimization from the first module together with measuring energy and material flows are mainly addressing the environmental part and should be extended in further modules towards improving social aspects. Economic benefits will arise by reducing energy consumption in data centre but aren't calculated yet. In general the "triple bottom lines" formulate the dimensions in IT-for Green project.

### 4.2. Dimensions for the Evaluation of the Greenness of ERP Systems

The dimensions for the evaluation of the greenness of ERP systems emanate from the "triple bottom lines" considered as dimensions in IT- for-Green project. In this regard they are supposed to assess the expected requirements out of ERP systems such that the greenness of optimal ERP solutions can be secured. In this regard the determination of the criteria for the evaluation of the greenness of ERP systems has been carried out based on the general ERP selection criteria in a pair wise comparison matrix and the Fuzzy Analytical Network Process (FANP) method has been applied to facilitate the comparison process. Based on the mathematical computation in the comparison matrix: Modularity, Scalability, Customization, Flexibility, and Technology have been determined as suitable criteria for the assessment of the greenness of ERP solutions.

A modular ERP system gives the possibility for an on-demand utilization of its functionalities such that the energy to run the temporary ideal modules can be saved. An ERP system should also be scalable in a way to bolt-in other systems. This enables to get the benefit of multiple systems with efficient energy consumption. The system should also be customizable to the critical requirements of adopting organizations such that the business can sustain their competitive edge and also manage processes effectively. This by in-turn contributes for efficient energy utilization. The system should also be flexible to adapt to possible or future changes when required. This can be assured by the upgradeability of the ERP system, and simplicity of integration and internal programming work. On the top of that the latest the ERP technology is, the longer its usage to the adopting company and also possible to have speedy execution of transactions. In general, an ERP system, which satisfied these requirements, can be considered as a Green ERP System.

Therefore, companies are expected to emphasis on such criteria when selection ERP systems, such that they will determine a Green ERP solution. This can be assured by providing more weights for these dimensions. The more weights are assigned for these criteria imply the more emphasis is provided to determine such systems and this by in turn will enforce vendors towards the manufacturing of Green ERP systems.

## 5. Summary and Conclusion

The study determined the important dimensions to be considered in evaluating the greenness of ERP systems. Companies can sustain the competitive advantages out of ERP systems by providing the required emphasis for the identified dimensions. In general the expected economic, social and environmental requirements can be confirmed by adopting Green ERP systems. For more comprehensive discussion on the determined dimensions, a meta-analysis study will be conducted in further studies of extending the dimensions. The study can also be extended to the broader field of “Software selection” and the dimensions can also be tested for suitability to evaluate other systems. The study will further report the determination process made to identify the dimensions for the greenness of ERP systems and will also address the structural and network representation of the criteria, which is important to facilitate the pairwise comparison process in evaluating ERP systems. It would be better, if a meta-analysis study on these dimensions is given.

## Acknowledgement

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# Environmental Information System for Waste Electrical Electronic Equipment (WEEE) Management: Case Study of Pernambuco (Brazil)

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## Abstract

The National Policy on Solid Waste (NPSW) brought a new dimension to waste management in Brazil. According to the requirements of this law, producers, traders, recyclers, importers, distributors, and consumers are each held responsible for waste outcomes. The establishment of reverse logistics systems, also proposed by the law, begins from the management of diffuse interests in support of environmentally sound disposal of waste. However, no form of monitoring or implementing process improvements is possible without knowledge of the managed resources and control of the activities. Energy usage from fuel consumption is a central concern for sustainable waste management through reverse logistics systems (RLS). The distances travelled, the type of fuel, and the defined routes are some of the criteria to be evaluated in energy performance improvement. Thus, as preliminary results of a survey of international cooperation between Brazil and the United States, we propose a method of operating waste collection systems, with the support of an environmental information system (EIS) and integration of electronic waste management stations from a cooperative of waste pickers located in Pernambuco (Brazil). Our findings suggest the importance of the EIS prototype in compliance with legal requirements and the potential for improvement of the proposed solution.

## 1. Introduction

The sustainability challenges facing Brazil require balancing environmental compliance, economic performance, and social equity. In a recent study carried out in 50 Brazilian companies, it was noticed that most institutions consider environmental sustainability as a business issue only with respect to legal and economic penalties [1]. The authors also discussed the disclosure of companies´ environmental actions, and their findings suggested that waste management is the most relevant issue, along with atmospheric emissions, for those companies.

In sustainable waste management systems, different agents are responsible for specific tasks in order to guarantee environmentally suitable return and treatment (e.g. recycling, reuse, refurbishing, remanufacturing and landfill disposal). In the majority of Latin American countries, systems for dealing with waste electrical and electronic equipment (WEEE) have formed spontaneously through the actions of informal waste pickers, people who collect, sort and sell different post-consumer materials [2].

As a result of the Brazilian National Policy on Solid Waste (NPSW), enacted in 2010 by the Law n. 12,305, states and municipalities are required to prepare waste management plans as well as reverse logistics systems (RLS) procedures. The law also requires the inclusion of waste pickers in these planned systems. Other laws and decrees are also in place, accounting for regional specificities and local infrastructure arrangements.

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Nowadays, solid waste management employs a plethora of regulatory mechanisms and technological tools, but not as many efficient or adapted information systems. Amongst other requirements, the NPSW proposes the development of a broad Information System (IS) named SINIR (National Information System on Solid Waste), in order to allow data management, monitoring, and decision-making regarding waste management. This system is currently under construction, and data collection and quality are among the main challenges in its implementation.

The core of the waste management Information System, in general, is the data input and availability on the collection, storage, and disposal phases of post-consumer materials and products. However, although the Brazilian legislation does not specify the necessary information for waste management, lack of trust in data from sources such as waste picker associations and cooperatives remains a weakness of these information systems. Therefore, it is necessary to make the collection and recording of these data as automated as possible, in order to increase the reliability and credibility of information and improve data quality and decision significance [1, 4, 5].

To that end, we propose a method for partially automated data collection and management, applying tracking and mass balance concepts to the activities of waste picker cooperatives and associations. Our paper focuses on an important common point in regulation: the inclusion of waste pickers in the waste management process through process and technology innovation.

## 2. Background

### 2.1. WEEE management in Brazil

WEEE is not solely a recent field of study [6, 7], but it is possible to note the evolution of related themes over the last two decades. From the years 2000 to 2010, approximately, most studies focused on the social effect of recycling actions, as well as legal and technical aspects [8-11], likely in response to European Directives requirements of the time. From 2010 onward, research shifted to focus on strategic overview and managerial themes [12-14].

In accordance with this tendency [15], presented a recent study based on the importance of defining the amount of WEEE generated as a strategic tool for waste management in Brazil. Additionally, [16] focused on technical and managerial approaches to e-waste management in Brazil. Both studies were based on the NPSW requirements.

One of the main concerns in the design of RLS in Brazil is the distances to be travelled. In a country of continental proportions, it is quite important to invest in efficient use of precious resources such as time and energy. In this context, [17] presented an interesting discussion about e-waste management trough reverse logistics tools and the energy consumption during post-consumer movements in Europe. The dimensional challenges of shipping between European countries are comparable to cargo movement across Brazilian states. The state of Pernambuco, for example, spans almost 100,000 km$^2$, stretching about 700 km from east to west, and about 300 km from north to south.

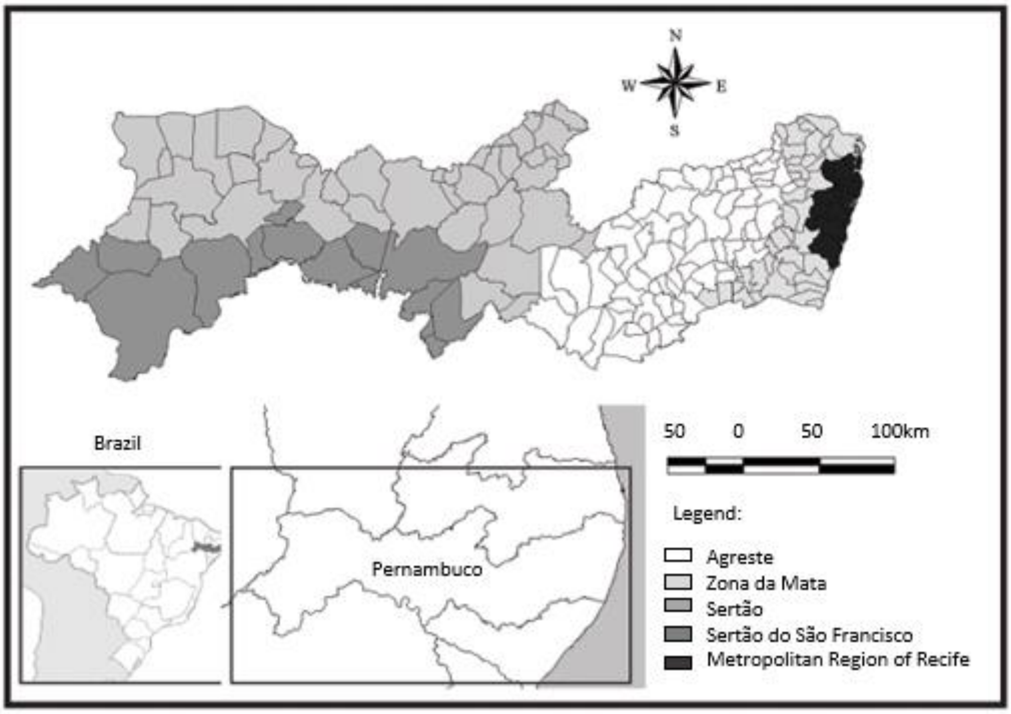


*Figure 1. Pernambuco and the Metropolitan Region of Recife (Brazil) [18].*

According to [19], of the 27 Brazilian states, only nine have specific state laws on e-waste management. According to this report, there are seven different business models for e-waste management successfully applied in Brazil (Table 1).

| Model | Nationality | Characteristics |
|---|---|---|
| Itautec (S/A) | Brazilian | Executes the whole recycling process in Brazil and then exports directly to a foreign company to extract the valuable materials. |
| Philips do Brasil | American | Collection, transport and recycling capacity over than 300 ton per year, from 40 collection points in the country. |
| Carrefour | French | Provide collection and delivery of e-waste to recycling partners: OXIL and Diassolog, in order to establish a model for its shared responsibility. |
| Oxil | Brazilian | Receives e-waste from 50 manufacturing companies around the country. As well as electronics, OXIL recycles refrigerators, extracting CFCs, and printer cartridges |
| Reciclo Ambiental | Brazilian | Collects and transports e-waste material from the client and delivers it to its own facility. Provides process tracking and brand protection. |
| Umicore | Belgian | Plays an important role in exporting e-waste, guarantees the correct destination, and assures payback for the e-waste recycling. |
| Oxigênio | Brazilian | A unique model in the country – a civil organization with public interest that can receive resources from all levels of government. |

*Table 1. Business models for e-waste management in Brazil.*

The main stages of the disposal of Waste Electrical Electronic Equipment (WEEE) systems are: the recovery of dispersed material in specialized collection centers; delivery to environmentally appropriate disposal points for reuse, reconditioning, repair, remanufacturing or recycling; and reinsertion into production chains. During the disassembly of post-consumer electronic equipment, it is possible to assign value to materials and components for marketing purposes along the reverse supply chain.

The assigned value is the result of product composition (valuable or hazardous materials, etc) and the processing cost of components and materials. However, large electronic equipment often has low added value; due to designs unconducive to recycling, they are difficult to re-integrate into the production chain.

The tasks and costs involved in post-consumer product warehousing, disassembling and treatment may be considered the operational axis of an RLS. As discussed by [20], disassembly is considered a crucial step in returned product disposal, and also an expensive sequence of tasks that must be carefully planned. Because of the complexity of electrical and electronic equipment, the integrity of materials, parts and components could result in either economic profit or extra disassembly costs.

Figure 2 shows a conceptual model for a reverse logistics system to be applied to different post-consumer products and materials from electrical and electronic origins.

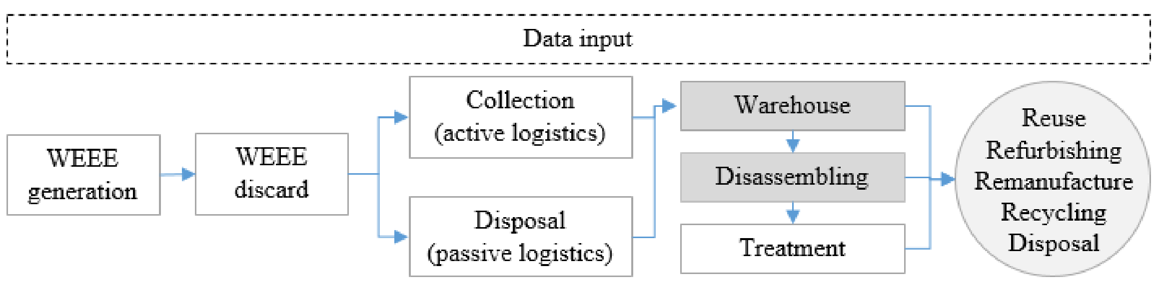


*Figure 2. Conceptual model of Environmental Information System for Waste Electrical Electronic Equipment (WEEE) management.*

The RLS we propose will feature tracing mechanisms for post-consumer stages, and can be expanded to cover all post-production steps, as well as mass balance based on the identification of the product and its materials. Products with simple composition, such as plastic or cardboard packages, glass, plastic bottles, and books and magazines, are easily disassembled and reincorporated into the recycling chain by means of reverse logistics. However, e-waste are, in most cases, complex products consisting of three or more types of materials; some of these have more severe potential environmental impact, such as printed circuit boards, CRT tubes, and mercury vapour lamps [21].

Supplying the waste management information system with more and higher quality information will improve the reliability of this system. In turn, this reduces uncertainty and increases the credibility of decision-making. Depending on the reverse logistics stage from where the material returns, the decision-makers may include the government, manufacturers, retailers, importers, distributors, and consumers – collectively known as Agents of Reverse Manufacturing (ARM).

After recovery, the product moves to the ARMs responsible for sorting and separating parts and/or constituent materials. Those ARMs who are interested in reselling the material must give an account of the origin of this material. Thereafter, we can trace whether a product was disposed of in a proper environmental manner.

### 2.2. EIS for WEEE management

The costs in RLS can be inflated due to logistical inefficiency, unpredictability and unreliable data. Some research has shown satisfactory results regarding the application of innovative tools that contribute to efficiency improvement and cost reduction, such as the use of RFID for reverse logistics [22] and e-waste management [23].

Nevertheless, in Brazil there are no e-waste studies on this concern. To this end, we use the concept of mass balance – the ratio of the weight of each material that can be extracted from a given material in terms of its total weight.

The method proposed for RLS monitoring requires automatic data input in order to provide reliability and credibility. These data may be provided by tag scanners, GPS devices, weight scales, and image capture. A central server manages the overall database system, and may have regional or national coverage. Local servers are responsible for local databases specific to the ARM responsible for their stage, for example a local waste picker association or cooperative, as well as the material categories and volumes managed. This method embraces and facilitates environmental knowledge, legal compliance, and technology in an environmental IS that may support the actual Brazilian SINIR and also include international best practices on WEEE management.

## 3. Research methodology

After literature review on the main studies related to the subject, we considered the following lines of action: (i) identification of needs for associations and cooperatives of collectors entering the recycling market; (ii) definition of system requirements in accordance with operational and legal requirements; (iii) testing the prototype in field studies, and (iv) verification of the material system through mass balance and tracking, with report generation.

## 4. Results

### 4.1. Waste management at MRR

The Metropolitan Region of Recife (MRR) (Figure 1), located in the State of Pernambuco, has one of the lowest Human Development Indices in Brazil [24]. A recent report [25] shows a larger contingent of waste pickers working in this region of the country, possibly because of the precariousness position in which a significant portion of the population lives. Many individuals need to compose or supplement their income from the collection and sale of recyclable material. These workers have a monthly income equivalent to USD 200.00, approximately.

Since the current strategy for their inclusion in the waste system relies on their involvement in waste picker cooperatives or associations, our method considers these organizations as the units of analysis for our data collection, including their membership characteristics, routes, and waste categories and amounts collected. Considering the local aspects of e-waste management and the legal requirements, we proposed a simple system to organize collection and treatment logistics, as well as provide reliability to the data collection.

The system is designed with the technical, educational and spatial constraints faced by waste picker cooperatives and associations. All parts are off-the-shelf products that are connected using open-source software available without license fees. The system is limited to the minimum components necessary to collect actionable data for the purposes of an EIS that integrates with other agents in the reverse logistics chain and complies with current legislation. Waste collection routes are recorded through a smartphone application used in the collection vehicle, in order to estimate transportation cost and impact (Figure 3).

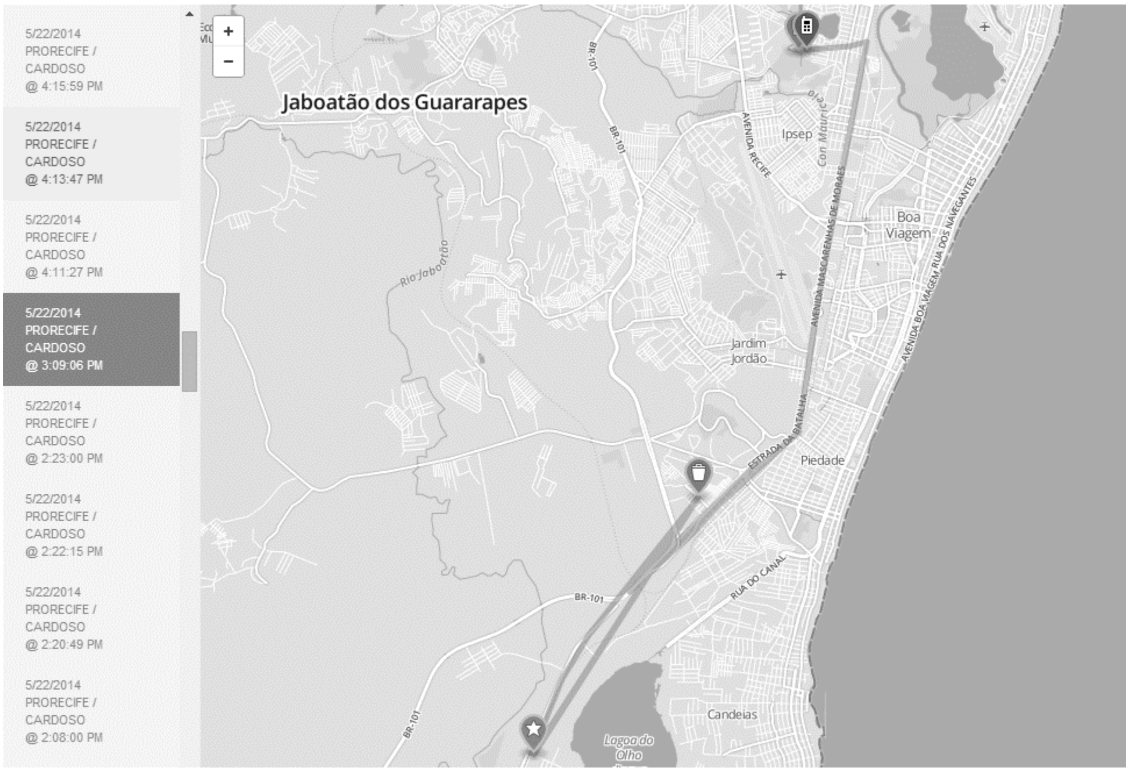


*Figure 3. Metropolitan Region of Recife (PE, Brazil) and a route detected by the smartphone application.*

The routes performed by waste pickers in the MRR were not so efficient as it could be. They use to repeat some sections and spend more time and fuel consumption (in the case of trucks collecting), than would be expected. Improvements could be provided by considering some variables such as: the responsible person and the location of collecting points, distances to be travelled, type of material to be loaded in the truck or collected by manual charts and the average time spent for the daily performance of the tasks. Besides managerial criteria, low cost technological alternatives were proposed to compound the RLS in the RMM.

Recorded weights and images of the collected e-waste provide the basis for calculating mass balances, with increasing accuracy as more and more material is documented. The proposed system collects most input automatically through the image capture webcam, scale for weighing the material or product, and bar code reader for identification and storage of information. All recorded information goes to a database that, according to legal requirement, must be available for inspection and monitoring of the process, and eventually, reverse logistics traceability of the post-consumer product (Figure 4).

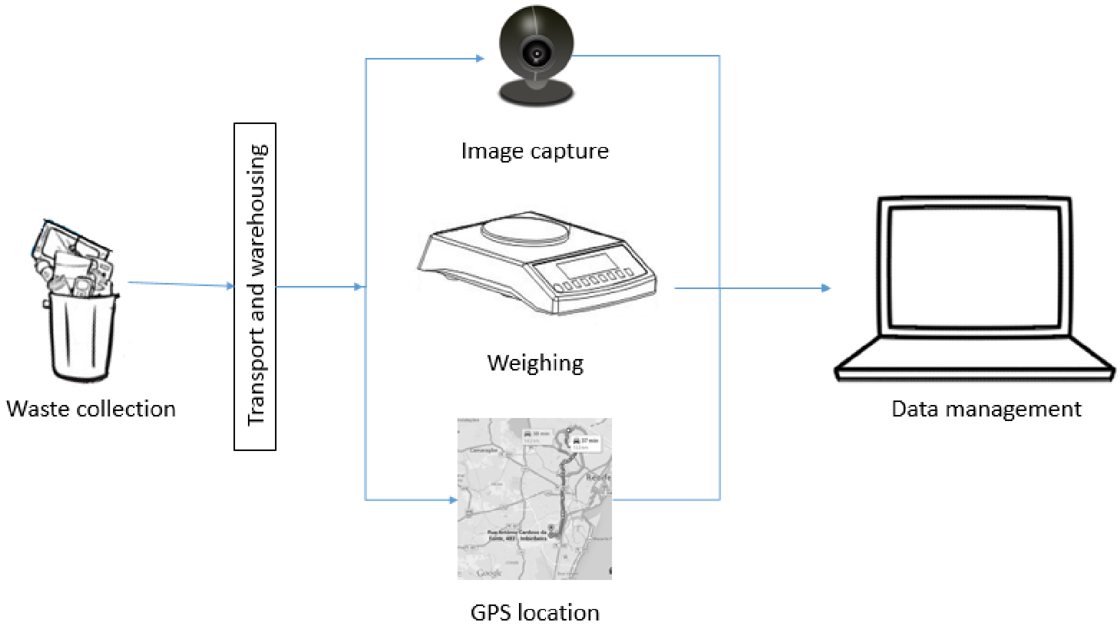


*Figure 4. General model proposed for e-waste management*

As expected, the system will also allow for optimization of routes traveled and reduced fuel consumption. In the future, it may also incorporate estimated $CO_2$ emissions. For example, since many waste pickers in Latin America still use vehicles powered by manual effort (e.g. hand carts), these could be considered as zero emission processes.

## 5. Conclusion and Discussion

The findings suggest that both environmental and energy aspects of e-waste reverse logistics may be improved through an efficient and reliable EIS. This system prototype considers the integration of different devices (scale, GPS device, and computers) in order to provide reliable data and support decision-making in a sustainable way. Information reliability is the main concern for policymakers, industry trade unions, and informal recyclers, while improving energy consumption in RLS would be an added benefit from previous sustainable decisions.

Our EIS setup represents a first step to capturing relevant data about collection, treatment and valorization in an environment that is a significant part of the value chain, yet is still dominated by informal practices and management. While this system needs to be tested extensively in the everyday practice of waste picker cooperatives, it allows capturing data about an until-recently little-known, yet ubiquitous part of the waste system.

Future research will consider specific requirements for other supply chains. By combining environmental services and technological support, we hope to reduce energy consumption and in waste collecting processes. Direct impacts could include using fewer trucks through better logistics planning of collection points and routes taken by the cooperatives.

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# Saving Energy on Mobile Devices by Refactoring

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## Abstract

Energy-efficiency is an import topic in information and communication technology and has to be considered for mobile devices, in particular. On the one hand, the environment should be protected by consuming less energy. On the other hand, users are also interested in more functionality of their mobile devices on hardware and software side, and at the same time, longer battery durations are expected. This paper shows an approach to save energy on the application level on mobile devices. This approach includes the definition, detection, and restructuring of energy-inefficient code parts. Energy savings are validated by different energy measurement techniques.


## 1. Motivation

Mobile devices and the mobile communication network are big energy consumer of information and communication technologies (ICT) in Germany [1] and their rising sales volume in the last years shows their significance in ICT [2]. Meanwhile, the energy consumption of mobile devices and the mobile network amounts to 12.9 PJ in Germany per year. This corresponds to the complete energy production of the atomic power plant Emsland [3] within four months. This amount shows that energy saving for mobile devices is also important to reduce the energy consumption in Germany, and hence, to protect the environment. In addition, the scope of mobile devices is increasing, due to new requirements, more powerful processors, and a broad variety of different apps provided on mobile devices. All these functionalities have an influence on battery duration and battery lifetime. This paper focuses on supporting developers to save energy on application level and does not consider the OS, e.g. selecting the most energy efficient network connection.

Therefore, an approach for saving energy on mobile devices on application level is described. Software evolution techniques, such as reverse engineering and reengineering, are used. *Reverse engineering* describes approaches to create abstract views of software systems to enable efficient code analyses. *Software reengineering* is a process to improve the software quality by reconstituting it in a new form without changing its functionality [4]. In this work, the energy consumption of existing Android apps [5] is changed by code analysis and transformation, which do not change apps' behavior. The process of code analysis and transformation is called *refactoring* in this work. The approach starts with defining energy-inefficient code parts called *energy code smells*. For these, a reengineering process [6] is described and validated by different, software-based energy measurement techniques [7]. Aim of this work is the collection and validation of energy code smells and corresponding refactorings which are presented in form of a catalog.

This paper is structured as follows: Firstly, the reengineering and the evaluation process to show energy savings by refactoring is described in Section 2. Secondly, in Section 3 validated energy code smells are described, in which the energy code smell *Data Transfer* (c.f. Section 3.1) and its restructuring are presented in more detail. Thirdly, measurement results of some energy code smells are summarized in Section 4. Finally, Section 5 concludes this paper with a summary and an outlook.

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## 2. Basic Techniques

Energy saving on mobile devices by refactoring needs two fundamental steps. Firstly, a *reengineering process* must be defined to perform the bad smell detection and the code restructuring. Secondly, the benefit (energy saving) for the refactoring must be shown by an *evaluation* which includes measurement techniques, checked smartphones and apps, and settings during the measurements.

### 2.1. Reengineering Process

The process to generate more energy-efficient code is depicted in Figure 1. It describes the platform-independent process from an energy-inefficient app to a more efficient one. The process starts with reverse engineering for the Java code of an app. In Step 1, the code is parsed into an abstract representation which conforms to a Java meta-model [8] and it is stored into a central repository to execute efficient analyzes. Android apps are parsed according the Java meta-model [5]. In the Steps 2 and 3, the refactoring by analyzing and restructuring the abstracted code is done and saved. The analysis is done by static code analysis which has proved itself in software evolution, to identify energy code smells. Restructure changes the abstract view without changing the intended functionality. In the last Step 4, the abstract view is parsed back into code (Android app) which can be compiled and executed.

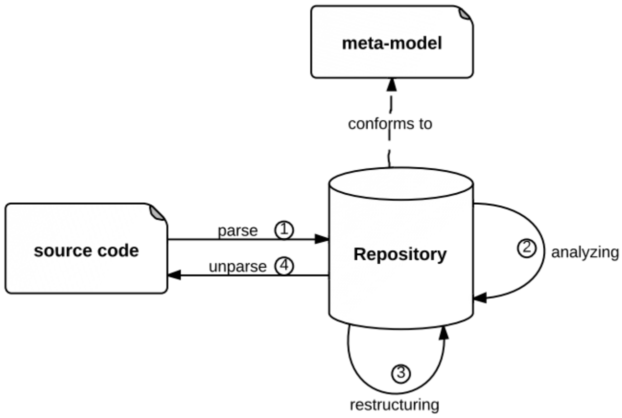


*Figure 1: Reengineering Process* [6]

The abstract view of apps' code is provided by TGraphs which can represent each programming language by nodes and edges. TGraphs are directed graphs, whose nodes and edges are typed, attributed, and ordered [9]. Thanks to the SOAMIG project [8], the tooling for the Java programming language is available and used for this work. This abstract view allows performing efficient analyses and transformations by static analyses and graph transformations. Therefore, GReQL (Graph Repository Querying Language) [8] and the JGraLab API [10] are used. GReQL can be used to extract static information and dependencies in source code represented as TGraphs. The JGraLab API implements the GReQL approach and provides means for graph manipulation. An example of the analysis and restructuring by JGraLab is shown in Section 3 for explaining the reengineering process in more detail.

### 2.2. Evaluation Process

After the refactoring, the energy improvement of refactored apps must be checked. Therefore, an evaluation process is created which includes the usage of different software-based *energy measurement techniques*, *hard*- and *software*, and the *measurement procedure* involving the duration and the mobile devices' settings during the energy measurement.

**2.2.1. Energy Measurement Techniques.** The approach uses three software-based energy measurement techniques: *file-based*, *delta-B*, and *energy profiles* [7]. These techniques are realized by the Android app Andromedar [11] which is used for validating the energy consumption of apps before and after refactoring. The *delta-B* technique calculates the energy consumption through the battery level, which can be read out with the Android BatteryManager API [12]. If the battery level changes, Andromedar calculates a new value of the current energy consumption by using the

BatteryManager API. The *system-file* technique uses an internal system file which is implemented by some mobile device vendors, only. It stores information about the current battery discharge and battery voltage. This information is used by Andromedar to calculate the energy consumption. *Energy Profiling* uses an internal XML file, which is created by the vendor or someone who has detailed information about the mobile devices' hardware components. This XML file gives information on the average power consumption of each hardware component built into the mobile device. In this case, the energy consumption is not measured directly, but the active time of all hardware components, i.e. Andromedar measures the time between switching components on and off. After measuring, the active time of each component in each particular state is multiplied with its average power, from which the energy consumption results.

**2.2.2. Hardware.** For validation, two mobile devices are used: aHTC One X [13] and a Samsung Galaxy S4 [14]. The HTC One X is used for the validation of all energy refactorings and the Samsung Galaxy S4 is only used for validating the *Backlight* energy refactoring (cf. Section 3.2). Both devices use the Android OS which is necessary to apply the reengineering process with the Java meta-model and the energy measurements by Andromedar. The HTC One X uses Android 4.1.1 with HTC Sense 4+. It has a 4.7 inch HD, super LCD 2 screen with a resolution of 1280x720 pixels. The Samsung Galaxy S4 uses Android 4.2.2 with TouchWiz. The screen is a 5 inch Full HD Super AMOLED screen with a resolution of 1920x1080 pixels. This information is listed to give an overview about considered components during the energy measurements in Section 4.

**2.2.3. Applications.** For validation, two Android apps are chosen: *GpsPrint* [15] and *TreeGenerator*. GpsPrint is a free Android app with about 1642 LOC. It locates the position of a mobile device and seeks via Internet for an address. TreeGenerator is a self-written Android app for this validation with about 345 LOC. Each second it displays another name of a tree, its type, and a picture of it. Both apps display advertisements at the bottom of the screen. GpsPrint is used for the energy refactorings: *Third-Party Advertisement* and *Binding Resources Too Early* (paragraph on Section 3). TreeGenerator is used for the refactorings: *Third-Party Advertisement*, *Statement Change*, *Backlight* and *Data Transfer* (paragraph on Section 3).

**2.2.4. Measurement Procedure**. The evaluation process for each energy refactoring is the same; hence, a short overview about the process is given. For each energy refactoring, ten energy measurements are done before and after the refactoring and an average is created to compare the results. Each energy measurement has a duration of two hours. To guarantee correct, comparable, and reproducible results, the mobile devices' settings should be the same during the different energy measurements. This includes *screen*, *notification*, *application*, *wireless and network*, and *gesture* settings.

**Screen:** The screen is permanently on but on lowest brightness because apps only run when the screen is active, and the lowest brightness is chosen to reduce and to normalize the energy consumption of the screen. Auto rotation of the screen is turned off, because the rotation sometimes interrupts the GPS connection. This was observed by first measurements with GpsPrint (2.2.3).

**Notification:** Automatic notifications are set off, such as email client, play store, calendar, etc. This is necessary to make comparable energy measurements which are not interrupted by individual notifications, such as emails or updates.

**Application:** All background apps, such as HTC Services, Google Services, 7digital, etc. are set off, so that only the tested app is running and energy consumption is not affected by further apps. Also, the power saver of the OS is turned off.

**Wireless and network:** The modules mobile data, blue-tooth, GPS, NFC, and Wi-Fi are set to off, if they are not needed.

**Gesture:** Additional gestures, such as the three finger gestures, are turned off to reduce the error rate when energy measurements are started, e.g. unwanted touches on the screen which makes repeatable measurements difficult, so the user interface is not viewed.

**Miscellaneous:** The HTC does not have a SIM card installed, with the result that the HTC seeks for it, permanently. Additional measurements checks the influence of the missing SIM card, and it shows that the influence is very small [16]. Also, no further apps are installed apart from the standard apps, the tested app, and Andromedar.

## 3. Energy Refactoring Catalog

The energy refactoring catalog includes a list of five energy code smells which are validated: *Third-Party Advertising*, *Binding Resources Too Early*, *Statement Change*, *Backlight*, and *Data Transfer* [16]. This paper describes one of the energy code smells in more detail, *Data Transfer*, and introduces further five which are described in more detail in [16] or [19]. The aim is to demonstrate possible areas of wasting energy by bad programming and strategies to improve apps' energy behavior.

The detailed description of *Data Transfer* follows a template which is developed in [16]. The template includes: a name, a definition, a motivation, constraints, an example, an analysis, a restructuring, and an evaluation. Thus, a consistent presentation of the energy code smells is ensured. A part of the template is derived from the description of code smells by Fowler et al. [17].

### 3.1. Energy Code Smell: Data Transfer

**Description:** Data Transfer refers to loading data from a server via network instead of reading pre-fetched data from the app's storage [18].

**Motivation:** Many apps use data, such as images, videos, and sound effects. Programmers can decide whether these data are stored on the apps' storage or on an external server. The measurements by [18] show that the usage of an external server needs more energy than the local one. Additionally, Android apps offer a further possibility to access data. Data are stored on an external server and are loaded into apps' cache during their runtime. While the cache is not cleared, the data do not have to be loaded again from the server. Hence, three variants exist: (1) data are loaded from server (every time), (2) data are stored on the mobile device, and (3) data are stored in the cache. These variants are considered in the following description and evaluation.

**Constraints:** The variants (2) and (3) request storage on the mobile devices while an app is installed. If memory size of the data is big, users will get a problem when installing many data-intensive apps. Variant (1) needs less storage on mobile devices, but requests high data traffic to load all data each time. If the data access of apps should be changed, many changes must be done. At first, the data must be collected to upload them to a server (for variant (1) and (3)) or to download and integrate them into an app (for variant (2)). For all variants, different Android APIs exist which must be known to detect this energy code smell.

**Example:** Example source code (TreeGenerator) showing the "*Data Transfer*" bad smell is demonstrated in Figure 2. It shows on the left side the code for loading data from server (1), and on the right side data is read from the memory card (2). The code on the left side loads data from the server in line 8 and 11 by the method `image(url, applicationCache, deviceCache, size, alternativeFile)`. If the Boolean `applicationCache` on the left side is changed, the usage of app's cache will be possible (3). The code on the right side calls the image files from the storage in line 8 and 12 by the method `getDrawable(file)` which contains the path to the image on the storage.

```
@Override
public void run() {
   i = (int) (Math.random() * 51);
   AQuery aq = new AQuery(pic);
   //tree list
   if(i == 1) {
      value.setText("Nikko-Tanne");
      aq.id(pic).image("http://
          mgottschalk.eu/img/bilder/
          nikko.jpg", false, false, 200,
           R.drawable.ic_launcher);
   } else if(i == 2){
      value.setText("Riesen-Tanne");
      aq.id(pic).image("http://
          mgottschalk.eu/img/bilder/
          riesentanne.jpg", false, false
          , 200, R.drawable.ic_launcher)
          ;
   }
   [...]
}
```

```
@Override
public void run() {
   i = (int) (Math.random() * 51);
   Resources res = getResources();
   //tree list
   if(i == 1) {
      value.setText("Nikko-Tanne");
      Drawable picture = res.getDrawable
           (R.drawable.nikko);
      pic.setImageDrawable(picture);
   } else if(i == 2){
      value.setText("Riesen-Tanne");
      Drawable picture = res.getDrawable
           (R.drawable.riesentanne);
      pic.setImageDrawable(picture);
   }
   [...]
}
```

*Figure 2: Example for Data Transfer* [16]

**Analysis:** Apps must be detected which use the `image` method of the `AQuery` API to know which part within the app must be changed. Therefore, a GReQL query is used. The query seeks for a class (`AQuery`) and an access (`image()`) vertex within the TGraph which is created by parsing the code from Figure 2 (left). These vertices must be a part of the same block and must be called in a specific order.

```
1  from cache : V{frontend.java.Literal},  block : V{frontend.java.Block}, image : V{
       frontend.java.Access}, aquery : V{frontend.java.Class}
2  with cache.value = "false" and aquery.name = "AQuery" and
       cache <--{frontend.java.HasOperand} ... block ->frontend.java.BlockContainsStatement
       ... aquery  and image <--{frontend.java.HasOperand} ... block
3  report cache
4  end
```

*Figure 3: Query for DataTransfer* [16]

Figure 3 shows the GReQL query (Section 2) which is used to detect this energy code smell. The query consists of three parts: `from`, `with`, and `report`. In the `from` part vertices and edges are defined which are needed to detect the energy code smell, e.g. the vertex `cache` of the type `Literal` must exist to detect the attribute `applicationCache` of the `image` method (Figure 2). The second part is the `with` part, which includes the content of the query. Firstly, the known values of the vertices are checked (in line 2: `cache.value = "false"` and `aquery.name = "AQuery"`). Secondly, the link between these vertices is checked by `cache <--{frontend.java.HasOperand} ... block`. This means, that the vertex `cache` is an operand of a further vertex which is connected via further edges with the `block` vertex. The last part is the `report` part which defines the vertex which will be returned.

**Restructuring:** If the query detects such a code part, the restructuring will start. Due to the complexity (saving images locally, calling each image) of the changes, this restructuring must be done manually from variant (1) to (2). The restructuring from variant (1) to (3) can be done automatically with the JGraLab API. Therefore, nearly the same query can be used, only a further vertex for the Boolean `applicationCache` must be added which must be detected and changed to `true`.

**Evaluation:** Figure 4 shows the energy consumption of the TreeGenerator app in all variants. Variant (1) (data are loaded from server) consumes the most energy with 4232 J in two hours. The difference to variant (2) (data is stored locally) with a switched-off Wi-Fi module amounts 368 J. If the Wi-Fi module is not switched-off, the difference is very small which shows that the data traffic does not have a real influence on the switched on Wi-Fi modul. Variant (3) (data is stored in app's cache) also saves energy which amounts 224 J in two hours. The results of the other two energy measurement techniques (delta-B and energy profile) are summarized in Figure 5. They show the same trend such as the file-based technique.

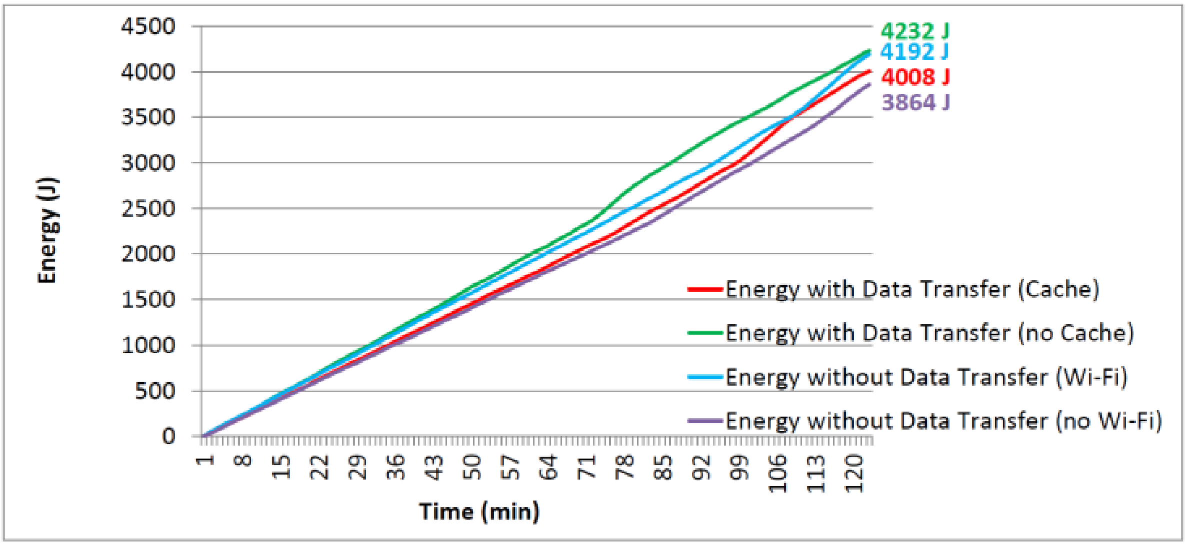


*Figure 4: File-based Measurement* [16]

### 3.2. Further Energy Code Smells

The following energy code smells are explained briefly to give an overview of further areas for saving energy. A more detailed descriptions of the first four can be found in [16]. However, their energy savings are summarized in Section 4. The last energy code smell is described in [19].

**Third-Party Advertisings** are integrated code parts within apps which display advertisements during operation. Thereby, advertisements do not have an influence on apps' functionality, but might consume energy through 3G or Wi-Fi connection [20]. If advertisements are deleted, programmers might have to change their business model, but the main functionality remains unaffected.

**Binding Resources Too Early** refers to hardware components, such as Wi-Fi and GPS, which are switched on by apps at an early stage when they are not yet needed by the app or user [21].

**Statement Change** describes alternative programming statements, such as `if` and `switch`, which can be substituted with each other, because they have the same functionality, but potential different energy consumptions [22].

**Backlight** refers to the background color of an app. For different screen technologies (e.g. Super LCD and Super AMOLED) the energy consumption can vary for different background colors [23]. Selecting an appropriate background color may decrease the energy consumption.

**Cloud Computing** describes the usage of external services via Internet to execute high energy consuming apps instead of running them on mobile devices. Thus, energy is saved on mobile devices, and it allows further energy optimizations on servers [19].

## 4. Energy Measurement

For the most described energy code smells in Section 3, the three energy measurement techniques (Section 2.2) are applied. The energy code smell *Cloud Computing* is described in another work [19], hence the results are shown there. In Figure 5, the measurement results with and without energy code smells are depicted. In addition, the difference between the energy consumption before and after refactoring is shown. If the difference is negative, the energy consumption rises after refactoring, i.e. the inverse of the energy code smell will save energy. The file-based measurement technique is not available for the Samsung Galaxy S4.

| Energy Code Smell | Measurement with Energy Code Smell | | | Measurement without Energy Code Smell | | | Difference (in %) | | |
|---|---|---|---|---|---|---|---|---|---|
| | File Based | Energy Profiling | Delta-B | File Based | Energy Profiling | Delta-B | File Based | Energy Profiling | Delta-B |
| Third-Party Advertisement "GpsPrint" | 6628 J | 268 J | 6405 J | 5272 J | 300 J | 5144 J | 20.5 | -10.7 | 19.7 |
| Third-Party Advertisement "TreeGenerator" | 5310 J | 308 J | 4814 J | 3681 J | 269 J | 3413 J | 30.7 | 12.7 | 29.1 |
| Binding Resources Too Early | 11903 J | 981 J | 19566 J | 11276 J | 706 J | 16032 J | 5.3 | 28.0 | 18.1 |
| Statement Change | 3965 J | 274 J | 3768 J | 3823 J | 297 J | 3382 J | 3.5 | -7.7 | 10.2 |
| Backlight HTC | 3681 J | 269 J | 3413 J | 3796 J | 272 J | 3768 J | -3.0 | -1.1 | -2.9 |
| Backlight S4 | --- | 26152 J | 10400 J | --- | 19184 J | 4517 J | --- | 26.6 | 56.6 |
| Data Transfer | 4232 J | 289 J | 4064 J | 3864 J | 265 J | 3497 J | 8.6 | 8.3 | 14.0 |

*Figure 5: Energy Measurement Results* [16]

As you can see, the energy profiling has one major problem, which was detected during the validation. After a firmware update, the internal XML files used for realizing the energy profiling was also updated and the measurement results differ from the other two techniques [16]. This indicates that the vendor provides one internal XML file for the latest mobile devices, which are transferred to all devices which get the new firmware; independent on the build-in hardware (e.g. the new internal XML file has more processor states for the same mobile device after updating). Hence, the new power profile is adapted to the old one and the results of the energy consumption are manually calculated. With the adapted profile, the energy consumption for *Third-Party Advertisement* amounts 4461 J before refactoring and 4426 J after refactoring, a difference of 1 %. This small value results from active time of the Wi-Fi component because in both calculations the Wi-Fi is not switched off to execute the application behavior and the different traffic transfer does not have a real influence.

## 5. Conclusion

The definition and validation of energy code smells demonstrate an approach to save energy for mobile devices. All measurement results show that it is reasonable to perform energy refactorings on code to reduce energy consumption on mobile devices. The presented energy code smells are validated for Android apps. However, the definition of the energy code smells can also be applied on other platforms, such as Windows Phone and iOS, but has to respect hardware and operating system specifics. These results show that saving energy by refactoring can support programmers to improve their existing apps and avoid energy code smells during developing new apps.

Next steps could be to extend the reengineering process to parse Windows Phone and iOS apps. Thereupon, the existing energy code smells could be validated for these platforms. Furthermore, hardware based energy measurement techniques could be used to confirm the software based measurement results. These would help to extend and to confirm the energy refactoring catalog in the mobile devices' area.

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# Expansion of Data Center's Energetic Degrees of Freedom to Employ Green Energy Sources

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## Abstract

Rising power consumption of data centers is a topic of great concern and therefore several power saving technologies exist. This paper describes the idea of a data center overall power saving and controlling strategy, allowing the data center to enter optimized minimum power states but also to control its own power consumption to apply demand response management. Therefore, the degrees of freedom a virtualized data center has are modelled and the methodology used to control its energy state is described, taking into account the IT hardware like servers and network gear as well as the influence of cooling devices and power distribution devices. In the paper, we describe our models used for our simulations, the methodology and the power saving potential of our system. We formulate the problem to control the data center's power consumption by applying different consolidation strategies as an extended bin packing optimization problem, where virtual machines must be packed on a specific number of servers. External constraints like the time-flexibility of the solution and the influence on supporting devices are applied by using cost functions. We present a greedy solver for this problem and show first results and the potential of the entire approach.

## 1. Introduction

Information and Communication Technologies (ICT) and especially data centers play a significant role in our today's world. Growing markets as cloud computing and on-demand services fortify this trend. As a result, the power demand of ICT components, including data centers, kept on rising during the last few years. Since the energy costs have also become a major economical factor, power saving and efficiency technologies for data centers have emerged. Among them are technologies like virtualization [1], server consolidation [2], and application load scheduling to times of lower energy prices [3, 4]. A fairly recent trend is to enable the data center to benefit from renewable energy sources [5 - 8], allowing it to operate at full load in times of high availability and cutting its load otherwise. Unfortunately, this methodology needs to alter the running applications, stopping their execution in the worst case or it needs a network of connected data centers in different geographical locations. This approach may be viable for many scenarios; however, often this is not possible. Instead, this paper proposes the idea of expanding the degrees of freedom a data center already has without altering any of its running applications. The goal of the methodology proposed in this paper is to let the data center mostly operate in a minimum energy state; however, to allow demand response management, it should be able to enter a specific energy state, hence be able to control its power consumption. This could, for example, be used to follow an external power profile induced by a Smart Grid. There are also data center internal motivations to control the power consumption of a data center subspace (for example a room or a cage). Especially when load balancing techniques are applied, a data center may have significant diverse power states in different rooms, leading to inefficient global device states or even harming the grid stability. In these cases, the possibility to control the power consumption of a subset of the data center's devices can become necessary. For this, the data center's existing degrees of freedom are identified and expanded to be able to reach a high power consumption variability, while still

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keeping the applications unchanged. A key aspect is the modeling and description of interdependencies between different device categories in data centers. A base technology for the methodology proposed is server virtualization that enables the data center to live-migrate virtual machines (VM) across different physical machines (PM, the terms *physical machine* and *server* in this paper mean the same thing). By using this technology, the migration of running applications encapsulated in VMs to different PMs can be used to intensely influence the server's power consumption, also affecting the amount of cooling and UPS load needed, thus changing the entire power consumption of the data center. Here, very dense states with minimal power consumption are possible, as well as loosely packed states with a higher consumption but also with increased flexibility. The methodology assumes a virtualized data center, where the following operations are allowed as adjustments: 1) VM migrations, 2) server switch-ons, 3) server switch-offs. Each action takes a specific amount of time. In this paper we address the problem of finding a suitable VM allocation on the existing servers to either enter a minimal power state or to enter a state approaching a specific power demand while taking into account possible side effects that may occur in combination with the data center's hardware devices and the time it needs to enter this state. We formulate the problem as an NP-hard extended bin packing problem [9] with a global cost function, where VMs (items) must be allocated to the PMs (bins). This approach is not new [10]; however in the approach presented here it is not always optimal to just minimize the number of active PMs to reach the desired state.

To the best of our knowledge, this is the first approach that researches a methodology that is able to control the data center's power demand using these adjustments while also taking into account interdependencies of the data center's hardware devices. To be able to evaluate the specific load states of a data center in terms of power demand, a data center simulation is presented that models the server's power demand, the efficiency of uninterruptible power supply (UPS) devices, cooling power demands via approximating meta-models and network flows in a sample simulated data center. The rest of this paper is organized as follows: Section 2 lists the related work, in Section 3 the models and architecture of the simulation is described, while Section 4 shows the problem formulation and the methodology used. In Section 5, we present first results and analyze the potential of the approach. We conclude in Section 6 and describe our next steps and further research.

## 2. Related work

The area of research this paper addresses is also focus of other researches. General server power models can be found in [11, 12] while [13] already proposes additional models for racks and cooling units. Energy models for data centers are found in [14, 15]. Our research partly bases on these results. In [5], the authors propose the idea to combine a data center with a local power network that includes renewable energy sources. Such a power network is, however, less complex than a smart grid, since it only consists of power producers. The authors also cover the aspect of the intermittency of these power producers. They propose to shift the work load to other data center locations, each profiting from individual energy advantages. A similar approach is covered in [6], including weather conditions at different locations. [16] proposes a *service request routing* for data centers to distribute the load according to the electric grid in a smart grid. In [7], the authors present the idea of a carbon-aware data center operation. They propose three key ideas to implement this concept: on-site and off-site renewable energies and *Renewable Energy Certificates (REC)*. In our research, the usage of RECs is, however, not a legitimate concept. Modeling of thermal behavior of data center components, especially of servers, has been researched before. In [17], the thermal load of processors and micro controllers is considered. [18] handles thermal predictions of processors and combines it with a Dynamic Voltage and Frequency Scaling (DVFS) technique.

Thermal modeling of a server rack is arranged in [19]. [20] presents a dynamic model for the temperature and cooling demand of server racks that are enclosed in hot aisle containment. The correlation of power consumption and temperature of server internal coolers is investigated in [21]. As a result, the authors state that it is possible to save power under certain conditions, when the Computer Room Air Conditioning (CRAC) adapts itself to a higher temperature level and the server coolers compensate this by applying a higher rotation frequency. They also model the time that cool air needs to travel from CRAC units to a specific server rack. However, a detailed correlation to server load is not handled. [22] handles the planning of VM migrations under consideration of VM interdependencies like communication, security aspects and other SLAs. These are not considered in this paper, since it aims at showing the concept to maximize the degrees of freedom. However, the methodology proposed here can easily be adopted to also support VM interdependencies, if needed.

## 3. Models and simulation architecture

The methodology described in this paper uses a data center simulation that is able to model the power consumption of IT hardware, in this case the PMs, and the supporting devices such as cooling and UPS devices. Figure 1 shows the architecture of the information flow of the models used for the simulation of the hardware devices in the data center. The simulated data center that is used for the evaluations in this paper consists of 960 PMs in 96 racks with 8 UPS devices. The devices are located in two different rooms. For each simulation, the number of VMs is static, meaning there are no VMs coming into the simulation or leaving it.

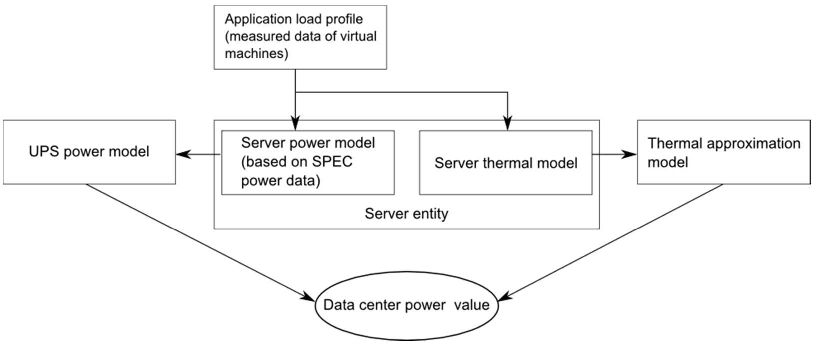


*Figure 1: Model architecture for the simulation of the data center's hardware devices*

The application load profiles of the VMs consist of load measurements of real applications hosted in a mid-sized data center.

***Server models and application load***

The simulated data center consists of heterogeneous server models, the model data is based on the publicly available results of the SPEC power benchmark and on own measurements [11]. The total power consumption of a PM is split into two parts: the minimum static power consumption $P_{st}$ that describes the consumption in idle mode and the dynamic power consumption $P_{dy}$ that is influenced by the utilization of the PM. As an indicator of the utilization, the CPU load is used as the only value; it has already been shown that it has strong correlations with the power consumption [8, 11]. The total power consumption of a PM is given by:

$$P_t = P_{st} + P_{dy}$$

The CPU utilization of a PM is calculated by adding all of the VM's utilizations at each instant of time. Let $n$ be the total number of VMs on a server at an instant of time and $C_{VMi}(t)$ the CPU utilization of the VM $i$, the total CPU utilization $C_{PM}(t)$ of the PM at the time $t$ is calculated as:

$$C_{PM}(t) = \sum_{i=1}^{n} C_{VMi}(t)$$

Our measurements showed that the variability in RAM allocations is very small; hence it is assumed that each VM has a static memory allocation. This value is retrieved by finding the maximum RAM allocation the VM had during the measurement duration. Each PM can operate a maximum number of VMs at each instant of time; this number is limited by the resource usage of each VM. Relevant values are the CPU load $C_{VMi}(t)$ at each time $t$ and the RAM allocation $M_{VMi}$ (as this value is static, is has no reference to time), where these in sum must not exceed the PM's physical resources $C_{PM}$ and $M_{PM}$:

$$\forall\, t\colon\ C_{PM} \geq \sum_{i=1}^{n} C_{VMi}(t)\ \ and\ M_{PM} \geq \sum_{i=1}^{n} M_{VMi}$$

The RAM allocation of VMs forms a hard and static boundary regarding the maximum number of VMs of each PM. Overprovisioning of RAM is not assumed. Finally, the total power consumption of a PM $P_{PM}(t)$ is calculated using the power models published in [8, 11] using the CPU utilization of the PM at the time $t$.

***VM allocation state***

A VM allocation state $A$ defines the power state of each PM (on or off) and for each PM that is powered on the list of VMs hosted on this PM. A state is legal, if all VMs can access the resources they need for their operation at the current time. To cross from one state to another, VMs will be migrated and PMs can be switched on or off respectively.

***UPS models***

The data center simulation uses a basic UPS model scheme that evaluates the efficiency for a specific UPS device. For most UPS, the efficiency increases with rising load. Hence, the UPS should always be operated with the best efficiency factor, for example, at least with 80% load. The methodology proposed in this paper uses the UPS model to find an allocation that leads to an improved UPS efficiency factor, compared to other methodologies that do not consider UPS power consumption. It is assumed that each UPS device has at least a minimum power consumption $P_{Umin}$, even if the devices (servers) attached to it are powered off. It is also assumed that UPS devices are not turned off if unused. Regarding this information, we formulate the following UPS power model that is used for the data center simulation: Let $P_U$ be the total power consumption of all devices the UPS powers (servers) including the UPS device's own consumption and $P_D$ the power consumption of all devices attached to the UPS. The efficiency factor function $i(P_D)$ defines the UPS efficiency at the power load $P_D$. Then $P_U(P_D)$ can be calculated as:

$$P_U(P_D) = \begin{cases} P_{Umin}, & if\ P_D < P_{Umin} \\ P_D + \left(1 - i(P_D)\right) * P_D, & else \end{cases}$$

***Thermal models***

The thermal models needed in this simulation need to evaluate 1) the power consumption of the cooling devices depending on the workload of servers in different data center locations (room, racks, cages) and 2) the time period the air takes to flow from the server outlets to the air-cooling device and the CRAC units need to adapt itself to the new heat situation. The main challenge is to develop fast models, since traditional (and accurate) approaches like computational fluid dynamics (CFD) simulations are too slow for the needs in this simulation. Therefore, a similar methodology as described in [23] is used. It is assumed that the heat produced by the servers $Q$ is equal to the power consumption of these devices so that $Q = P_{servers}$. Based on these models, we define the function $P_{th}(P_{servers})$ that calculates the needed cooling power for a given server power consumption at the time $t$.

***Network topology model***

The network of the simulated data center is modeled as a graph while the used topology is VL2 (see Figure 2). It is assumed that the network connections between the different switch layers have different bandwidth sizes, allowing different amounts of parallel network traffic. In this paper, the network graph is used to determine the amount of live-migrations of VMs that can be performed in parallel. To be able to reach a different VM allocation state, often several migrations will occur; if most of them can be run in parallel, the target allocation state can be reached in less time.

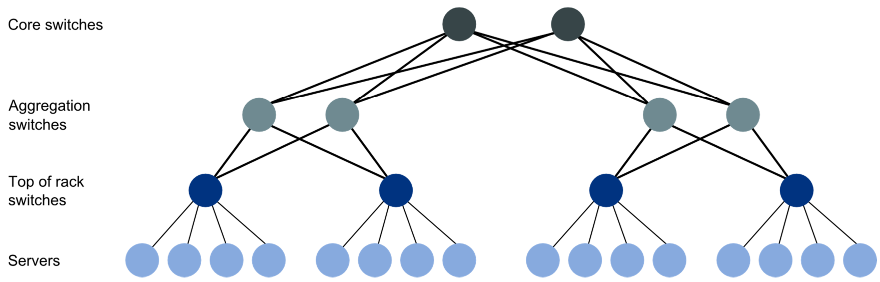


*Figure 2: Network topology (VL2)*

The following rules apply to parallel migrations: 1) Each PM may only be the source or the target of one migration at the same time. 2) Each switch node in the network graph can only handle as much migrations so that the maximum bandwidth is not exceeded for more than 50%. In our model, this ensures that the running applications can still access the network safely; in other network scenarios this value might be changed according to the real conditions. When a new allocation state should be entered or evaluated, our algorithm calculates the needed migrations to cross from the current state to the new state and finds its involved PMs and their network paths respectively. It also evaluates which PMs can be switched off or have to be switched on. It then creates a migration plan where as much parallel migrations as possible are scheduled. Based on this information, the algorithm calculates the amount of steps $s(A_{current}, A_{target})$ that is needed to migrate from the current allocation state $A_{current}$ to the new state $A_{target}$ where each step takes a constant amount of time (defined by the duration of migrations and server switches).

## 4. Problem formulation and methodology

The goal of the presented methodology is to let the data center migrate from a current allocation and power state to another state with a specific power consumption, either a minimal or a given consumption under the consideration of the time it needs to enter the desired state. As stated in the introduction, we formulate the problem as a combinatorial NP-hard multidimensional bin packing problem with a cost function. The classic one dimensional bin packing problem aims to distribute a number of items into a finite number of bins where the optimization goal is to minimize the number of bins used. However, applying this approach to the problem described here may lead to inefficient solutions. If the methodology just minimizes the number of servers, power savings will occur for the IT hardware but not for the supporting devices like UPS and cooling. These may run into significantly inefficient states, destroying the savings achieved by switching off servers. Similarly, if a specific power consumption should be approached, the modifications caused by the reactions of the supporting devices may lead to severe deviations. To eliminate these problems, a new approach is presented that still uses the bin packing representation of the problem; however, instead of trying to minimize the amount of bins used, a cost function is used to rate the effectiveness of the entire solution regarding power consumption and the time needed to reach the new state. The formal definition of the problem is as follows: Given is a set $V = \{v_1, \dots. v_m\}$ of VMs in the data center with resource demand vectors $r_{v1}, r_{v2}, r_{v3}, \dots, r_{vm}$ and a set $S = \{s_1, \dots., s_k\}$ of PMs available with resource capacity vectors of $x_{s1}, x_{s2}, x_{s3}, \dots., x_{sk}$. Find an allocation $A$ of all elements in $V$ to an arbitrary number $\delta$ of elements in $S$ so that for each $s \in S$:

$$\sum_{i=1}^{j} r_{vi} \leq x_s + b$$

where $b$ is a buffer value used to prevent overloading a PM and $j$ is the number of VMs on the PM $s$. The optimization goal is, in contrast to the classic bin packing problem not to minimize the number of used PMs, but instead to maximize the fitness of the allocation $f(A)$. This function evaluates the allocation $A$ in terms of the proximity towards the desired power consumption (minimal or target value); the time it needs to enter this allocation is then considered when a new solution is chosen. The function is presented in detail in the following.

***Fitness function***

To measure the fitness of each allocation, first the total data center power consumption $P_{DC}(t, A)$ under the allocation $A$ is calculated.

$$P_{DC}(A) = P_U\left(\sum_{i=1}^{\delta} P_{PMi}\right) + P_{th}(\sum_{i=1}^{\delta} P_{PMi})$$

Next, the duration in steps to migrate from the data center's current allocation state $A_{current}$ to the solutions state $A_{solution}$ is retrieved using the network graph.

$$d = s(A_{current}, A_{solution})$$

In normal operation state, the methodology tries to let the data center operate in an energy efficient state, hence the optimization goal is to minimize $P_{DC}(A)$. The fitness function is then defined as follows:

$$f(A) = \frac{1}{P_{DC}(A)}$$

If the methodology is used to apply demand response management, target power consumption for the data center is given as $P_{DCtarget}$. In that case, the optimization goal is to minimize the deviance to the given consumption $a$:

$$a = |P_{DCtarget} - P_{DC}|$$

In this case, the fitness function uses $a$ instead of $P_{DC}(A)$.

The second optimization goal is always to minimize the amount of steps $d$ needed to reach the new allocation state, since the new state should always be reached with as few operations as possible. When two allocations are compared, first the fitness value is used and as a second condition the number of steps $d$ is compared, for example if a solution needs a significantly lower amount of steps and the fitness is only marginally worse, this solution is preferred.

The methodology described in this paper works as follows: starting from an initial state in the data center, a first fit decreasing (FFD) algorithm is used to create a first solution. This is densely packed, but as already described not the optimal solution. This solution is used as a starting value for a heuristic search algorithm. The main challenges for this algorithm are 1) the creation of fast and convenient heuristics to evaluate each sub-step on the way to a better solution; 2) apply these heuristics to find neighbor states in the global neighborhood.

## 5. Analysis and potential

We evaluate a sample scenario with the data center described in Section 3. At first, the operation state of the data center is in the initial non-optimized state where each PM is powered on. In this case, the simulated data center had a power consumption of about 145kW. After applying the FFD optimization, which is analog to traditional power saving methodologies only taking the server hardware into account, the power consumption was 78kW (see Figure 3 at point **A**). However, using the algorithm that also accounts for the efficiency factors of the infrastructure devices, the power consumption could be decreased to 66kW, additionally saving about 15% energy. The algorithm's run time for this case was about 2 minutes on an Intel Core i5 (2.5 GHz) computer. At the time point **C**, a demand response request (DRR) is received, the data center enters the given power state and at time point **E**, it goes back to the optimized state (**F**).

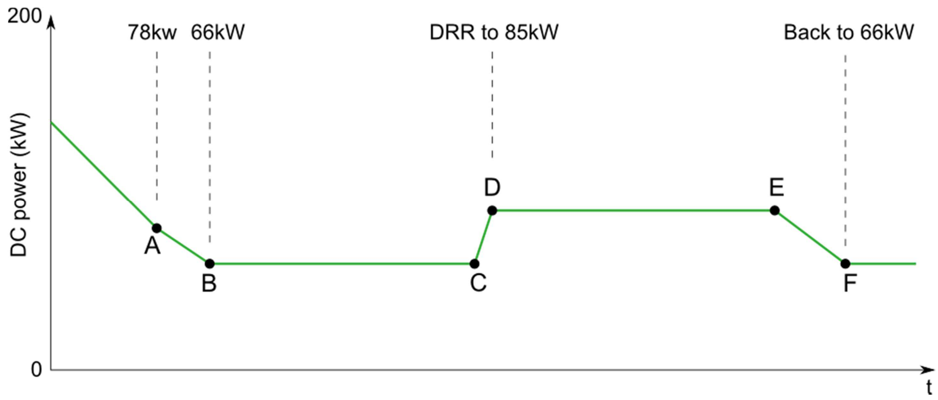


*Figure 3: Schematic view of the results and the potential of the power saving and control strategy using the methodology described in this paper*

The methodology described in this paper is thus not only able to reach additional power savings but also to allow the data center to apply demand response management.

## 6. Conclusion

In this paper, a methodology was described that allows the data center to improve its energy efficiency by taking into account the IT hardware (servers) and the infrastructure devices (UPS, cooling) when finding VM allocations. This approach leads to an additional saving potential of about 15%. The methodology is also able to find fast transitions from the current allocation state to specific power states, enabling the data center to apply demand response management. Our future research will create more detailed thermal models for different cooling strategies (free cooling, chillers, etc.) and an improved method to retrieve optimal parallel migration plans using the network model. We are also working on evolutionary algorithms to find an allocation state near the optimum while still completing in realistic time frames. Since the problem to solve is very complex and it is generally hard to determine the "real" optimum, a competitive analysis is planned for the evaluation of the algorithm. It is also planned to integrate a load forecasting method from [2] into the methodology that is used to predict VM application load, thus allowing the methodology to act proactive.

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# Cloud Computing for Mobile Devices - Reducing Energy Consumption[1] -

Veronika Strokova[2], Sergey Sapegin[3], Andreas Winter[4]


## Abstract

Being powered by the batteries that are limited in their capacity is one of the main restrictions of mobile devices. Further enhancement of their characteristics and mobile Internet mounting speed incite the growth of user's demands. Users request the most sophisticated applications to work rapidly and being available all the time. Thus, availability of mobile devices should not be decreased by inefficient energy consumption.

This paper presents the approach which is able to decrease the power consumption on mobile gadgets. The core idea lies in migrating parts of the application's functionality to remote servers in order to reduce energy consumption on the mobile device. Heavy-loaded code blocks are extracted from mobile apps and transferred to server-side applications. It is expected that, if energy spent on client-server communication is less than power needed to execute the task on phone or tablet; battery life time can be extended on the mobile device. Depending on the amount of data, available internet speed, and cloud computing capabilities, systems performance can also be affected.

Experiments are conducted on migrating three Android applications to the cloud. The paper describes the migration approach, shows changes in energy consumption and demonstrates conditions to be met, when doing energy migrations to the cloud, successfully.


## 1. Introduction and Approach

One of the main restrictions of using mobile devices is their restricted uptime caused by limited battery capacity. Since current battery techniques do not offer means to increase their capacity [8], other strategies to increase the runtime of mobile devices within one battery cycle have to be found. This paper presents an approach to decrease the power consumption on mobile devices by outsourcing parts of an applications' functionality to a remote server in the cloud. Experiments are conducted on three Android applications and show how functionality can be migrated to the cloud, and how this effects systems behavior and energy consumption on the mobile device.

The objectives of this work, which summarizes [12], are to elaborate an approach to migrating parts of mobile applications to the cloud and to define its value from the perspective of saving power on a mobile device. Since further elaborated techniques for optimizing energy consumption in the cloud exist [7], this paper only focusses on the mobile device, mostly aiming at increasing its uptime without further charging the battery.

Applications, suitable for being migrated to the cloud, contain rich functionality in "heavy-loaded" blocks of code, which are responsible for the pivotal functions of the app. But at the same time, these blocks take most of the consumed energy. These may include complicated transformations, calculations, or data processing. The presented approach follows classical software reengineering strategies to improve the applications quality, which here, aim at improving the apps energy consumption. The major reengineering steps include (1) identifying the code to be migrated to the

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cloud, (2) extracting it from the applications code base, (3) moving it to the cloud, and (4) making it available to the app again by remote access. In such a way, when a user runs an application, a part is still executed on the mobile device, but the energy consuming parts run on a remote server, possibly saving energy on the mobile device. If data transfer to and from the cloud eats less energy than saved by doing the calculations externally, the energy consumption on the device will be reduced, which results in an extend battery live phase.

The core idea of the approach is to delegate parts of functionality from mobile devices to the cloud. To state its effectiveness clearly, the following preconditions have to be ensured:

- The energy needed for data transmission from device to a server and for sending results back to the mobile device must be less than the energy consumed for executing the same functionality at the device;
- The apps' code contains some "heavy-loaded" code blocks which can be identified, extracted, and migrated to the cloud, without influencing the application functionality.

Migrating functionality to the cloud will also affect the performance of the app. That is why we consider the time the operations needed to be executed. Heavy data exchange can slow down the application's speed, whereas high performance calculation in the cloud, e.g. by using cluster computer, can also speed up the application.

## 2. Experiments

Migrating functionality to the cloud requires finding the "heavy-loaded" blocks of code. It looks sensible to look for:

- code containing complicated calculations which load the CPU significantly and may take a lot of time,
- methods with a few lightweight parameters, but lots of sophisticated functionality inside. As we will see later, you will not benefit from transferring a huge deal of data over the network sometimes,
- existing asynchronous Tasks. All long running operations, on the one hand, should be implemented as asynchronous tasks; on the other hand, it is beneficial to run them remotely. HTTP communication should be done as asynchronous Task in order not to block the app, as the connection is unpredictable.

Three applications which process data locally on mobile devices were investigated: *Finite-ElementCalculator*, *AsciiCamImage* [3] and *AsciiCamVideo*. The presented experiments were accomplished on a Samsung Galaxy Nexus as test device.

The power is measured with Little Eye [10]. It is a desktop performance analysis tool by Little Eye Labs for Android applications. It measures app's power consumption (separating total amount, CPU, WiFi, and display usage), network data transfer and memory usage. Little Eye also shows the key events happening while the application is going on, such as grabbing and releasing the lock, display going on and off, the current app state, etc. After the measurement is stopped, it is possible to return to any time point and explore what was happening. The great feature is an option of building graphic report which is divided into power, data and memory sections.

Each application was run in three modes: on a device, using the cloud with fast internet connection, and using the cloud and slow internet connection.

*FiniteElementCalculator* performs complex mathematical calculations based on significant but not very large amount of data and uses asynchronous tasks. Due to the absence of platform-specific code and clear modularization of the code, responsible for the required mathematical operations, it was easy to identify and to migrate the calculations to the cloud. The energy consumption was decreased significantly, since only a relatively small amount of data had to be packed into JSON [9] and transmitted over the net.

Table 1 [12] illustrates saving on battery power, CPU resources, and time, while running the application with a server in comparison to the case when only the resources of a mobile device are used (column “Local”) Two different ways of connecting mobile device and server were applied (columns “Fast connection” and “Slow connection”). Cases are the amount of user's tasks to be completed. The volume of outgoing and incoming data is deliberately not summarized in the second and third cases to differentiate between calls to the server.

| | Local | | | Fast connection (D 6-12 Mbps/ U 7,7-12) | | | Slow connection (D 0.9-2.4 Mbps/ U 0,6-0,8) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Battery, % | CPU, % | Time, s | Battery, % | CPU, % | Time, s | Battery, % | CPU, % | Time, s | Data volume (out/in), Mb |
| FiniteElementCalculator | | | | | | | | | | |
| 1 case | | | | | | | | | | 3.2 / 103.34 |
| *Average* | 29.3 | 31.8 | 32.3 | 17.35 | 3.83 | 15.3 | 16.6 | 2.9 | 20.3 | |
| *Standard deviation* | 1.26 | 2.02 | 1.53 | 0.7 | 1.2 | 7.5 | 0.15 | 0.48 | 4.04 | |
| 3 cases | | | | | | | | | | 3.2 + 17.92 + 8.16 / 103.68 + 72.24 + 122.12 |
| *Average* | 30.3 | 36.3 | 123.3 | 16.6 | 3.13 | 52.3 | 16.7 | 2.3 | 72.3 | |
| *Standard deviation* | 0.41 | 0.48 | 4.62 | 0.39 | 0.1 | 3.79 | 0.25 | 0.31 | 9.7 | |
| 5 cases | | | | | | | | | | 1.63 + 3.2 + 3.2 + 17.92 + 8.16 / 111.79 + 103.34 + 103.68 + 72.24 + 122.12 |
| *Average* | 30 | 36.4 | 181.7 | 16.9 | 3.2 | 78.7 | 16.7 | 1.87 | 136.3 | |
| *Standard deviation* | 0.27 | 0.19 | 4.62 | 0.3 | 0.36 | 10.4 | 0.12 | 0.04 | 3.79 | |

*Table 1. FiniteElementCalculator power measurement results*

Figure 1 and 2 illustrate the energy consumption during one of the use cases. The CPU's and total consumption and time decreased dramatically, the network consumption is not significant in this case.

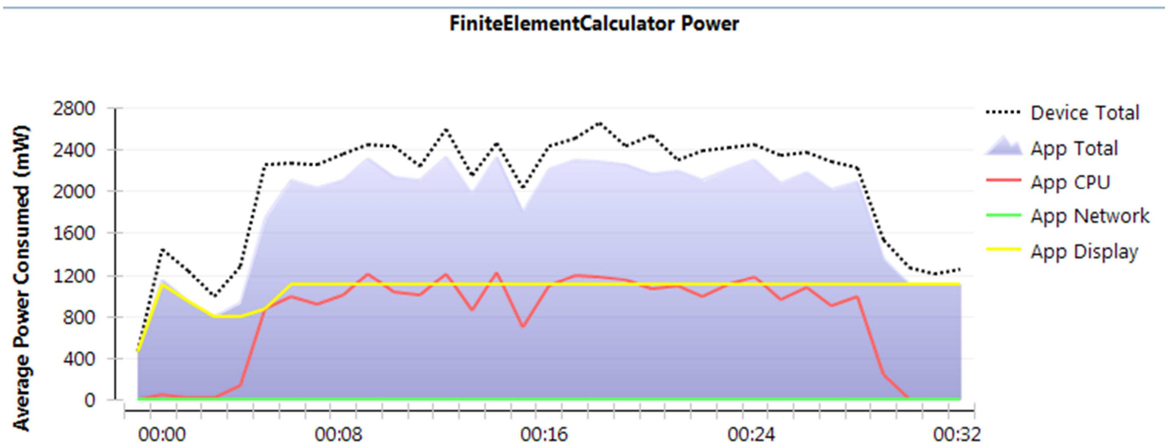



*Figure 1. FiniteElementCalculator power consumption while running on a mobile device*

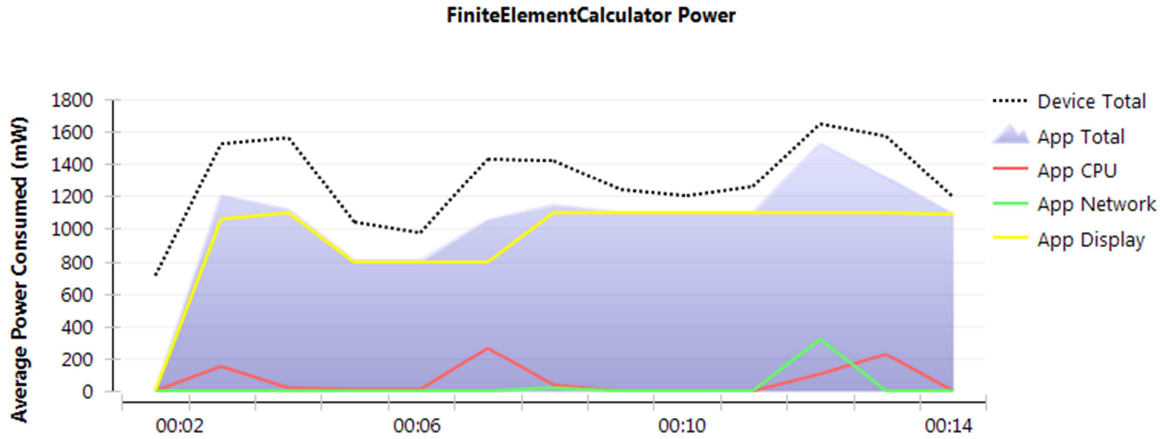



*Figure 2. FiniteElementCalculator power consumption while using the cloud*

The power consumption decrease is gained by CPU loading relief. Figures 3 and 4 show how the CPU usage changed for both activations.

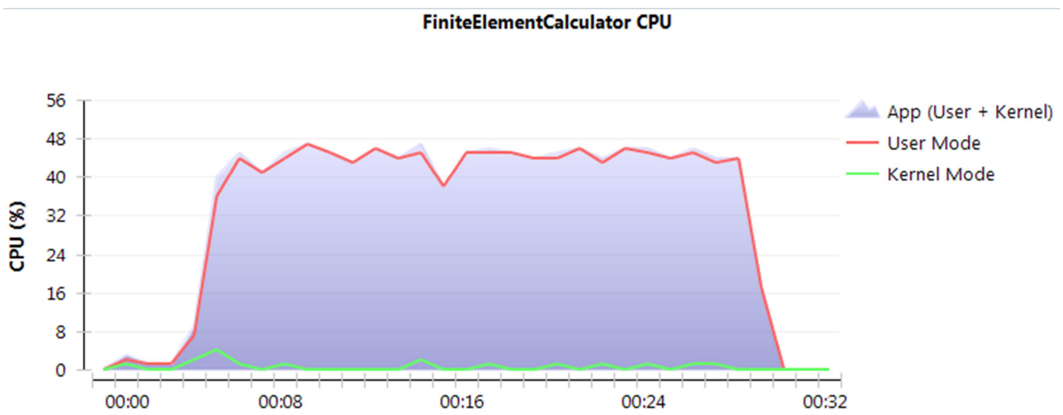



*Figure 3. FiniteElementCalculator CPU load while running on a mobile device*

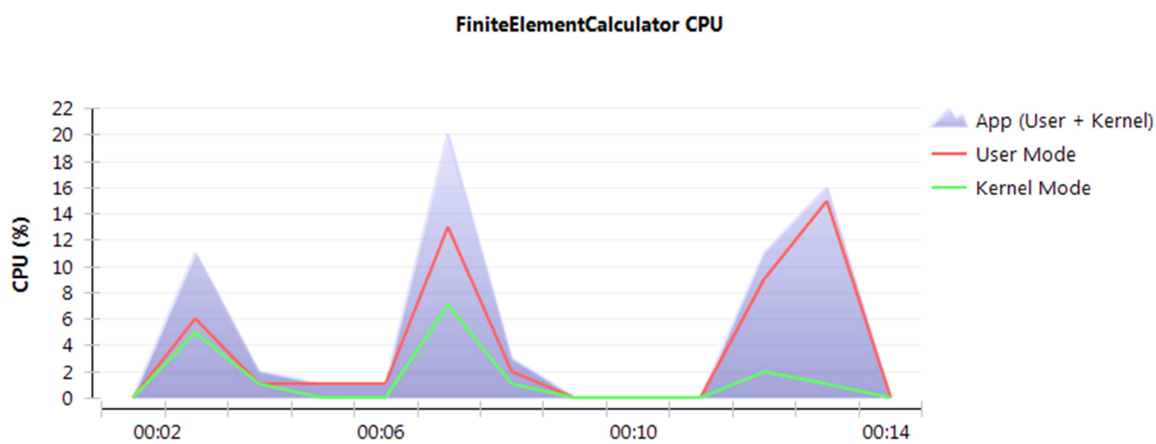
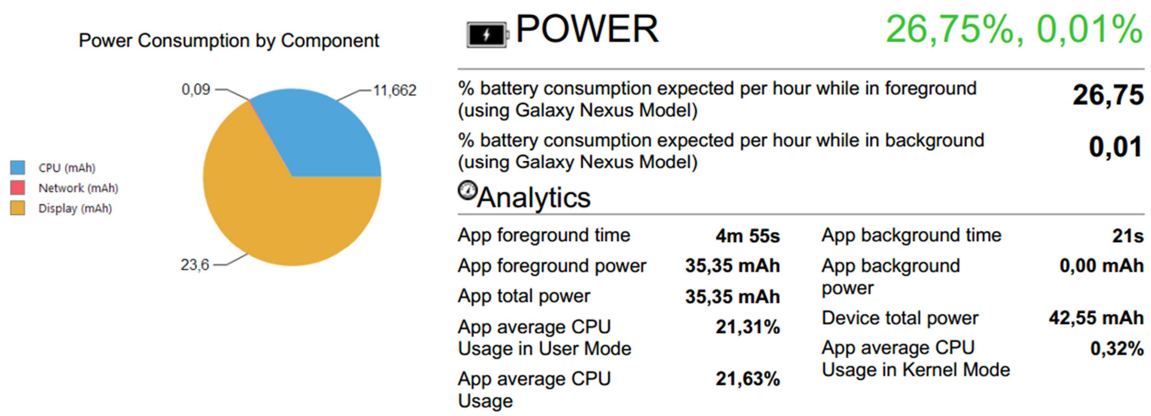
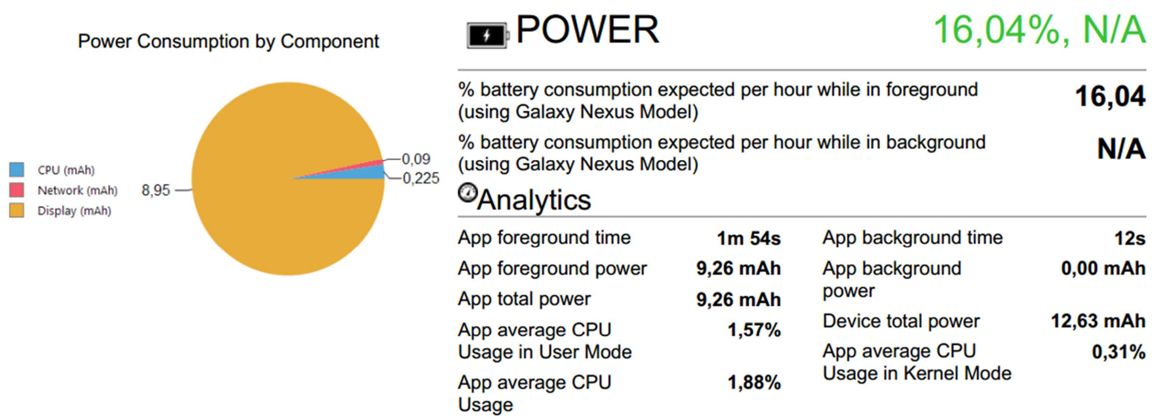



*Figure 4. FiniteElementCalculator CPU load while using the cloud*

The pie diagrams (figure 5-6) display how power consumption has altered. Both runs are based on the same test scenarios.




*Picture 5. FiniteElementCalculator power consumption per component while running on a mobile device*




*Picture 6. FiniteElementCalculator power consumption per component while using the cloud*

It is also shown, that it takes less time to execute the tasks remotely. So in this case, migrating functionality to the cloud not only decreased energy consumption on the mobile device it also decreased calculation speed.

*AsciiCamImage* converts an image into an ASCII picture. The *AsciiCamImage* example has revealed some restrictions on the approach. Migration to the cloud required the adaptation of platform specific libraries. Consequently, the *AsciiCamImage* implementation referred to Dalvik-specific code (that is, the code depending on the Dalvik virtual machine), which had to be adapted to the JavaVM used on the server. Exchanging data with JSON (JavaScript Object Notation) [9] also loaded the CPU more intensively, when large data was to be transferred. In that setting it was not possible to reach the key conditions for reducing energy consumption. Consequently no power was saved (cf. Table 2). Moreover, this experiment also showed that slow connection speed also effectuates an unacceptable performance. The challenges faced while working with this application are summarized in "Lessons learned" section.

The *AsciiCamVideo* application is an extensive modification of AsciiCamImage which converts video files to videos showing the appropriate ASCII pictures: the initial application was improved in order to divide an input video into the frames, process each frame into an ASCII picture, and, finally, build a new video out of these ASCII frames. In contrast to the previously sketched simple AsciiCamImage migration to the cloud, both, energy consumption and performance were improved

| | Local | | | Fast connection (D 6-12 Mbps/ U 7,7-12) | | | Slow connection (D 0.9-2.4 Mbps/ U 0,6-0,8) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Battery, % | CPU, % | Time, s | Battery, % | CPU, % | Time, s | Battery, % | CPU, % | Time, s | Data volume (out/in), Mb |
| **AsciiCam Image** | | | | | | | | | | |
| Heavy image | | | | | | | | | | 5487.25 / 150.86 |
| *Average* | 22.5 | 33 | 32 | 26.3 | 45.4 | 116.8 | | | | |
| *Standard deviation* | 2.54 | 2.74 | 5.39 | 4.18 | 4.37 | 62.95 | | | | |
| Medium image | | | | | | | 13.69 | 18.95 | 800 | 2887.77 / 68.8 |
| *Average* | 18.4 | 29.8 | 26 | 28.1 | 41.9 | 36.7 | | | | |
| *Standard deviation* | 2.94 | 5.2 | 5.29 | 0.51 | 1.08 | 3.79 | | | | |
| Light image | | | | | | | | | | 430.67 / 116.23 |
| *Average* | 18.4 | 25.2 | 17 | 24 | 32.3 | 20.7 | 14.5 | 37 | 230 | |
| *Standard deviation* | 2.94 | 3.03 | 1 | 1.38 | 2.23 | 1.53 | 0.28 | 1.15 | 7.55 | |

*Table 2. AsciiCam Image power measurement results*

when processing video files. The power measurement results (Table 3) show that using the cloud allows to gain more than two times decrease in energy consumption. The reason is that video files are sent to the server as they are, instead of writing and reading JSON. Not using JSON does not load the CPU significantly, and consequently power was saved, although the amount of data is bigger than in the case with pictures.

| | Local | | | Fast connection (D 6-12 Mbps/ U 7,7-12) | | | Slow connection (D 0.9-2.4 Mbps/ U 0,6-0,8) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Battery, % | CPU, % | Time, s | Battery, % | CPU, % | Time, s | Battery, % | CPU, % | Time, s | Data volume (out/in), Mb |
| **AsciiCam Video** | | | | | | | | | | |
| Short video | | | | | | | | | | 2.73 / 30.26 |
| *Average* | 34.8 | 47.7 | 1260 | 16.6 | 38.5 | 224.7 | 16.3 | 40.7 | 809 | |
| *Standard deviation* | 3.2 | 5.3 | 129.62 | 2.75 | 0.79 | 53 | 0.87 | 1.52 | 188 | |

*Table 3. AsciiCam Video power measurement results*

Summarizing, it can be seen, that for all successful experiments on migrating functionality to the cloud, it was possible to reduce energy consumption by 30 - 54% and run time by 25 - 83%.

## 3. Lessons Learned

Before moving the code to the cloud, it's worth to estimate:

- the ratio of time to transmit the data over the network to time needed to process the data on a device. If the first is much longer, probably, it does not make sense to migrate tasks to the cloud;
- the additional CPU load which appears when we want to execute the task remotely (for example, writing data to JSON before sending), as it may be very resource-hungry;
- the CPU load while executing the task on a device. If the CPU speed is low and required time is little, probably there are no benefits when migrate the task to the cloud.

Based on these experiences code should not or cannot be migrated to the cloud towards improving energy consumption:

- if the required changes modify the applications state without returning the new value,
- if the code uses operating system or platform-specific classes and stubs,
- if the code uses native code (that needs to be recompiled or licensed for the server).

As for native code, applications using Android NDK "*will be more complicated, have reduced compatibility, have no access to framework APIs, and be harder to debug*" [13] Using native code does not necessarily result in performance improvements [6] and it may be sensible to refrain from using it.

Acquiring data from the system services such as getting a GPS signal or processing sensor updates is very power hungry, but mostly cannot be managed in the cloud without the device's hardware. However, it is claimed that new sensors introduces with Android 4.4 KitKat are more reserved concerning energy consumption [2]

Energy consumption of applications in cloud can be different, depending of hardware devices and the structure of load of processing resources. But almost all devices in remote datacenters, used for cloud computing, satisfy to Energy Star standard from EPA [14], used for technologies with advanced energy efficiency. Furthermore, moving more functionality to data centers also allows for more energy optimization and better load balancing. Using virtualization techniques and switching of not used (hardware) servers, will decrease energy consumption in data centers (cf. e.g. [7]). Probably, even from a global point of view, energy might be saved, when migrating functionality to the cloud. This requires more in depth analysis, not shown in the small experiments, presented here.

## 4. Related Work

Benefits on remote code execution towards power saving were studied in several works.

Jason Flinn [4] implements local, remote and hybrid applications' execution and shows their effects on energy savings. The author refers to 30% savings when using remote execution. The experiments presented in this study achieves up to 54% reduction.

Miettinen and Nurminen [11] analyze factors affecting energy consumption of mobile clients in cloud computing. They present the measurements about the central characteristics of contemporary mobile devices that define the basic balance between local and remote computing.

Abdelmotalib and Wu [1] explore the energy consumption of mobile devices' components, such as CPU, display, wireless interfaces and others. This information serves as a basis of this work.

Moreover, the presented approach applied reengineering techniques, and provided recommendations for the developers doing the required migrations. Moving functionality from an integrated system to a distributed system using cloud services requires intensive architectural migration activities ensuring the migrations quality. The used migration process (cf. [5]) should consider, clearly identifying code fragments to be migrated, and deciding on the most suited migration strategy leading to measurable energy savings and clear estimations on changes in performance.

## 5. Conclusion

Basing on the experiments of this work, only code

- not modifying the state of the application,
- not using Android-specific resources, such as UI or system services,
- not using platform specific classes and stubs,
- not using native code (or needs to be recompiled for the target server)

could be migrated without additional effort.

The experiments showed that delegating parts of mobile app’s functionality to the cloud can save battery power on mobile devices.

Firstly, applying a migration approach saves energy in many cases. This is achieved by reducing the CPU load, as a device now does not have to compute all the results by itself, but this function is delegated to the cloud. The amount of energy required to send data to and receive it from the server is usually less than the power needed to execute these methods on a device itself. But there can be exceptions. For example, if you have very big data to transfer by JSON strings, then you are probably going to increase the device's CPU load and therefore energy will not be saved. Thus, you should consider adjusting the way to transfer data to its amount and type.

Secondly, each application accomplishes some functionality which requires a lot of resources. These blocks of code can be extracted and ported to the cloud to be executed there. This process is can be divided into some particular steps (described in chapters 3 and 5), but a number of challenges can be faced while doing this. Some code could be closely coupled with the mobile platform, so it may occur to be troublesome to run it on another one. Depending on the quality of the source system, it also can be difficult to identify those code fragments forming a coherent functionality to be extracted and migrated. The example systems investigated here, were clearly structured, so this issue did not rise.

Thirdly, the performance (time) of the app can change. The performance depends on the apps complexity, the amount of data to be exchanged between the device and the server, and the speed of internet connection. That is why you should test your application in order to decide whether the performance variations are acceptable for a user. It may be sensible to provide a timeout to run a task locally if there is no answer from the cloud.

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# A Data Center Simulation Framework Based on an Ontological Foundation

Ammar Memari[1], Jan Vornberger[1], Jorge Marx Gómez[2], Wolfgang Nebel[1]

## Abstract

The IT-for-Green project aims at developing the next generation of Corporate Environmental Management Information Systems (CEMIS). Green IT being one important aspect of this, the IT-for-Green project seeks to support the analysis of a given data center situation and to support the simulation of alternative architectures to find ways to increase energy efficiency. To facilitate this, we develop a data center simulation framework, designed to be part of a larger CEMIS platform. This is achieved through a focus on flexibility, high interoperability and open standards. Flexibility is especially achieved by building the framework on top of an underlying data center ontology. This ontological approach allows us to derive many components of the framework from a single source, maintaining the ability to quickly adapt to future requirements.

## 1. Introduction

Spending on data center infrastructure is projected to surpass $126.2 billion in 2015 [1], and in line with this, energy demand of ICT infrastructure is rising continuously and almost doubling between 2000 and 2006 [2], [3]. While server hardware has generally become more energy-efficient, it has increased even more in performance, resulting in a net increase in energy consumption. This has reached a point where energy costs are now a dominant factor in the total cost of ownership [4].

This development has spurred new research into more energy-efficient data center architectures. One approach in this research is to build some type of model of the data center, which can then be used to quickly iterate on the design and try to optimize both individual components (depending on how fine-grained the model is) as well as the interplay between them. But besides optimizing the architecture, such a model can also be used to get a better understanding of which application workloads are using the most resources. Creating accountability in this way can create a feedback loop that helps to drive efficiency improvements on the software side.

The research we describe in this paper was conducted as part of the IT-for-Green project. This project aims at developing the next generation of Corporate Environmental Management Information Systems (CEMIS) and also addresses aspects of Green IT in its context. For those businesses which operate their own data center, the IT-for-Green project develops tools to help with analyzing their current data center situation and allow simulating the effects of changes and upgrades on the infrastructure to be able to find ways to increase energy efficiency.

In the remainder of this paper we describe a simulation framework that we have designed to meet these goals. The following section will explain the approach we took. Section 3 will then detail the complete simulation framework. We tevaluate the framework in section 4 based on the initial goals.

## 2. Materials and methods

Since our framework is part of a larger CEMIS solution, one of our main design requirements is flexibility and high interoperability. We have therefore taken great care in choosing appropriate

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open standards where applicable and a flexible architecture to facilitate integration with other systems. This also led us to the decision of utilizing an ontology as the foundation of the framework. The main goal here is to have as few hardcoded components in the framework as possible, and derive everything from a single source instead. Evolving the framework is then a matter of updating this source and having the updates propagate through the rest of the system.

An ontology is a capable tool for reaching this goal. We can capture all the components of a data center and their possible interactions in the form of a rich ontology. From this we can then derive many different tools and other representations needed for a complete data center simulation. By choosing a standard ontology format (OWL), we also take our goal of compatibility and interoperability with existing tools and systems into account. Among other things, we derive a toolbox for a graphical editor from such an ontology. This editor can then be used to model an existing data center to prepare for a simulation. One goal here is to provide a reasonably fast and user-friendly way of creating such a model, also taking into account that the user may want to import inventory data from other sources.

Finally, we have decided to target the modeling language Modelica to be used in performing the actual simulation. It is an object-oriented, declarative, and multi-domain modeling language, and by leveraging it we can reuse many existing modeling tools. The next sections will describe each of these steps in more detail and how they tie together to form the full simulation framework.

## 3. Simulation framework

As the previous section already touched on, the workflow of the simulation framework looks as follows: Domain experts create the foundational ontology (we provide an initial attempt at that, but it can be extended further). From that ontology a toolbox for the graphical data center editor is generated. The editor is used by a user of the framework to create a model of a data center he or she wishes to study. This step is supported by both syntactic as well as semantic checks of the model, enabled by the underlying ontology. This model is then converted into a Modelica output using a Modelica component library as an additional input, and then used to run the actual simulations.

### 3.1. Data center ontology

In preparation for designing an ontology for the data center, we studied a number of ontologies which might be relevant in this context. The following is just a brief summary of our results, more details can be found in [5]. We looked at ontologies from three main categories: Top-level ontologies are ones that provide definitions for general-purpose terms, and act as a foundation for more specific domain ontologies [6]. Mid-level ones come directly underneath and are a bit more domain-specific. Low-level ontologies are the domain-specific ones defining terms and relations of a certain narrow domain. For example, [7] have built their low-level “Green IT” domain ontology complying with the mid-level “observation and measurement” ontology of [8], which in turn is built in conformance to the DOLCE foundational ontology [9].

Authors in [9] characterize foundational top-level ontologies to be ones that (1) have a large scope, (2) can be highly reusable in different modeling scenarios, (3) are philosophically and conceptually well-founded, and (4) are semantically transparent and richly axiomatized. Ontologies belonging under the same top-level ontology can be easily integrated; therefore we find it vital not to start from scratch by defining our own top-level terms but to focus on our domain and make sure our work integrates well by keeping its compliance to well-known top-level ontologies.

We selected DOLCE as our top-level ontology to build upon. It is a fairly abstract ontology dealing with basic concepts from a philosophical point of view. It defines four top level categories [9]:

- Endurants are entities which are wholly present at different times. In our case these are things like servers, routers or racks.
- Perdurants are entities that are extended in time and therefore have different parts at different times. The categorization of an entity as endurant or perdurant is often a matter of the desired temporal resolution, as most endurants become perdurants over long enough time spans. In our case perdurants are things like a power failure or a load balancing procedure.
- Abstracts are entities outside time and space, like the number “26”.
- Qualities map particulars to abstracts, such as the temperature on a specific point of a hot aisle is assigned to “26”.

An alternative top-level ontology would be SUMO [6] and to get the best of both worlds, we define mappings to a number of SUMO's concepts. For example:

```
GreenIT#Server             ===    SUMO#Server
GreenIT#Cooling          <-is-a-  SUMO#AirConditioner
GreenIT#ACPowerSource      ===    SUMO#ACPowerSource
GreenIT#Rack             -is-a->  SUMO#ChestOrCabinet
```

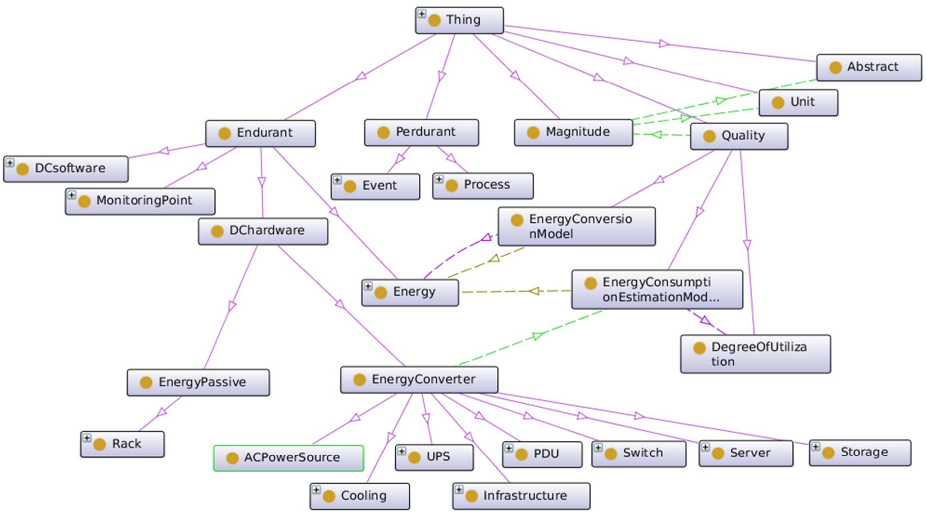


*Figure 1: Data center ontology*

On top of this base layer, important aspects we specify are three abstract flows in the data center: Power flow, heat flow and network traffic flow. All data center elements are looked at from the point of view of their effect on these flows. Therefore elements of the data center are viewed as `HeatSources`, `HeatSinks`, `EnergySources`, `EnergySinks`, and/or `TrafficFilters`. For example, a server is a `HeatSource`, an `EnergySink`, and a `TrafficFilter` whereas an air conditioner is a `HeatSink`, and an `EnergySink`. Figure 1 shows the current state of the ontology as a work in progress that is nevertheless usable for our requirements, as the rest of the simulation framework is derived from it.

### 3.2. Toolbox generation and document template

Based on this ontology, we then generate a toolbox in the next step, which can be used to model a specific data center. The generation of the toolbox is performed with the help of an XSLT file. The goal here is to provide building blocks, which can be assembled in a graphic interface to build a model of the data center. We chose to extend the graphical editor VUE (Visual Understanding Environment, [10]), which is provided with the generated toolbox and enables the user to build the data center model by dragging and dropping the provided components onto a canvas and specifying relevant relations (e.g. heat exchange, electricity exchange). The user does not necessarily have to start from scratch for this task, as it is also possible to import CSV files of data center inventory, which can be used as a starting point to quickly model an existing data center.

### 3.3. Design verification

As the toolbox that was used to build the data center model is based on our initial ontology, we can leverage the ontology again to run a number of consistency checks in the next step. These are both syntactic checks (e.g. every server needs to have a label) as well as more complicated semantic checks. An example for the latter would be the requirements, specified in the ontology, that every server needs to be at the receiving end of a `sendsPowerTo` relation. A semantic reasoner, we chose HermiT [11], is used to verify all these requirements. Any errors that are found are transformed into a visual representation, and presented back to the user for correction.

### 3.4. Operational simulation model

After ending up with an error-free data center design, the workflow goes further into generating an operational model out of the design using again an XSLT transformation. This model is written in Modelica language. To follow best-practices and keep intra-component mathematical models apart from inter-component relations, the model is generated as two linked parts: Modelica package as a library that contains components' mathematical models, and the operational data center design which contains relations between instances of these components, and refers to component models from the former.

Data center Modelica package:

This package contains all component models and serves as a library. It is generated from the metamodel ontology through an XSLT transformation. Object-oriented quality of Modelica is utilized in this package to define generic types of component models, and then parameterize them with training data into final models of concrete components. An example of a generic server model is shown in figure 3. The code defines a server model that relies on a lookup table of load and consumption to predict by regression consumption value for a given load. The lookup table set in this generic model would be assigned values later in the concrete components.

```
block ServerLookup
  Modelica.Blocks.Interfaces.RealInput LoadIn
  Modelica.Blocks.Interfaces.RealOutput EnergyConsumption
  Modelica.Blocks.Tables.CombiTable1Ds lookupTable(table = fill(0.0, 0, 2))
equation
  connect(lookupTable.y[1],EnergyConsumption)
  connect(LoadIn,lookupTable.u)
end ServerLookup;
```

*Figure 2: An excerpt from the DC package showing the definition of a lookup model of a server*

```
block ProLiant_DL360
  extends ServerLookup(lookupTable.table = [0.0,0.001;1.0,35.0;20.0,35.0;50.0,60.0;100.0,90.0]);
end ProLiant_DL360;
```

*Figure 3: An excerpt from the DC package showing the model of a concrete server as an extension of a generic model*

Another generic model of a server could be formulated by measuring its consumption at the idle point where zero load is applied, and then again when it is 100% loaded. Under the assumption that between these points consumption relates to load in a linear fashion, we get a simple model of a server which requires minimal training but provides lower prognosis accuracy.

Concrete component models are defined as extensions of the generic models. Extension is performed in the general case by setting values to certain parameters. For example, the server

`HP_ProLiant_DL360` is modeled using the `ServerLookup` as shown in figure 4. Training data concerning the HP_ProLiant_DL360 is used for setting the lookup table values. Models of concrete components are instantiated in the data center design explained next.

Operational data center design:

This design is a translation of the data center XML design into the Modelica language. It captures, however, only functional properties of components and relations ignoring information about their physical location and layout. Instances of the components are related to their corresponding classes contained in the data center package where all intra-component information resides. Simulation tools that run Modelica models, such as the OpenModelica Shell, are able to run this design and return simulation results. The design can be run with live load measurements as input stream, outputting energy consumption and exhaust heat production at each component and measurement point. It can be run on historical or presumed load data as well with the aim of examining different what-if scenarios.

Hardware profiling:

In building the data center Modelica package we face the challenge, that data sheets for data center components are often not detailed enough to allow for the construction of an accurate simulation model of this component. To address this challenge, we develop tools to quickly profile a given component (i.e. measuring energy consumption in different load situations) and then perform regression analysis to derive an approximate model to be used in Modelica.

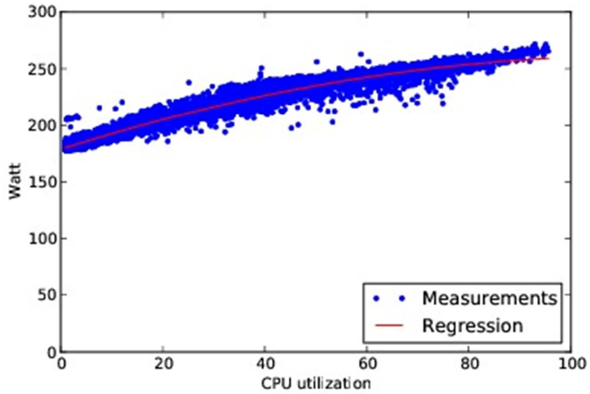


*Figure 4: CPU activity vs active power for a test server*

One major category of components we look at this way contains the servers themselves. They typically exhibit different energy consumption depending on their current work load. A number of researchers have looked at creating energy consumption models for servers [4], [12]–[19]. Some of the simpler models assume that the CPU is the most important factor and postulate a roughly linear relationship between CPU utilization and energy consumption. Authors of [12] have shown that even such a simple model can work fairly well and be within 10% mean accuracy. Of course this works best if indeed the CPU is the biggest consumer of energy. In combination with memory, the CPU did indeed dominate total power in the research done in [13]. An additional beneficial factor for a CPU-only model might be the fact that activities of the CPU seem to be well correlated with the power consumption of the rest of the system, as authors of [14] were able to show. Further successful applications of a simple CPU-based linear model can be seen in [13], [15]–[17].On the other hand, authors of [4] claim that the CPU no longer dominates platform power in modern servers and expect this trend to continue, as processors are adopting more and more energy-efficiency techniques. This is supported by the findings in [18], which reports that power consumption of a server can vary by a factor of two while CPU utilization levels stay constant. Authors of [19] go as far as suggesting that accurate power modeling is only possible if the specific workload running on the server is taking into account and report errors as high as 50% in application-oblivious power models. Because of these different approaches to server models, we have striven to keep the ontology and simulation framework flexible enough to support different kinds of models. At the same time we have implemented a simple CPU-based linear model to be used as a starting point.

Our current approach to profiling servers and other load-sensitive components is therefore to instrumentalize the component temporarily with power measuring equipment and at the same time record the system status (for example CPU utilization) via SNMP. This workflow can fairly easily be carried out inside a production data center, as it requires no software agents on the servers and therefore poses minimal risk to the production work load. On the collected data (see figure 5 for an example) we run regression analysis to build models for the data center Modelica package. For a better accuracy of the models, we try to generate them based on further parameters besides the CPU utilization. The aim of this is to produce the model as the polynomial:

$$P = x_1 * C + x_2 * M + x_3 * I + x_4 * D + x_5$$

Coefficients vector ($x$) of this polynomial is estimated from the measured data by calculating multiple correlation. The method conducted by [20] is widely used in this regard, and is very well supported by the various tools. The approach used for estimating and testing the models starts by loading the measured data as a multi-column matrix containing power consumption ($P$), CPU utilization ($C$), used memory bytes ($M$), IP datagrams sent and received ($I$), and disk read and written bytes ($D$) measurements at specific timestamps. After loading and preparing the matrix, further variables are generated. These include the square of each measured variable so that correlation is calculated later for the squares and not only the linear variables. The next step is to apply the method of [20] to calculate the coefficients then compose the model. Calculated power consumption is then added to the matrix as an extra column, and the difference to the measured consumption is visualized.

## 4. Results and discussion

The sought-after flexibility of the framework is defined in terms of adaptivity to changes in DC hardware components and their interrelations. This attribute is measured by how smoothly these changes are incorporated and streamlined. To discuss this, we propose an example of an emerging technology in DC power supply and study the effect of its incorporation into the framework. The example technology is summarized in using Direct Current (DC) power in the data center instead of the Alternating Current (AC) power [21]. This is motivated by the energy savings that result from avoiding AC to DC and DC to AC conversions at the UPS, at the PDU, and at the front end of the power supply unit (PSU) on servers. Evaluating this trend is out of scope for this article, but we will focus instead on outcomes of its adoption, and ability of the framework to absorb them.

Researchers supporting this idea suggest that one AC to DC conversion takes place at the UPS. All power thereafter is DC power. This would require a new class of UPS that does not convert DC power coming out of its battery back to AC power, but rather delivers it as it is as DC power output. A new class of PDUs for distributing DC power is recommended, and a new PSU class which would result in a new DC server class is required. These new classes of equipment come accompanied with new restrictions on their power inputs and outputs.

Representing the new classes and relations within the framework requires modifying the ontology representing the metamodel. This can be achieved simply by adding an attribute to the `PowerSource` and `PowerSink` classes that determines if the input or output is an AC or a DC.

This attribute is then inherited automatically by all classes related to the aforementioned two through the `is-a` relation. This includes the `Server`, `UPS`, and `PDU` classes among others. Setting its default value to AC releases the designer from the burden of changing its value in existing components. Same attribute is added to the relation `sendsPowerTo`, and then its domain and range are restricted to be `PowerSources` and `PowerSinks` with a complying type of current. New component classes that use DC are then added normally into the ontology with one difference from conventional components that is the value of this attribute. Mathematical models of these new components are inserted as well into the ontology advocating thereby its role as the central metamodel. In a following step they will be automatically extracted from the ontology and collected into the data center Modelica package as mentioned earlier.

This is all it takes for the new components to be fully incorporated into the framework. Changes in the ontology are reflected automatically on the toolbox which will start listing the new components making them available for the designer. Semantic verification would check the domain and range of `sendsPowerTo` relations and detect inconsistencies without any additional effort. Generation of the operational model would translate the verified design including the new components into Modelica code and link them properly to their mathematical models. Flexibility is additionally incarnated in the ability of choosing different mathematical models to represent the same component. This allows seamless update of the component models through the ontology without having to edit the data center design itself.

We define framework interoperability as the ability of the framework to work in conjunction with other systems. This feature is achieved in our case mainly through relying on open standards like XML, OWL, SVG and XSLT which enables interoperability out of the box. Additionally, interoperability is approached by keeping the metamodel ontology aligned with widely-used top-level ontologies like DOLCE [9], and SUMO [6] as mentioned in section 3.1 and detailed in [5]. This alignment allows interoperation on the data level with other systems that utilize these top-level ontologies or their descendants, and the number of such systems is not to be underestimated. For example, ontology alignment allows our framework to seamlessly integrate data collected from monitored data centers around the globe through alignment with the ontology that is created in [7] to serve the purpose of such data curation. This data serve parameterize mathematical models of components with training data as mentioned in section 3.4 without having to go through the training phase. This interoperability on the data level is achieved by aligning the two ontologies, which is a relatively simple task having in mind that both correspond to DOLCE.

## 5. Conclusion

In this article we demonstrated a framework for data center modeling. The framework is composed of an ontology as a metamodel, and a workflow of transformations leading the designer through the design process from the toolbox into a fully operational model. All stages of the design throughout the workflow are governed by and accorded with the metamodel ontology, which was built with interoperability in mind. Additionally, we have included tools for hardware profiling to provide basic component consumption models. The framework was discussed later from the flexibility and interoperability points of view. The studies were based on actual example cases where these features exhibit a high demand. Having a central, interoperable, (re-) usable, and comprehensive metamodel proved useful under these circumstances and conferred flexibility and interoperability on the framework as a whole. Additionally, sticking to open standards in representing the metamodel, transformations, and the different stages of the design grants the framework additional interoperability, prevents a vendor lock-in, and allows a wide array of tools to access and manipulate data and processes.

## 6. Acknowledgement

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# A Master Program on Engineering Energy-Aware Software

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## Abstract

Software-intensive systems support most if not all aspects of modern society and in all industrial sectors. Because of software' pervasiveness and crucial role, its energy consumption and impact on sustainability cannot be neglected anymore. As computing resources are necessary to run software, and as software runs more and more globally (e.g. in data centers and by cloud providers), time has come to engineer *energy-aware software*. This means educating current professionals and future generations with the appropriate skills and competencies.

This paper describes the design of our program in "Software Engineering and Green IT" within our Computer Science curriculum and extending our Master Track in Software Engineering. We also introduce four types of modules that we defined to design our program, and for each type discuss the underlying rationale, learning objectives, risks and related mitigations, with the idea to offer them as building blocks for other educators.

## 1. Introduction

Software-intensive systems support most if not all aspects of modern society. Because of their pervasiveness and crucial role, their energy consumption and their impact on sustainability cannot be neglected anymore. So far modern software engineering implicitly assumes endless resources (like processing power, data storage, network speed, and energy). We know by now that computing resources, indeed, become increasingly more powerful and less expensive. However, the energy necessary to keep them on and available is becoming scarce, and is nowadays a major global problem that all major nations (as well as the European Union) aim at tackling aggressively.

As computing resources are necessary to run software, and as software runs more and more globally (e.g. in data centers and by cloud providers), time has come to engineer *energy-aware software*. This means educating current professionals and future generations with the appropriate skills and competencies. This paper describes the design of our program in "Software Engineering and Green IT" within our Computer Science curriculum.

To start providing these competencies, few professional education programs have been recently emerging worldwide: they are mostly centered on best practices and initial competencies that allow optimizing the use of (hardware) computing resources. Further, in the Netherlands some higher education institutes are starting offering specific programs related to Green IT[2], but most of them are at the Bachelor level (in universities of applied sciences, or Hoogschool), and no one addresses software engineering. With this proposal we offer a Software Engineering (SE) program addressing related Green IT topics, in general, and specifically of developing energy-aware software-intensive systems.

To integrate energy-awareness in our SE program we have adopted a mix of the *distributed approach* and the *centralized approach* identified in [5]. Accordingly, we both revisited pre-existing courses across the whole curriculum (distributed approach), and created few dedicated

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[2] Green IT (Information Technology) is used here in its broad definition, i.e. "The study and practice of designing, manufacturing, using, and disposing of computers, servers, and associated subsystems efficiently and effectively with minimal or no impact on the environment" [8].

specific courses (blended approach). Such mixed approach is quite difficult but is said to bring a greatest impact. To ensure a sustainable implementation of the new program, which will start in academic year 2014/2015, we planned it carefully.

In this paper we describe the program and discuss the rationale, learning objectives, risks and related mitigations for both revisited modules and new ones. We also compare and contrast the program against the ones that already exist. By disseminating our plans we aim at starting a conversation within the community at large on providing higher education in the fields of energy-aware software engineering, and hopefully in creating new opportunities for our students to extend their horizon to collaboration outside the strict world of computer science, and perform their studies in collaboration with other disciplines.

In perspective, this track will open up for future potential inter-disciplinary and multi-disciplinary education: sustainability can be defined along four dimensions, these being environmental-, technical-, social-, and economic sustainability 3]. While software engineering would address technical- and environmental sustainability more centrally (e.g. system qualities like reliability and energy efficiency, respectively), both economic sustainability (e.g. returns on the investments in green software) and social sustainability (e.g. software supporting/influencing more sustainable social behaviors) are very relevant, and have natural links with topics like lifestyle informatics, big data, healthcare, smart cities, transportation (just to mention few).

## 2. Related Work

Green IT and the impact of technology on the environment have gained importance, and attention, in the past years thanks to the commitment of organizations (like Greenpeace) and international agreements of leading nations worldwide. However, while the key role of technology in supporting our society is undisputable, its energy- and sustainability footprint is still unclear, and highly underestimated.

Some reasons contributing to this lack of attention include, in our opinion, the relative young age of IT, the complex relation IT has with all sustainability dimensions of our society, and the intrinsic interdisciplinary nature of green IT. In addition, and sadly enough, greening their IT is never a top priority in the agenda of companies, in spite of the enormous expenditures dedicated to IT with a dramatic, steep increase every year – hence hindering progress towards a more mature sustainable society.

We lack understanding of the areas that can significantly reduce the IT energy- and sustainability footprint, and we lack mechanisms that help us gaining this understanding. To address this issue we need to equip current and future generations with socio-technical skills and competencies to understand the impact of IT on sustainability, and in particular energy efficiency, identify areas for improvements, and develop solutions to realize such improvements.

While the impact of (hardware) technologies on e.g. energy consumption and the whole lifecycle is gaining maturity, hence becoming mainstream in commercial organizations and markets, the impact of software systems and applications is almost neglected and misunderstood at best: many still believe that the impact of software is negligible, or irrelevant, in spite of the fact that computing technologies are developed and deployed with the purpose to run software on top of them; and in spite of the acknowledged exponential growth of data volumes (see big data phenomenon and the uncontrollable increase in number/size of data centres), data traffic, and software components, applications, and systems governing our society.

Industry is slowly acknowledging this lack of competencies, and starts expressing the need for higher education to provide future employees with specialities in various areas related to green IT

[7]. In this respect, we identify two types of needs: *competencies around sustainability* in broad terms and involving multiple disciplines/aspects of an organization (e.g. economically sustainable business processes, sustainable life cycle management); and *competencies around energy efficient IT* (e.g. energy-aware software engineering and resource management, energy efficient computing resources).

The survey presented in [6] surveyed higher education initiatives providing either/both such competencies within green IT (i.e. Greening by IT and Greening of IT, respectively). It identified initiatives in a total of 19 universities, 10 in Europe and 9 outside Europe (5 USA, 3 Australia, 1 Canada). Most consist in individual modules that either focus on green IT specific subjects (e.g. a module on Sustainability) or address green IT related topics within a technical subject (e.g. sustainable business processes within a module on virtual organizations). Among all, only two initiatives emerge: Leeds University is the only one offering a full Master program on Sustainable Computing, and the University of Lorraine is the only one offering a module related to Green Software.

Next to our Master track in SEGIT, another related education program is the professional certificate in Green IT (15 ECTS) offered by the Lucerne University of Applied Sciences and Arts, Switzerland, and specializing ICT professionals in competencies especially relevant to the ICT industrial sector, like energy management, certification, and data centre management.

Taking an orthogonal perspective, the work of Mann et al. [5] defined a framework meant for educators to design modules/programs addressing sustainability. As reported in the Introduction, it also classifies sustainability-focused education approaches in three types (centralized, distributed, and blended). Finally, the work in [11] studied how sustainability can be introduced in pre-existing modules in a variety of programs (among which Computer Sciences).

To summarize, the program we present in this paper seems to provide one among very few programs addressing green IT or sustainability issues, and to our knowledge the only one both adopting a blended approach for its design, and specifically focusing on green software engineering. The next Sections describe the program and discuss the blended characteristics of its modules.

## 3. Program Organization

The Master in Computer Science (mCS) at the VU University Amsterdam is a 2-years Master program yielding a total of 120 ECTS[3]. It offers students with six specialization tracks structured as: a “Master core” (48 ECTS) common to all tracks and including the Master project, module Literature Study and Seminar, and module History of digital cultures; a “Track core” (30 ECTS) of five compulsory modules characterizing the related track; and a set of constrained choice modules and electives that provide necessary background knowledge and advanced subjects, respectively. Among the six specialization tracks, from academic year 2014/2015 the track Software Engineering has been renamed into “Software Engineering and Green IT” and fully revisited to address sustainability aspects of ICT and in particular software energy efficiency. The schedule is organized in such a way that students attend a mix of all module types over the first three semesters, followed by the Master project in the fourth and last semester.

[3] www.vu.nl/nl/studiegids/2014-2015/master/c-d/computer-science/

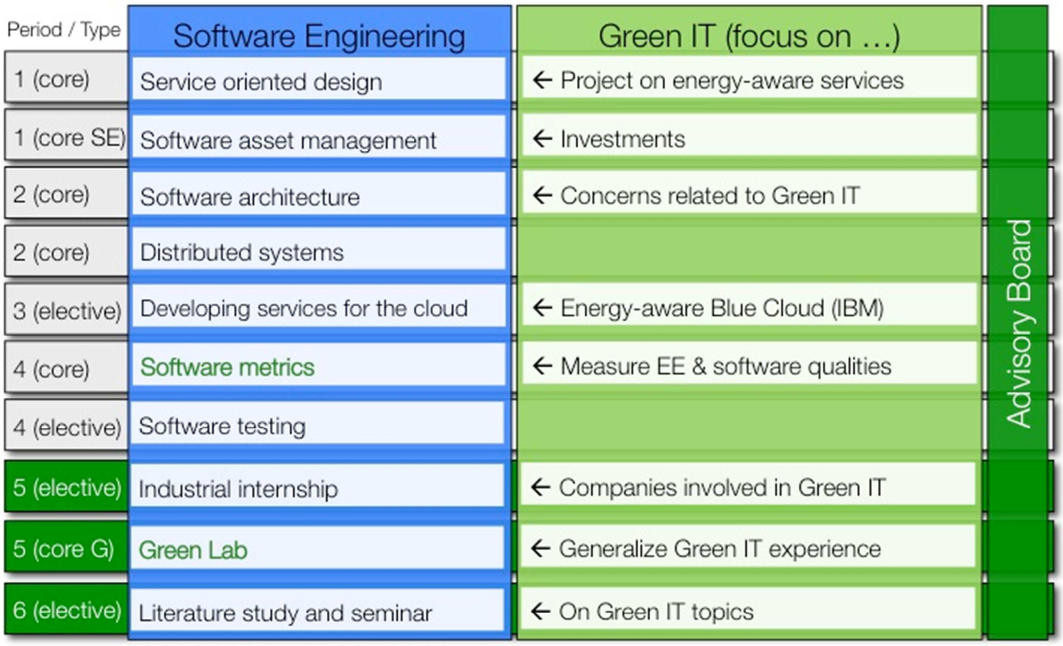


*Figure 1: Overview Program-specific Modules*

Extending the mCS track in Software Engineering and Green IT (SEGIT) has been the result of experience built up by the author over the past 3 years in few modules combined in an incremental implicit shift in focus from traditional software engineering (focused on the socio-technical competencies required to develop large and complex software systems) to the role played by software in our society, and its impact on all four dimensions of sustainability – technical, social, economic, and environmental [3][10]. The result is illustrated in Figure 1, where we show (see first column) the modules that make up the Track core as well as advanced modules that can be selected by the students as electives.

In particular, there are 10 modules (6 ECTS each) that provide the skills and competencies specific to SEGIT. We adopted a blended approach [5] for two modules, Software metrics and Green Lab (written using a green font in the Figure) that have been developed to *provide competencies crucial for green software*. All other modules (written using a black font) were pre-existing but have been revisited to *create awareness* in the students about the role played by software engineering with respect to sustainability (and in particular energy efficiency), according to a distributed approach.

With this education offer, the program aims at targeting the professional ambition of the students to acquire one among two types of specializations:

- A "traditional" Software Engineering specialization is possible even though blended with the awareness about the role and impact of green IT and sustainability in the profession.
- A "green" Software Engineering specialization is introduced with the new modules and with courses that (if this specialization is chosen) will have a specific "green IT" focus.

Such Green IT focus is summarized in Figure 1 by the third column. Further, the last three modules in the Figure (with a green banner as background) offer the students with specific practical training: in collaboration with industry, the students specializing in green software engineering will deepen their theoretical background in green IT (in module Literature study and seminar), will put theory into practice (in module Industrial internship) by carrying out a project at one of our industrial partners active in the field of Green IT, and finally generalize the acquired industrial experience (in module Green Lab) by experimenting with engineering energy-aware software-intensive systems, measuring and/or monitoring their energy consumption, and learning the energy impact of different software engineering practices and design decisions.

Industrial relevance and this attention to practice is emphasized by the introduction of an industrial Advisory Board (see right-hand side of Figure 1), informally already active since years and that will include key companies in the Green IT market, interested to provide research questions from an industrial perspective as well as (Master thesis) internship possibilities, guest lectures, and projects within various modules. We envisage the role of the Advisory Board especially useful for modules Green Lab and Industrial internship.

In our vision, the program presented in this paper will open up for future potential inter-disciplinary and multi-disciplinary education: sustainability can be defined along four dimensions, these being environmental-, technical-, social-, and economic sustainability; while software engineering would address technical- and environmental sustainability more centrally (e.g. system qualities like reliability and energy efficiency, respectively), both economic sustainability (e.g. returns on the investments in green software) and social sustainability (e.g. software supporting/influencing more sustainable social behaviors) are very relevant, and have natural links with topics like lifestyle informatics, big data, healthcare, smart cities, transportation (just to mention few).

## 4. The Building Blocks

This Section synthetizes and explains the type of modules we designed in our program: for each module type, Table 1 illustrates the design characteristics and objectives related to green IT, the potential risks and the way we planned to mitigate them. The specific modules of our program belonging to a certain type are enlisted in the second column. In our vision, these module types can provide some inspiration to educators in pursuing a similar endeavour, and ultimately represents the building blocks underlying an innovative program such as ours.

We identified four model types:

- *Project-based* and *assignment-based modules* both bring in the module active participation and involvement of industry/practice, but at different scales and complexities.
- *Centralized modules* are especially developed to provide skills and competencies on green software engineering, and as such demanded for special attention on how risks around the relative immaturity of the field can be turned into an advantage.
- *Ad-hoc modules* include pre-existing modules that did not undergo specific changes but in the focus, which can be topics within “traditional” or “green” software engineering (depending on the specialization followed by the student).

## 5. Conclusion

In this paper we present the design of our CS Master specialization track in “Software Engineering and Green IT, and introduce four types of modules (project-based, assignment-based, centralized and ad-hoc) that we defined to design our program: for each type we illustrate the underlying rationale, learning objectives, risks and related mitigations, with the idea to offer them as building blocks for other educators.

| **Module type** | **Program-specific modules** | **Design characteristics** | **Objectives**[4] | **Risks** | **Risk mitigation** |
|---|---|---|---|---|---|
| Project-based | Service oriented design, Software architecture, Developing services for the cloud, | 1. A *practical project* is carried out in teamwork to put theory into practice.<br>2. An *industrial partner* proposes the project and acts as customer / project owner.<br>3. The *project is common* for all attending students.<br>4. The project entails module-specific *technical topics* augmented with relevant *green IT topics*. | 1. Experience *hands on* the impact of green IT in practice.<br>2. Experience the innovative character of green IT topics in industrial practice; create awareness and motivate the students.<br>3. –<br>4. The students *not* specializing in Green Software Engineering become aware of the impact of software and IT on the relevant sustainability issues. | Not all educators have (sufficient) expertise in green IT. | Involvement of industry specialized in green IT topics for the company's business provides experts that help educators understand the implications for software engineering.<br>In addition, the involvement of practitioners motivates further the students by illustrating the relevance of the program for their future carrier. |
| Assignment-based | Software asset management | *(Design characteristics resemble those of Project-based modules, with the difference that assignments are of smaller size and complexity than a project)*<br><br>1. A subset of the assignments address/cover topics related to green IT. | 1. (Same as objective #4 in Project-based modules) | (Same as above) | (Same as above) |
| Centralized | Software metrics, Green Lab | 1. The module is design to explicitly address the needs of practice in relevant green IT topics. E.g. module Software metrics allows building sound metrics as well as measure the impact of software on sustainability-related aspects.<br>2. The module builds upon establish traditional software engineering theory (e.g. metrics of software systems' properties like complexity or performance, or theories for empirical experimentation) and adds novel theory specific for green software engineering (e.g. energy efficiency metrics, or experimentation practices especially conceived for green software) | 1. Acquire new competencies especially needed in practice to introduce sustainable innovation.<br>2. Extend software engineering competencies with green IT specific ones, so that new professional profiles are created for the relevant industry sectors. | Education material (specific for green software engineering) is still subject to ongoing, pioneering research, hence immature and subject to continuous revision. | • By following the education philosophy of *Community of learners* [1], our students are actively involved in research. This way this risk is turned into opportunity, and research challenges for our students.<br>• Also, students can contribute to this emerging research with more and larger scale experimental results; attract further interest from industry.<br>• Modules of this type are especially designed for |

[4] Here we highlight only the objectives that are specific for Green Software Engineering, or that have a specific relevance for Green Software Engineering.

| | | | | | |
|---|---|---|---|---|---|
| | | | | | active student research involvement. |
| Ad-hoc | Industrial internship, Literature study and seminar | 1. The module is the same for students specializing in either traditional- or green software engineering; the difference is in the selected subject.<br>2. The students acquire *advanced knowledge* in specific SEGIT topics of interest.<br>3. The students acquire *hands-on experience* in industry. | 1. –<br>2. Feed the personal passion for a SEGIT topic; shape an own professional profile in related to Green Software Engineering.<br>3. Learn the state of the practice in organizations that are active in the field of green IT or that want to introduce innovation towards some sustainability objectives. | (These modules are long established, no specific risks are identified) | – |

*Table 1: Analysis of underlying program design*

While some modules have been informally revisited over the years to focus on green IT topics, the track will start officially in academic year 2014/2015. Key organizations from various industry sectors already expressed eager interest to sponsor the program and participate in various related practical education activities.

While our past research investments have been dedicated to create a sound scientific basis of theories and knowledge to transfer to our students (e.g. [2][4][9]), we expect industrial involvement to further accelerate knowledge creation and learning, especially needed in such a novel higher education program. In our future work we will monitor the development of competencies and the dissemination and adoption of knowledge from and to practice.

## Acknowledgments

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# Adaptive computing and server virtualization in German data centers - Potentials for increasing energy efficiency today and in 2020

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## Abstract

Adaptive computing solutions can significantly contribute to saving energy and other resources in data centers. Examples of such solutions include load and power management of servers, adapting air conditioning to dynamic loads, and dynamic distribution of computing loads to various data centers. Several solutions of this kind were developed and their potentials for saving energy and other resources were calculated in the project Adaptive Computing for Green Data Centers (AC4DC).

Server virtualization is the fundamental prerequisite for using adaptive computing technologies. Therefore, this contribution focuses first on the extent to which server virtualization is used in data centers and calculates both the current figure and the development through 2020. The calculations are based esp. on market research surveys, surveys of data centers, and a Delphi survey, which generated data for calculating possible energy savings through the use of adaptive computing technologies.

## 1. Introduction

Adaptive computing promises high potentials for improving energy efficiency in data centers, but the opportunities for using it depend strongly on the extent to which server virtualization is used today and in the future. Unfortunately, cross-company studies that permit conclusions about the average usage of server virtualization are few. Previous studies on virtualization and energy efficiency focus mainly either on the advantages of virtualization for individual companies [e.g., 1-4] or the share of companies using various kinds of virtualization [e.g., 5]. Hardly any data on the numbers of physical servers in Germany or other countries on which virtual systems are installed or the average numbers of virtual machines (VMs) running on a physical host are available to date. The few studies and statements on this topic by analysts and market research institutions such as Gartner, IDC, or Techconsult [e.g., 6-8] usually refer to the current situation and look only at the near future (two to three years), if at all.

This paper first presents the research questions and the methods employed to answer them (chapter 2) and then the potentials for savings provided by adaptive computing solutions. Of the solutions developed in AC4DC, this contribution focuses on two technologies promising major energy savings: dynamic load and power management of servers and comprehensive HVAC (heating, ventilation and air conditioning) control algorithms (chapter 3). Scenarios for the future development of server virtualization from which the energy savings potentials of adaptive computing solutions in 2020 can be derived are presented in chapter 4. Savings potentials will be calculated for a selected reference data center and estimated for the totality of data centers in Germany (chapter 5). A brief discussion of the results concludes this contribution (chapter 6).

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## 2. Research questions and methods

The following research questions will be studied, using Germany as an example:

- To what extent is server virtualization used in German data centers today? How large is the total number of VMs? What is the proportion of physical hosts running VMs?
- How can the usage of virtualization be expected to develop through 2020?
- What are the implications of the increasing usage of virtualization for the potentials of adaptive computing to achieve energy savings?

The results of previously conducted surveys, statements by analysts, and data generated by the market research institutions EITO/IDC [7] and Techconsult [8] on the number of physical hosts and the prevalence of virtual systems in Germany provided the basis for answering these questions. The Borderstep Institute purchased these data from the market research institutions. Unfortunately, the contractual arrangements do not permit publication of the data, so this contribution can only provide figures derived from the original data.

In addition, statements with regard to the importance of server virtualization in data centers of various sizes were derived using a structural data center model for Germany developed at the Borderstep Institute.

A Delphi survey among IT manufacturers, data center operators, trade association representatives, firms offering total system-based solutions, and IT analysts was conducted in the spring of 2014 in order to estimate the future development of server virtualization through 2020. The selection of interviewees is very important concerning the quality of the results of Delphi surveys. Interviewing a large number of respondents does not necessary lead to a better result [9], and limiting the number of experts surveyed to a small number of carefully selected specialists regarding very detailed aspects of future developments [e.g., 10-12] has proven advisable. We surveyed eight experts, including four leading manufacturers of IT hardware (servers, storage, network technology), two IT executives in major data centers, one analyst, and one trade association representative.

An online tool was used for the two-round expert survey. The results of the first round were anonymized and presented to the experts at the beginning of the second round. The overall results of the survey were discussed with the AC4DC project partners, some of the respondents, and additional experts at a workshop on 17 June 2014.

## 3. Potentials for savings provided by adaptive computing solutions

### 3.1. Load and power management of servers

The proactive load and power management (LPM) for servers and services that was developed in AC4DC adapts the number of active servers to the actual resource needs of the services at any point in time [13]. This requires that the servers are operated in a virtualized environment and that the services are encapsulated in VMs. Live migration, a technique that enables uninterrupted shifting of VM between servers, permits dynamic management of the services and consolidation of entire servers.

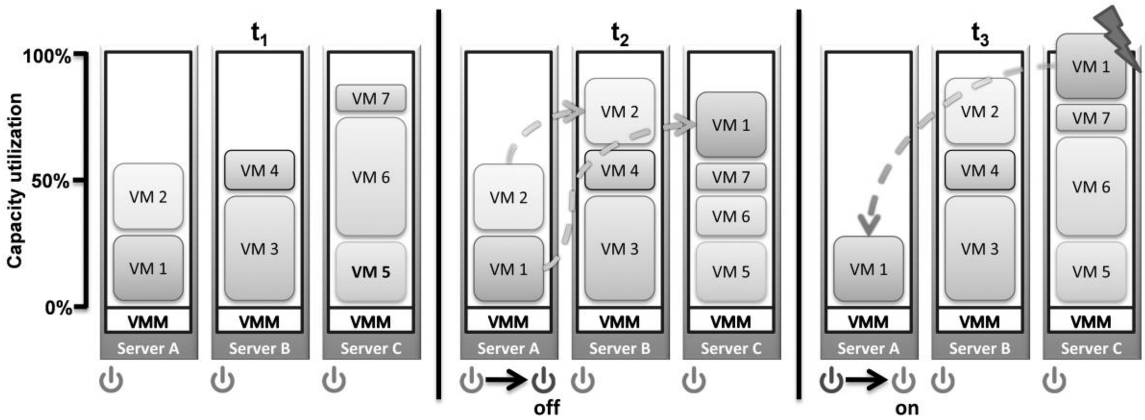


*Figure 1: The principle of dynamic load shifting to save energy in virtualized environments [Offis]*

Figure 1 shows the principle approach using the example of an environment with three servers. If sufficient server capacity is available (t2), servers can be consolidated by migrating the VM of one server to other servers. Then, the idle server is deactivated. As idle servers still require a certain amount of their maximum power consumption (20% to more than 50%), this approach can save a lot of energy [14]. But LPM must also react if resource needs increase, as shown for t3. Since booting a server and migrating VMs takes time, proactive measures are essential to avoid bottlenecks. Therefore, LPM uses predictions of the services' resource needs.

The application of LPM was compared with a static, pessimistic distribution of the VMs using simulations, resulting in savings potentials of 30% to 55% of the server hardware's energy needs. The maximum savings potential was achieved even if the number of VMs was as low as approx. 100. Measurements in a test environment – consisting of 8 blade servers running 62 virtual machines – confirmed the results of the simulations. Here, energy consumption for operating the server was roughly halved.

### 3.2. Comprehensive HVAC control algorithm

One adaptive computing solution pertaining to data center infrastructure is a comprehensive HVAC control algorithm. The solution was developed by AC4DC project partner Rittal and is to be incorporated in the manufacturer's future products.

Climate control in data centers involves equipment for generating, transporting, and distributing cold. So far, the components in such a cold chain have been regulated individually, with an operating point selected for each one. This local optimization approach disregards the interrelationships within the system. The comprehensive HVAC control algorithm succeeds in regulating the entire system so that the data center reaches an optimal operating point and operating costs are minimized.

The solution was tested in a data center. Controllable load banks simulate the server load with typical load curves. Cold air is taken in and heated, and warm air is blown out at the back. All components and monitoring points were recorded by data center infrastructure management software (DCIM). Figure 2 shows the improvement of Power Usage Effectiveness[4] (PUE) compared with a configuration without a comprehensive HVAC control algorithm. Although the basic configuration, with a PUE between 1.13 and 1.27, is already a very good climate control solution, the solution with the comprehensive HVAC control algorithm was significantly better, in

[4] PUE is a measure of the efficiency of data center infrastructure, indicating the ratio between energy use of the entire data center and the IT hardware's energy use. The closer the PUE value is to 1, the more efficient the data center's infrastructure. By definition, the PUE is always greater than 1.

particular when the load was low. If the basic configuration is not as good, the comprehensive HVAC control algorithm can improve PUE by 0.2 to 0.3. Overall, this technology permits data centers to cut power consumption by 15 to 20%.

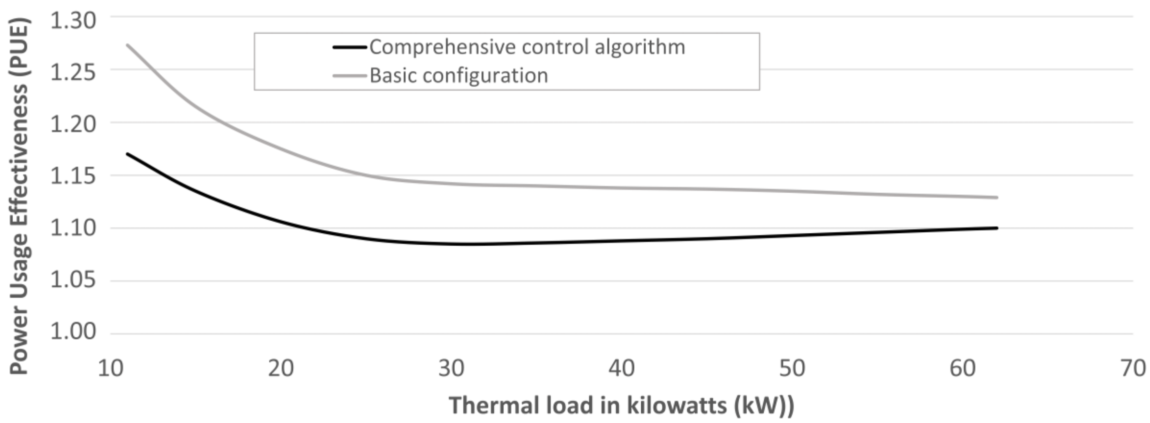


*Figure 2: Improvement of Power Usage Effectiveness (PUE) by means of a comprehensive HVAC control algorithm [Representation by Borderstep on the basis of measurements by Rittal]*

## 4. Scenarios for the future development of server virtualization

### 4.1. Goals and substance of the scenarios

In this section, the potential development of the extent of server virtualization in German data centers through 2020 is presented on the basis of various scenarios. A baseline scenario (trend scenario) and two scenarios based on the results of the Delphi survey were developed. The three scenarios assume the same development of the economy and the underlying conditions for Germany as a data center location.

The difference between the scenarios is the number of VMs in 2020 and the number of physical systems required for them. Even if the various possible developments also may affect the data centers' network and storage infrastructures, this is not taken into account.

### 4.2. Use of server virtualization in German data centers in 2014

Various indicators can be used to describe the extent of virtualization. The data center model with various categories of data center sizes developed at the Borderstep Institute uses the following indicators:

- The number of physical servers in 2020 ($n_{phy\ Systems,i}$)
- The percentage of physical servers running virtual systems ($p_{virt,i}$)
- The average number of virtual servers per physical host on which systems are virtualized ($\rho_{virt,i}$)
  (given in each case for the data center category i)

These indicators are also the relevant factors for developing the scenarios and serve to calculate the total number of virtual systems ($n_{virt}$). It results from the formula:

$$n_{virt} = \sum_{i=1}^{n} n_{phy\ Systems,i} * p_{virt,i} * \rho_{virt,i} \quad (1)$$

The number of virtual systems and the indicators mentioned above can be used to calculate the degree of virtualization. It is defined as the quotient of virtual systems divided by the total number of systems (virtual systems + non-virtualized physical servers) and is given in percent. In cases of complete virtualization, the degree of virtualization is 100%.

The indicators are subject to considerable uncertainties even for the present. In the following, we show the results of the analyses conducted in the project AC4DC. A Monte Carlo analysis was conducted as a final step to determine the magnitude of the uncertainties.

The number of physical servers in Germany was calculated on the basis of the sales figures for physical servers gathered by market research companies such as Gartner, IDC, or Techconsult. The figures presented by the various institutes differ – in part significantly – because of different survey methods, among other things. According to Techconsult, for example, the number of servers sold in Germany in 2013 is more than 30% higher than the figures given by EITO/IDC. The Borderstep Institute has been calculating the number of servers installed in Germany on the basis of Techconsult figures every year since 2009. For 2013, the number of servers installed in data centers was 1.6 million [15]. An additional approx. 700,000 servers are operated as standalone servers outside of data centers, so a total of 2.3 million physical servers can be assumed.

Various studies by Gartner, IDC, and Veeam provide information for determining the percentage of physical systems running VMs. Gartner assumes that 14.3% of the newly purchased x86 servers in 2012 are virtualized and expects the percentage to rise to 21.3% in 2016 [5]. IDC assumes higher numbers and states that 33% of the x86 servers purchased new in 2013 are virtual systems. Their share was to have been just 30% in 2012 [16]. A 2011 survey of larger data centers by Veeam [17] determined that VMs are running on approx. 18% of the physical systems. Taking into account that the number of virtualized servers is smaller for x86 systems than for other ones (Unix/mainframe), it is safe to assume that VMs are running on an average of approx. 25% of the physical systems in German data centers in 2014. The degree of virtualization varies between data centers of different sizes. Up to 35% of the physical servers in the two medium data center categories (100 to 5,000 physical servers) run VMs. In the smaller locations, the percentages can be significantly lower (10 to 15% for average server closets). In large data centers with more than 5,000 servers, the fraction of virtualized physical hosts is approx. 25%. One reason for this is that 45% of large data centers in Germany are colocation data centers with many different customers. A significantly lower fraction of virtualized servers is to be assumed for standalone servers. Calculations based on the Techconsult data [8] show that the number of physical hosts is approx. 5% for standalone servers.

Hardly any information is available to date regarding the average number of virtual systems per physical host. Although 20 or more VMs per physical x86 host are technically possible without problems, the average figure seems to be significantly lower in practice. Veeam calculated a figure of 6.3 VMs per physical host in 2011. An average of approx. 7 VMs per physical host is assumed for 2014.

On the basis of these estimates, the number of VMs in Germany was calculated to be 3.045 million. This number is slightly lower than the approx. 3.1 million VMs in 2014 assumed by Techconsult [8] (see Figure 3). In other words, the number of VMs is clearly larger than the number of physical servers today. This corresponds to the statements made by Gartner's analysts, who assume that approx. 2/3 of the server load of x86 servers are virtualized [18].

The Monte Carlo analysis conducted in AC4DC showed that, with a probability of 95%, the number of VMs in Germany in 2014 is between 2.5 and 3.6 million.

## 4.3. Baseline scenario

The baseline scenario is based on the current use of server virtualization and an extrapolation of the development of previous years into the future. The baseline scenario includes in particular the figures and prognoses by Techconsult [8] and EITO/IDC [7] for server sales and the number of virtual systems in Germany through 2015.

According to the baseline scenario, the number of VMs in Germany will continue to increase at a constant rate. Both Techconsult and EITO/IDC assume slightly increasing server sales in Germany in the coming years. That is why the baseline scenario assumes that the number of physical servers will also continue to increase slightly (Figure 3). The average number of virtual systems per virtualized physical host will continue to rise slightly and will be approx. 8 in 2020. The share of physical systems in data centers that are virtualized is approx. 30%. This amounts to a degree of virtualization of 74% in 2020.

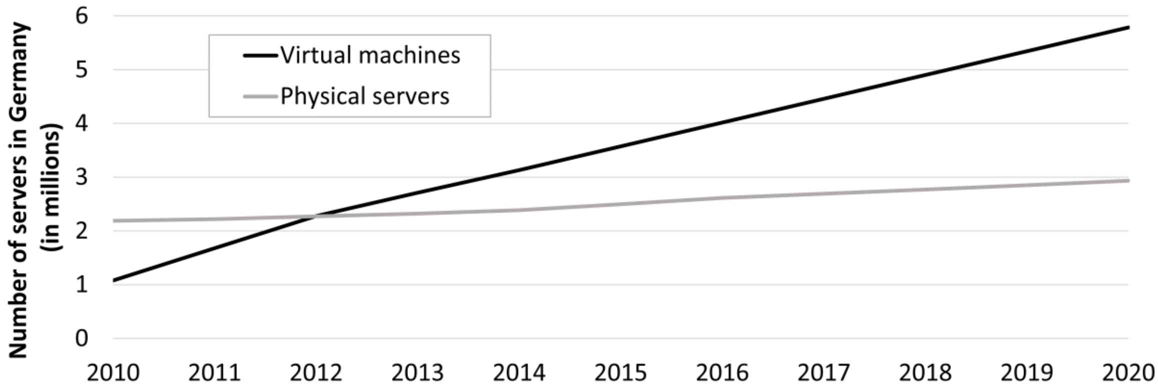


*Figure 3: Development of the number of servers (physical servers and VMs) in Germany through 2020 in the baseline scenario (Borderstep – calculations based on Techconsult)*

### 4.4. Alternative scenarios

The analysis of the results of the Delphi survey showed that the experts assume significantly higher rates of virtualization in 2020 than described in the baseline scenario. This applies both to the average number of VMs per physical host and the percentage of the systems that are virtualized (Figure 4).

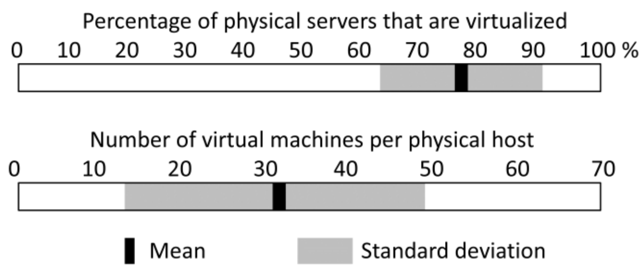


*Figure 4: Results of the Delphi survey (Borderstep)*

It is known that technology experts interviewed in Delphi surveys often tend to overestimate the development of technology. This was also discussed in the expert workshop and accepted as plausible. Two scenarios were developed on the basis of these deliberations and the results of the Delphi surveys: the scenario “Virtualization as the standard technology – scenario A,” which assumes comprehensive server virtualization in 2020, and the scenario “Accelerated virtualization – scenario B,” which assumes significant acceleration of the trend developments toward virtualization (Table 1).

| Scenario | Number of VMs in data centers | Number of physical servers in data centers | Percentage of virtualized physical servers | VMs per hypervisor | Degree of virtualization |
|---|---|---|---|---|---|
| Virtualization as the standard technology (A) | 25.6 million | 0.8 million | 80% | 40 | 99% |
| Accelerated virtualization (B) | 12 million | 1.6 million | 50% | 15 | 94% |

*Table 1: Scenarios for increased usage of virtualization in 2020 (Borderstep)*

Scenario A assumes a distinct decline in the number of physical servers in Germany, dropping to half their number compared with 2014. The number of VMs, in contrast, will be more than four times as large as in the baseline scenario in 2020. Scenario B, in which the number of physical servers remains constant at the 2014 level, also sees the number of VMs increasing sharply, to twice the number in the baseline scenario.

## 5. Energy savings potentials of adaptive computing solutions in 2020

The energy savings potentials of the adaptive computing technologies calculated in the AC4DC project are presented in this section. They are based on the results of the analysis of the scenarios on the development of server virtualization and differentiated between the level of data centers and the level of the German economy.

As demonstrated in section 3.1, LPM enables energy savings of up to 50% in the server systems even today. Taking into account, however, that VMs are running on only approx. 25% of physical servers in average data centers and that storage systems and network technology also consume electricity, significantly smaller savings potentials of 6 to 11% emerge, depending on the type and size of the data center. Further power savings of a similar magnitude can be achieved by the comprehensive HVAC control algorithm. An average medium-sized data center (approx. 1,000 physical servers) can cut its energy usage by approx. 25% by using the technologies mentioned.

The potential savings increase with increasing usage of virtualization. According to the baseline scenario, the potential savings in an average medium-sized data center in 2020 are approx. 30 %, in scenario B 35%, and in scenario A up to 45%.

The electricity consumption of servers and data centers in Germany was just under 10 terawatt-hours (TWh) in 2013, and it will continue to increase slightly through 2020. This already takes into account that adaptive computing will be used to a certain extent. Necessary basic technologies such as live migration or distributed power management are already available today. The comprehensive HVAC control algorithm developed in AC4DC will be marketed by project partner Rittal.

The scenarios reflecting increased usage of virtualization, compared with the baseline, result in dual energy savings potentials, which were calculated in AC4DC. Virtualization saves energy because fewer physical servers are needed. The potential savings this can achieve amount to 0.8 TWh for scenario B and 3 TWh for scenario A. Adaptive computing can achieve additional energy savings of 1.6 TWh (scenario B) or 1.7 TWh (scenario A) in Germany.

## 6. Discussion

The results concerning the development of server virtualization presented in this contribution show two things very clearly. Firstly, the extent of server virtualization through 2020 is unclear even among experts. Regarding the number of VMs in 2020, the scenarios, all of which describe plausible possible future developments, differ by a factor of four. The number of physical servers in 2020 also depends on the extent of virtualization. Here, developments ranging from a continuing slight increase in the number of systems to a 50% drop are plausible. Secondly, the contribution shows clearly that server virtualization has the potential to save energy and other resources directly. In addition, adaptive computing (which requires server virtualization) has enormous savings potentials of roughly 20 to 40%.

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# Geo-referenced Imaging and Co-simulation for Continuous Monitoring of Built Environment

Peter Kohlhepp, Jens Buchgeister[1]

## Abstract

The building sector, accounting for roughly one third of total energy use in OECD countries, provides huge and well-known potentials for energy savings which may be reached technically by highly efficient insulation systems and HVAC systems. Assessing and optimizing the energy performance in practice, however, needs a holistic approach covering the entire life cycle and focusing on the interactions within the building and between its natural and urban environments. An integral planning process requires information technology support based above all on the building information model (BIM) and building performance simulation models.

This paper describes a new technology for verifying the performance of existing buildings by continued design simulation in the use phase. Infrared thermography localized in six degrees of freedom with concurrent numerical simulation is proposed for parameter calibration. In this way, the model keeps track of the current building condition. Forward simulation and inverse parameter estimation together provide for the quantitative interpretation of thermal images which is lacking in building thermography today. Preliminary simulation examples will motivate the approach.

## 1. Introduction

Sparing use of energy resources or high energy efficiency (EE) is not an end in itself but a means for a building to impart productivity and utility to its occupants while reducing the carbon footprint. Quantitative performance metrics can assess how well it meets that purpose. Assistance by simulation tools during design is customary at least for commercial and public buildings (schools, hospitals, offices). Figure 1 illustrates the design and use phases in the building lifecycle, advocating *continuous* performance assessment [8] to test actual performance against the design baselines and to explain and understand deviations. The term 'building sector' is used as a synonym for all economic activities in the building lifecycle, with an emphasis here on occupancy.

### 1.1. Building Lifecycle

While lifecycle analysis proper covers all pre-chains and post-chains (fabricating components, providing end energy, demolition, and recycling), this paper focuses on the design and use phases.

The design work proper can be divided into conceptual, preliminary, and final design [15]. In the design phase already are *interdependent* and often *conflicting decisions* made. Consequently, a globally optimal combination is difficult to obtain. Early design choices such as orienting the building, roughly shaping its envelope and roof, composing the façade and glazing, assigning room shapes and sizes, designing principal air flows and paths of daylight have the greatest impact on the overall EE, and curtail options that are available later on. These decisions are long-lasting and hardly change and, as they shape the building character and its visual appearance, they are made by architects. Later on in the design, engineering choices of heating, ventilation, and air-conditioning systems (HVAC), building services and materials will follow.

The use phase comprises the construction completed by initial commissioning and the occupancy phase proper. Discrepancies may be detected between design intents and details of the current

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building construction, between statistical and actual occupancy schedules or between predicted and actual modes of HVAC operation, possibly due to prevailing weather conditions. Efforts known as *continuous commissioning* are being made to adjust and optimize building operation [9, 11]. In the course of a building life, the envelope condition degrades and diverges from specifications, causing reduced airtightness, traces of moisture, compaction of insulation material, delamination, heat-structure interactions, or UV fading of coatings [12]. Rash and possibly inadvertent changes in HVAC control settings or unnoticed component failure may jeopardize the energy-saving or commissioning benefits achieved in the past. Informed decision-making is needed for planning retrofits, to balance benefits, costs, and impairments to tenants. The *building stock* will not benefit from major formalized design efforts anyway, but contribute much to the actual energy performance in the building sector.

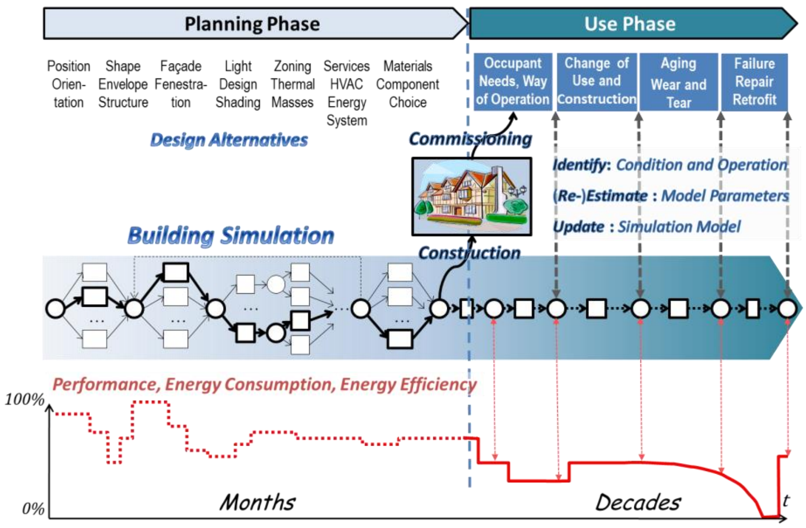


*Figure 1: Towards lifelong performance simulation, adapted from* [7]

## 1.2. Tools and Deficiencies

While simple tools perform demand calculations under stationary conditions, e.g. according to DIN V 18599, in terms of heating, cooling, air, and daylight, whole-building performance simulators (BPS) also predict transient building response under realistic load and assess components in their unique building context using comprehensive criteria. There is empirical evidence of BPS indeed resulting in a significant reduction of the emission of greenhouse gases and substantially improving comfort levels [5]. Yet simulation is put aside in the use phase because calibration and validation are admittedly difficult and under-determined, and the high effort hardly pays off [15].

Monitoring, taking regular measurements of mostly energy consumption is performed for an operational rating during continuous commissioning [11] but casts a narrow perspective on performance and provides little *diagnostic* value. Complementary diagnostic aids, such as building thermography for damage inspection, require human expertise for interpretation. Often, the precise measurement context (environment) is lacking, and so are the quantitative impact and significance of findings. There are few exceptions, e.g. Asdrubali et al. [2] who presented a quantitative evaluation method for thermal bridges in buildings under steady-state conditions by calculating temperature differences between the zone air and the inner walls weighted by area. Specialized procedures for non-destructive testing (NDT), e.g. Active Thermography or ‘Lock-in- Thermography’, provide deeper insight by estimating quantitative parameters of an operational component model characterizing a defect or damage. However, they focus on *components*, only.

The new concept of *quantitative geo-referenced thermography* (QGT) aims at preserving the advantages of qualitative thermography for fast, non-intrusive thermal mapping. Using geo-referenced (mobile) IR camera images to estimate energy-related model parameters extends the NDT principle to cover *whole buildings*. Inspecting in-situ (indoor and outdoor) under natural weather and occupant influences greatly generalize the context of a part fixed in a mock-up and subjected to sinusoidal heating. Of course, relaxing the NDT assumptions goes at the expense of higher disturbances and inaccuracies (section 4). By predicting the impact of estimated parameter values on overall performance, BPS is integrated into the use phase of the building life cycle.

## 2. Whole-building Performance Simulation

Building simulators accept as raw input time series of building load (local weather data, occupancy, and user actions / commands) and produce time series of the energy supply required (fuels, electricity) and the zone temperatures. From these, the performance measures are calculated (figure 2).

Significant results are obtained by statistical aggregation. First, a probability density function (pdf) of load curves (e.g. Markov processes of typical weather at the building site) is specified. Next, the simulator is fed with random samples from the load pdf, preferably in a way covering the probability space evenly and efficiently, to collect performance values. Finally, the frequency distribution of performance is accumulated and moments (mean, variance, and extremes) are extracted.

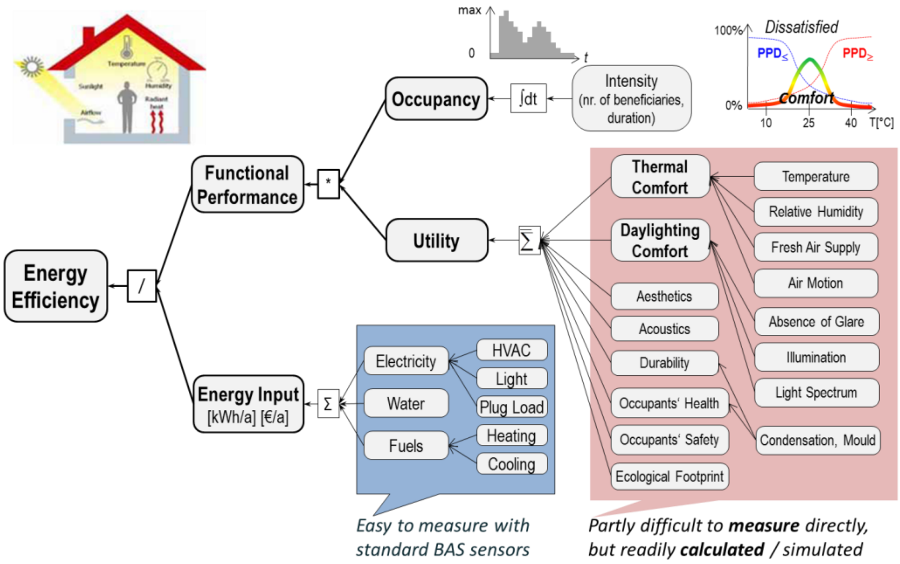


*Figure 2: Building performance criteria and calculation, adapted from [7]*

One advantage of simulating existing building is its ability to calculate complex performance criteria that cannot be measured directly by sensors. These criteria serve as a yardstick throughout the lifecycle. For instance, thermal comfort is readily calculated from the percentage of people dissatisfied, ascertained once and in a standardized fashion (e.g. by the Fanger metric, see Figure 2).

Model solution complexity ranges from stationary heat balance equations (demand calculations) to transient thermodynamic solutions of ordinary differential equations (ODE) to computational fluid dynamics solving partial differential equations (PDE) for transport of air and moisture.

A web site maintained by the U.S. Department of Energy (Building Energy Software Tools Directory, DOE 2011) provides a long list of available BPS tools and vendors. A survey by Crawley et al. [3] updated since 2005 as a live document compares the capabilities of twenty major BPS in terms of practitioners' needs. Most BPS programs evolved as standalone packages (e.g. EnergyPlus, ESP-r, TRNSYS, IES-VE), while others rest upon numerical frameworks or simulation languages (such as HamLab on Matlab / Simulink, or Modelica). The second class better supports component-based development and creation of novel interfaces for mobile sensors. Another aspect important to our project is interoperability between BPS and BIM (using IFC, gbXML or CityGML as exchange standards). This goal may be operationalized by automatic export of geometry and material for simulation [4]. Alternatively, BPS may run inside an integrated BIM runtime environment; see [7, 13].

## 3. Concept and Architecture

This paper focuses on IR thermography as the main sensor for condition estimation. Figure 3 provides a survey of sensor and software components and data flows between them. Before applying thermography, the building model should be pre-calibrated to reasonably predict the *actual building's energy use* [7] recorded by heat quantity meters.

Which parameters can be estimated typically? There are, for example, thermal conductivities and capacities of composite slabs, façades, and insulation material; thermo-optical properties of glazing (reflectance, transmittance, and absorbance); air exchange rates of zones and openings; effective thermal resistance and operating coefficients such as load or utilization factors of HVAC facilities. Built-in sensors such as flow meters may be combined with mobile remote sensor measurements.

The primary purpose of estimation is detecting *deviations* of actual parameter values from design expectations (documentation versus reality) or values drifting by operational wear. Estimation via an *inverse model* maximizes the likelihood of measurements given their prediction as a function of parameters. Predictions are based on the *numerical* (iterative, temporally evolving) *solution* of the governing equations; an *analytical* one is not available in closed form, in general. The final goal is to quantitatively assess how the estimated parameter changes impact the performance indicators.

The following key assumptions must be met:

- Parameters must be *observable* from the thermal building response (an image sequence). I.e., the system will respond differently for different parameter values under otherwise identical conditions.
- *Camera position* and *orientation* must be determined in six degrees of freedom for each image or must be continuously tracked to generate corresponding predictions.
- *Initial* and *boundary* values as well as the *load* acting on the building during inspection must be *measured* and be *imposed on* the model execution. Furthermore, the *model bias*, i.e., the discrepancy between modelled and real building, must be identified independently [7].

The *building information model* (BIM, shaded in gray in fig. 3) forms the backbone of the model and a starting point for the dynamic state equations. It determines the paths of heat transfer (conduction, convection, and radiation) and the flows of air and moisture through geometry and topology (shapes, sizes, and relationships). The building materials attached specify the dynamic thermophysical properties of heat and mass transfer. Graphically, the BIM represents the part hierarchy of the entire building, possibly embedded in its neighborhood, as a 3-D scene graph. The BIM serves as the main link between the simulator predicting the behavior by solving the state equations and the *inspection system* localizing itself with respect to the coordinate frame of the BIM.

The core simulation model consists of an ODE system of purely thermal state components (state $\mathbf{T}$ in fig. 3) and may be assumed to be linear and time-invariant (LTI) in simple cases. System matrix coefficients are functions of the parameters $\mathbf{p}$ changing at a slower rate than states (e.g., specified by an aging function). Parameters may be state-dependent on their part; e.g., conductivity is temperature-dependent, making the ODE time-dependent and nonlinear. Parameters change also in discrete events during the building lifetime when components break down or are replaced. PDE of fluid dynamics combining heat, air mass, velocity, and moisture content become 'ODE' after spatial discretization.

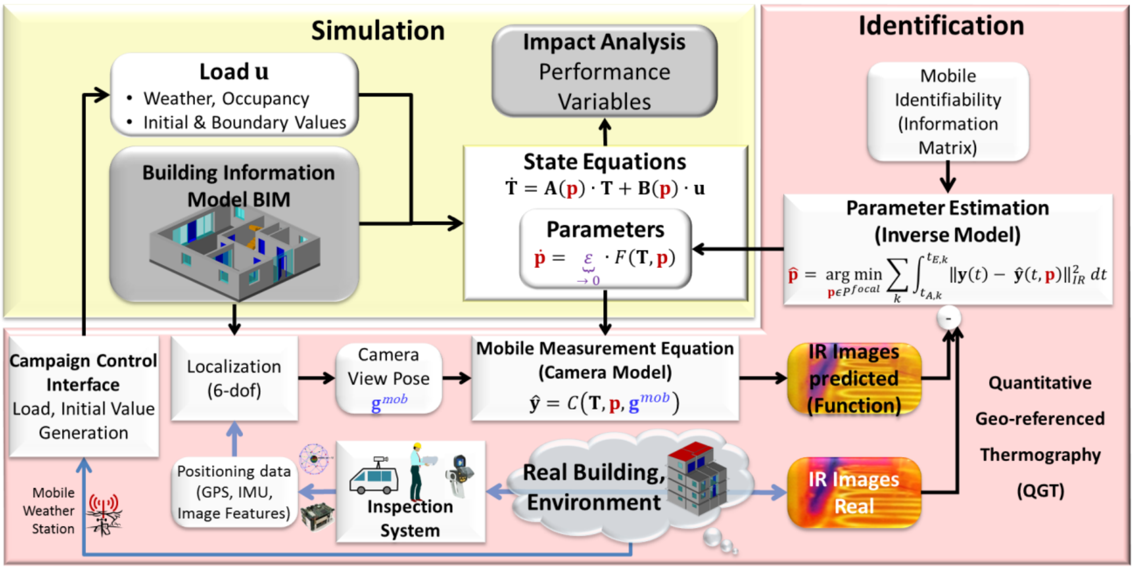


*Figure 3: Data flow diagram of quantitative geo-referenced thermography (QGT) identifying the building condition. Directed arrows symbolize the flow of information between data repositories and processing instances. Real-world sensor measurements are shown by blue arrows.*

The inspection and localization system consists of a mobile IR camera (hand-held or mounted on a vehicle) and auxiliary sensors and software to estimate its position and orientation.

For prediction, the camera view pose (coordinate frame) acts as an 'index' into the BIM scene graph to find the components that the IR camera should 'see', i.e. from which it receives thermal radiation directly or by reflection. The simulation model is queried for the thermal state values of these components at the time of image capture. Disturbing radiation from the sun or the night sky and reflections from background objects are present, depending on the viewing geometry, and are accounted for. An essential part of prediction is the IR camera model [1] converting thermal radiance into a virtual IR image according to the detector's spectral response function. However, not a rendered image but its *explicit functional dependency* on the *parameters* is the main purpose of all calculations, yielding a *mobile measurement* or *error function*.

The inverse model attempts to estimate only few parameters at a time as free variables, the ones associated with parts seen in the camera field of view, in order to make estimation 'less underdetermined' [7]. Several different images in space and time may be combined in one error function; the final function shape appears at inspection time, only. Main tasks of the inverse model for a maximum-likelihood problem statement are to calculate the Fisher information matrix expressing how sensitive measurements are to parameters, to minimize the error (nonlinear regression) including regularization terms, and to estimate the uncertainty (covariance) of the minimizing parameters by assuming a known uncertainty of the imaging process.

Unlike continuous estimation e.g. by means of an Extended Kalman Filter, QGT identification takes place in *discrete* inspection *campaigns*. The building state at campaign start must be measured to set up the simulation with correct initial and boundary values. Quickly changing weather data, e.g. solar radiation and wind speed, and occupant actions such as entering or leaving, opening windows, and changing HVAC settings, should be *recorded* during a campaign, *translated*, and *imposed* on the co-simulation. These are the sometimes complex tasks of campaign control.

With a well-designed and detailed model and identical starting values, the parameter values explaining the thermal images best reveal some aspects of the true building condition. The scope of a parameter may be an entire zone, e.g. the infiltration rate, or a small region, such as a thermal bridge or a moist patch on a wall with locally deviating heat capacity or conductivity. The information gained is the difference from prior values or other parts. Impact analysis has to translate this into a difference in global performance, like expected energy cost per year or loss in thermal comfort. Therefore, the forward simulation model is run and compared under large sets of identical building loads outnumbering by far the load conditions during inspection and identification.

## 4. Scientific Challenges

This concept gives rise to serious scientific questions for which we have no final answers yet:

*Localization*: GPS and compass based positioning known from mobile city guides (smart phone app) does not work reliably indoors, and its orientation accuracy is limited. In contrast, efficient and inexpensive *range* cameras like *MS Kinect* may be overcharged outdoors or in large buildings due to their short range. Geo-referenced thermography (without thermodynamic co-simulation) was implemented and analyzed by Stilla and Hoegner [14] with two IR cameras mounted on a street vehicle. They applied GPS for coarse absolute localization and feature matching for fine registration using a 3-D CityGML street map of an urban district. Registration results served to map the thermal images onto building surfaces. One problem of thermal images for localization is the disparity of features: Thermal edges in IR images versus geometric edges in CityGML models. A localization system for *ThermoTracer TH 7800* including a stereo camera and vehicle sensors (GPS, inertial measurement unit, compass) was recently designed in a diploma's thesis [10].

*Error Function*: As an executable function, its coefficients depend on the *iterative solution* code, the *simulation time*, and the *camera view pose*. Differentiating the error function at run-time may require symbolic processing and automatic differentiation. Though the state vector components 'viewed' by the camera are found efficiently by GPU (graphical processing unit) rendering, the corresponding finite-volume elements may disagree with the original design geometry referred to as the BIM and assumed as scene graph. Transformations and refinements, e.g. due to gridding algorithms, are opaque to simulation users and to external tools. Identification with mobile cameras and co-simulation therefore requires novel interfaces providing deep access to the simulator code. Most building simulation packages are not prepared for this. These challenges persist notwithstanding the formulation of the error function as a deterministic prediction or Bayesian likelihood (pdf).

*Observability*: Active thermography for non-destructive testing utilizes a *periodic* heating source and admits identification methods in the *frequency* domain. In QGT, image responses contain many frequencies apart from the typical diurnal and weekly cycles. Furthermore, the errors by far exceed the ones encountered in NDT applications, as discussed in [7], section 4.2. Identification therefore needs methods in the time domain or fully Bayesian inversion. Two error sources dominate: Firstly, inaccurate capture of starting values and input trajectories acting on the building, and secondly, model bias or mismatch or discrepancy, see Kennedy and O'Hagan's seminal paper [6]. Model bias lets the estimation abuse parameters as 'tuners' or 'tweaks' rather than indicators of the true equipment condition unless the bias is identified separately from the correct parameter values.

## 5. Preliminary Examples

A simple transient simulation of a single-zone cuboid building (thermal-only, in Matlab) was performed to answer basic questions: Are different operating conditions (thermo-physical parameters) distinguished by the thermal responses of the building? The building has a flat roof, a massive adiabatic floor slab, a large south-exposed window, and a heating and cooling control algorithm. Walls and ceilings are composed of different materials. The weather interface accounts for internal solar gains. A stochastic weather generator for a climate similar to Karlsruhe was invoked for 10 days in winter with identically repeated trials. The following thermo-physical building conditions represented by parameters are clearly observable from the curves and can be quantified:

1. Rate of infiltration / natural ventilation
2. HVAC: Thermal resistance of the heat exchange between zone air and circulating fluid
3. Envelope heat coefficients (conductivity and diffusivity of slabs / façade)
4. Thermo-optical window performance parameters (transmittance of glazing, shading Y/N?).

A few examples are shown in figure 4. Due to the coarse model, the potential of thermography measuring spatially highly resolved temperature fields has not yet been traded on; one average value per building slab and zone air is insufficient, in general, to detect and explain deficiencies.

## 6. Concluding Remarks

Cautious readers may notice that building simulation is just one application example – perhaps not the most rewarding one - of remote identification of *transport models* using mobile camera networks. This evolving computational discipline opens up many applications, for example:

- Efficient remote validation / calibration of urban climate or energy simulation models;
- Efficient condition-based maintenance of petrochemical plants or district heat infrastructure;
- Remote identification of process plants after an accident or disaster causing destruction of built-in sensors.

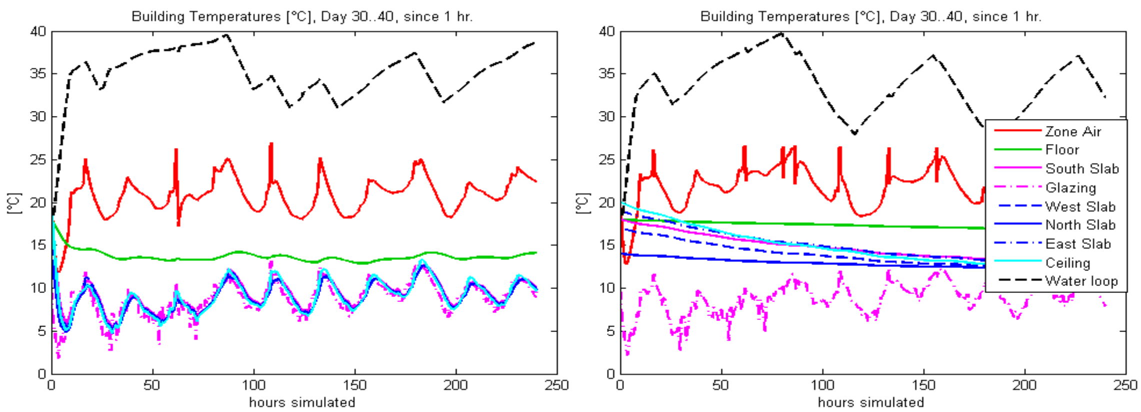


*Figure 4a: Thermal responses for an envelope of high thermal diffusivity (left) and low diffusivity (right). Slab temperatures on the left stay closely together and show a marked diurnal oscillation; on the right, they are independent with little oscillation and converge to a joint mean in the long run.*

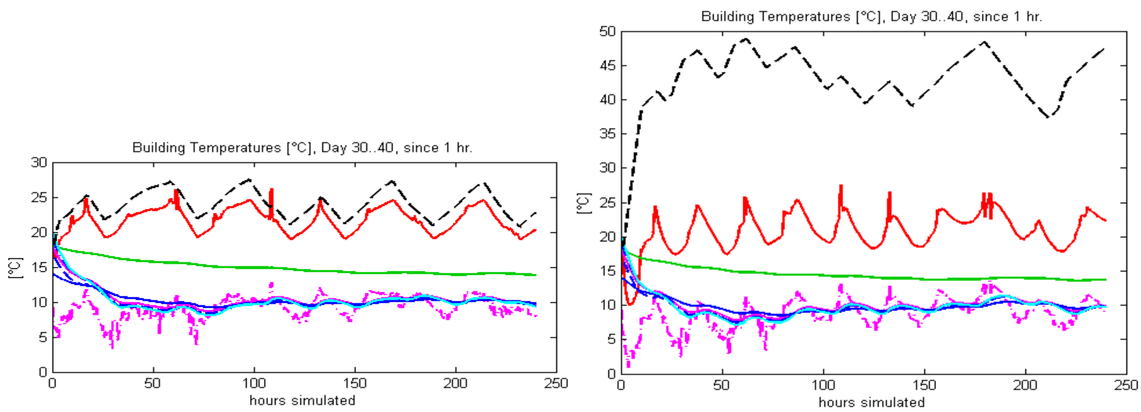


*Figure 4b: More and less efficient heat transfer between heating / cooling medium and zone air. Left: Small total resistance $R_{exch} \approx 0.01$ [K/W] $\Rightarrow$ tightly corresponding air and water temperatures and a moderate amplitude of air temperature ([19°C, 26°C]). Right: Larger resistance $R_{exch} \approx 0.1$ [K/W] $\Rightarrow$ high water return temperature and higher amplitude of air temperature ([17°C, 28°C]).*

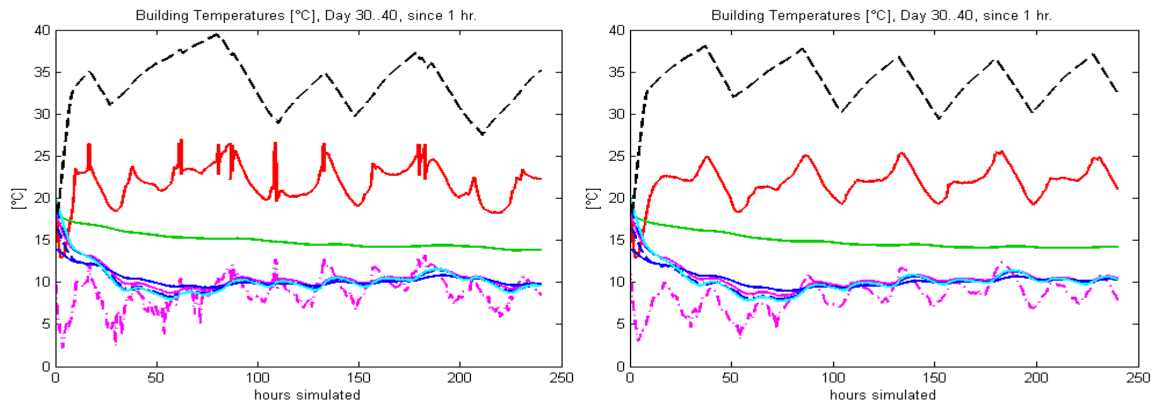


*Figure 4c: Window glazing of high solar transmittance ($\tau$ = 0.7) and no blinds (left) compared with ultra-low-transmittance ($\tau$ =0.3) glazing and shading device (right). On the left, frequent overheating and subsequent under-cooling periods occur, while the air temperature curve on the right is smooth.*

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# Mapping Service Environmental Noise Schleswig-Holstein

Friedhelm Hosenfeld[1], Ludger Gliesmann[2], Andreas Rinker[1]

## Abstract

This contribution presents the "mapping service environmental noise Schleswig-Holstein": The main component of this web platform consists of a WebGIS with strategic noise maps ("Noise Atlas"). The system was developed in order to support the demands for the first period of the EC Environmental Noise Directive in 2007. The Noise Atlas was since then enhanced continuously, the additions include among others download options for action plans and integration of the well-known evaluation platform Disy Cadenza. Especially participation options for the concerned municipalities lead to improved data quality and acceptance of the web platform.

## 1. Overview

With Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise (“Environmental Noise Directive: END”) the European Union defined a concept in assessing and reducing impact of noise (European Commission, 2002).

Main aims include:

- Determining pressure using strategic noise maps
- Assessing and if necessary avoiding or reducing environmental noise by action plans

In 2007 strategic noise maps had to be created and presented for the first time in order to comply with the directive’s first period (2008 – 2013). In 2012 updated and enhanced data were made accessible for the second period (2013 – 2018).

In general evaluation and when required revising of noise maps and actions plans is scheduled at least every five years.

Making information about existing environmental noise publicly available and dissemination of noise maps and action plans to the public as well as public participation in action planning are the directive’s key issues.

In Schleswig-Holstein the State Agency for Agriculture, Environment and Rural Areas (LLUR) is responsible for reporting the implementation of the Environmental Noise Directive to the national and European authorities and it supports the municipalities in creating their strategic noise maps and action plans.

The state agency was in need for a tool which supported the described tasks. The mapping service tool, designed for these requirements, is presented in this paper. All legal obligations for publishing the noise maps and action plans are met by the presented mapping service (“Noise Atlas SH”) in Schleswig-Holstein.

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# 2. Development steps

## 2.1. Initial development for the first reporting period

In 2007 it was soon clear that the requirements for informing the public and the needed participation would be met adequately using a commonly available WebGIS application.

The company DigSyLand was mandated to develop the Noise Atlas as a special version of the existing and successfully employed Agricultural and Environmental Atlas Schleswig-Holstein [2 – 4]. In addition to the presentation of noise maps the Noise Atlas (see 4.1) offered details about the municipalities and specific numbers of the people affected by environmental noise in those areas (see 4.3).

Furthermore each municipality received a user account which enabled them to provide the public with own information via the Noise Atlas platform and to download specific packages with noise simulation data concerning their communes.

## 2.2. Enhancements for the second reporting period

In 2011 further functions were integrated into the platform in order to support the implementation of the Environmental Noise Directive concerning the second period. This included various evaluation and correction functions regarding the input data for the noise simulation models, which were made accessible for the municipalities by means of the WebGIS (see 4.2). Other enhancements involved modules for uploading and presentation of action plans by the municipalities (see 4.4).

Because the State Agency had to maintain all contact and address data of the about 500 affected municipalities in order to fulfil reporting obligations (e.g. serial letters), create information brochures and support the municipalities it was evident to move all needed data consequently into the central database system. The widely-used evaluation platform Disy Cadenza was integrated as evaluation tool for certain information issues, e.g. to assemble mailing lists (see 4.5 and 4.6). Especially the extensive manual acquisition of indicator values demanded by the EU including scanning of non-digitized action plans could be transformed into an automatic reporting procedure supported by Cadenza, in which the municipalities upload the PDF files and submit the required indicator values.

The mapping service environmental noise is complemented with comprehensive information within the central government Internet platform.

# 3. Technical basics

The Noise Atlas web application was developed using the scripting language PHP, while the WebGIS module is based on the UMN mapserver. Data is maintained by an Oracle database management system (currently Oracle 11.2). Input data for noise simulation models are held with geometry attributes also within the Oracle database, while the strategic noise maps are integrated as shape files. Simulation input data include for instance speed limits, road surface, building types and noise reduction walls.

Evaluation duties are performed by Disy Cadenza Professional which offers direct access to the operational database.

# 4. Implementation of Noise Atlas modules

## 4.1. Presentation of strategic noise maps

The Noise Atlas offers all noise maps defined by the EU (e.g. 24 h road traffic or nightly road traffic noise) to be selected alternatively by the user. Results of the first period (computed 2007) can be compared with the results computed for the second period 2012. Using standard functionalities like arbitrary zooming, scale-selection or a printing option (see Figure 1) the simulated environmental noise could be visualized as demanded. Aided by a special search feature for municipalities the specific noise impacts for a chosen location can be exhibited.

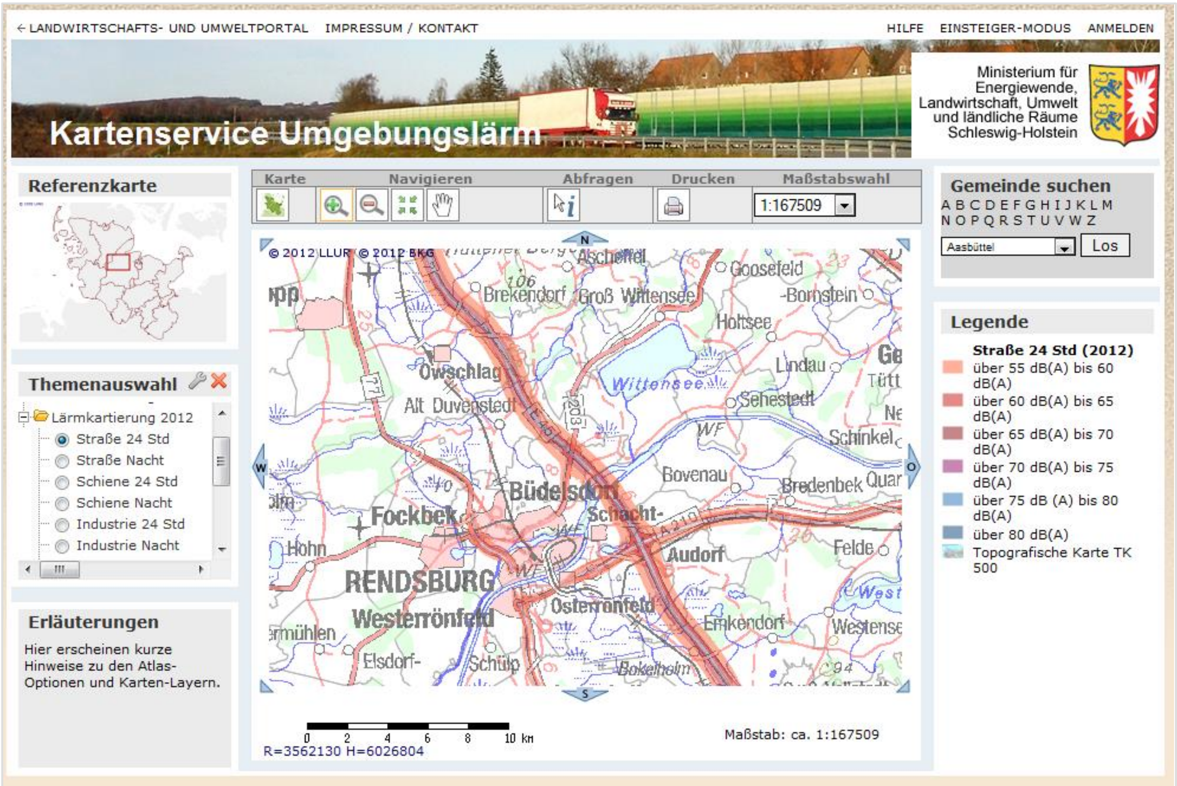



*Figure 1: Presentation of strategic noise maps*

## 4.2. Maps of simulation input data with editing facilities

In order to prepare the second reporting period of the EC directive in Schleswig-Holstein it was decided to enable the municipalities to review the input data for the noise simulation models. They should be facilitated to verify the data related to their municipal territory and to correct the data directly online: After selecting one data layer like e.g. speed limit, traffic intensity or building type, a mouse click on the road segment or on the building offers a pop-up window where the input data could be edited and supplemented with remarks (see Figure 2).

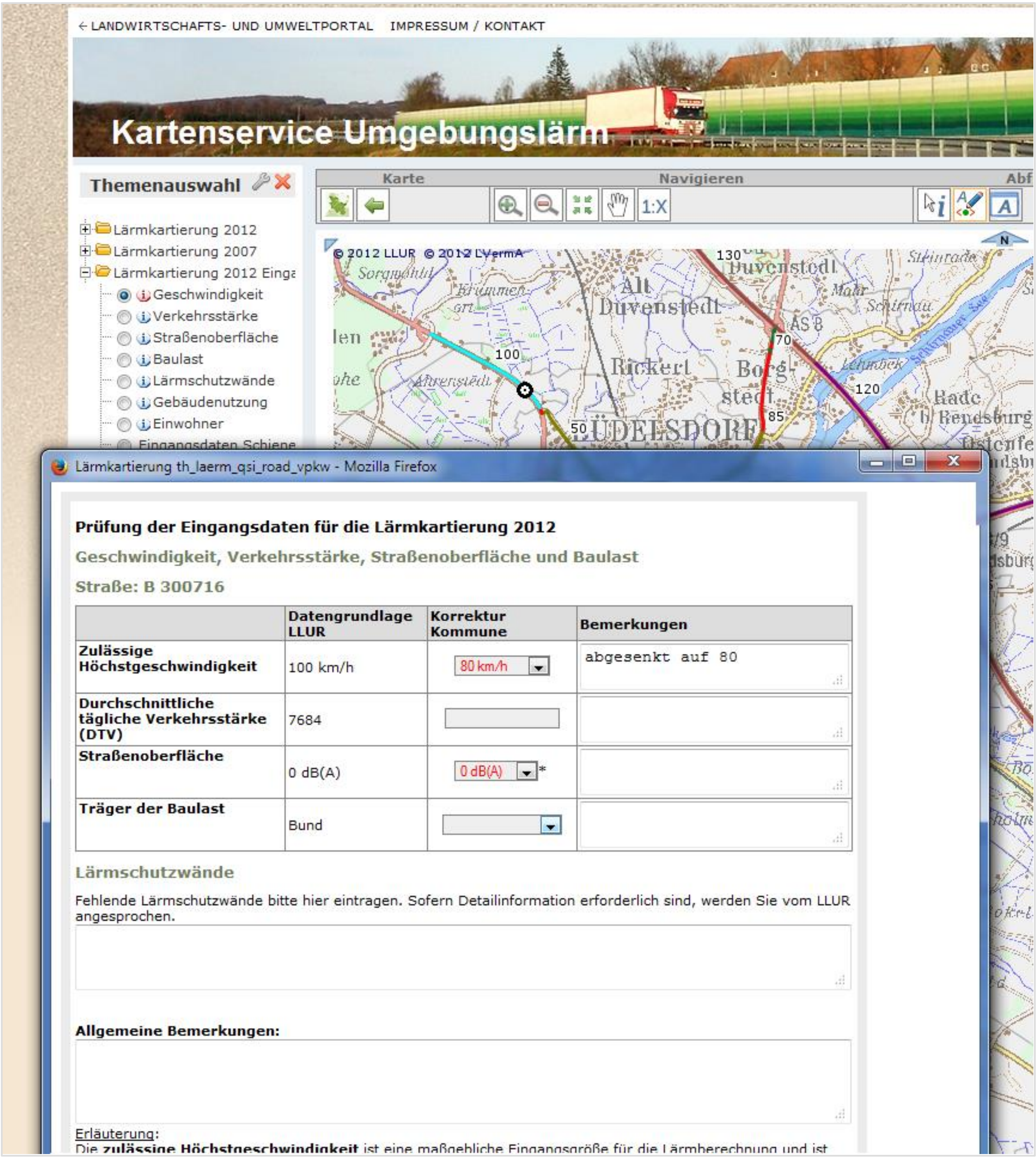


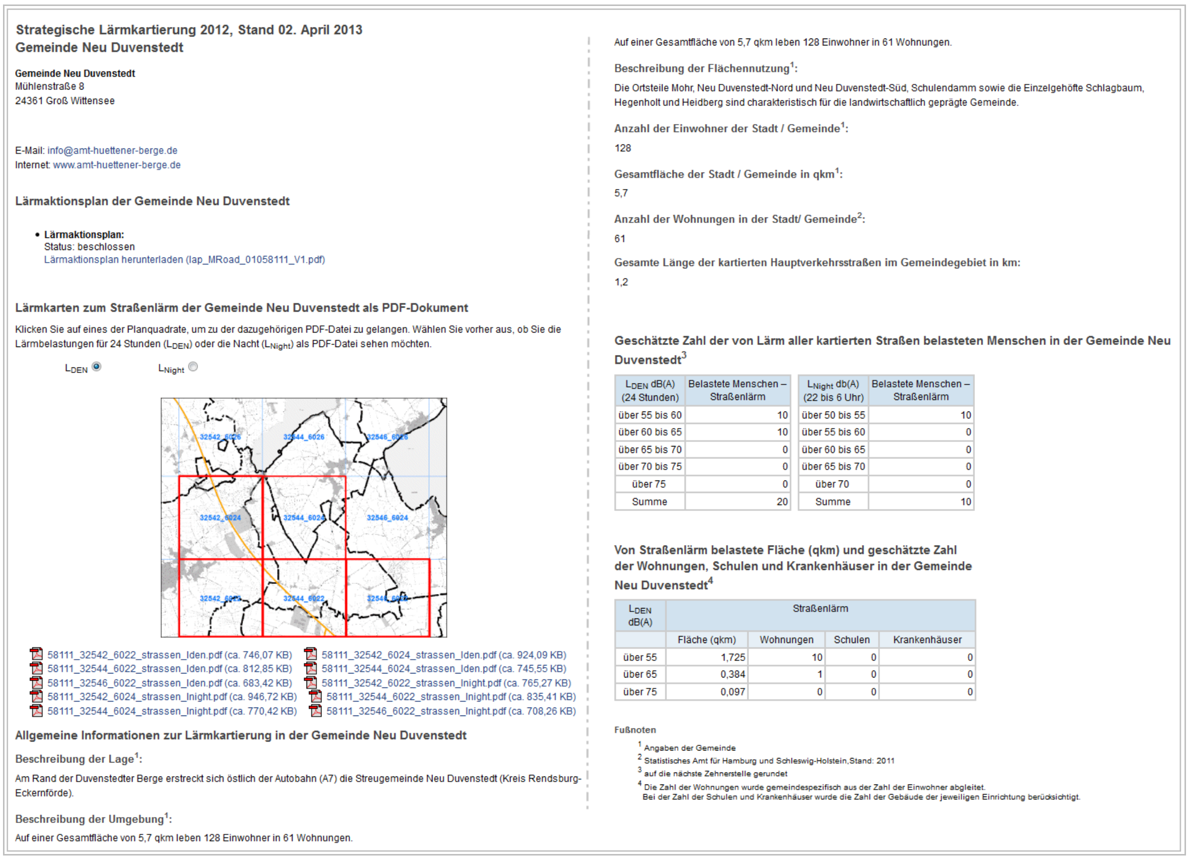

*Figure 2: Editing of input data for noise simulation models (sample data)*

## 4.3. Presentation of details about municipalities and affected people

Complementing the strategic noise maps for each affected municipality additional details could be retrieved which are supplementary legal elements of the noise maps. This includes basic municipality data but also tables containing quantities of affected people and buildings (see Figure 3).

In addition to the GIS based maps all noise maps generated by the company Lärmkontor GmbH, Hamburg covering each municipal area can be downloaded as PDF files, each extent can be selected on a clickable map (see Figure 3).

All required details are managed in the central Oracle database facilitating data updates uncomplicated and promptly. According to their user accounts the municipalities are able check and update their data and release it for publication.



**Strategische Lärmkartierung 2012, Stand 02. April 2013**
**Gemeinde Neu Duvenstedt**

**Gemeinde Neu Duvenstedt**
Mühlenstraße 8
24361 Groß Wittensee

E-Mail: info@amt-huettener-berge.de
Internet: www.amt-huettener-berge.de

**Lärmaktionsplan der Gemeinde Neu Duvenstedt**

- **Lärmaktionsplan:**
  Status: beschlossen
  Lärmaktionsplan herunterladen (lap_MRoad_01058111_V1.pdf)

**Lärmkarten zum Straßenlärm der Gemeinde Neu Duvenstedt als PDF-Dokument**

Klicken Sie auf eines der Planquadrate, um zu der dazugehörigen PDF-Datei zu gelangen. Wählen Sie vorher aus, ob Sie die Lärmbelastungen für 24 Stunden ($L_{DEN}$) oder die Nacht ($L_{Night}$) als PDF-Datei sehen möchten.

$L_{DEN}$ $L_{Night}$

58111_32542_6022_strassen_lden.pdf (ca. 746,07 KB)
58111_32544_6022_strassen_lden.pdf (ca. 812,85 KB)
58111_32546_6022_strassen_lden.pdf (ca. 683,42 KB)
58111_32542_6024_strassen_lnight.pdf (ca. 946,72 KB)
58111_32544_6024_strassen_lnight.pdf (ca. 770,42 KB)
58111_32542_6024_strassen_lden.pdf (ca. 924,09 KB)
58111_32544_6024_strassen_lden.pdf (ca. 745,55 KB)
58111_32542_6022_strassen_lnight.pdf (ca. 765,27 KB)
58111_32544_6022_strassen_lnight.pdf (ca. 835,41 KB)
58111_32546_6022_strassen_lnight.pdf (ca. 708,26 KB)

**Allgemeine Informationen zur Lärmkartierung in der Gemeinde Neu Duvenstedt**

**Beschreibung der Lage[1]:**

Am Rand der Duvenstedter Berge erstreckt sich östlich der Autobahn (A7) die Streugemeinde Neu Duvenstedt (Kreis Rendsburg-Eckernförde).

**Beschreibung der Umgebung[1]:**

Auf einer Gesamtfläche von 5,7 qkm leben 128 Einwohner in 61 Wohnungen.

Auf einer Gesamtfläche von 5,7 qkm leben 128 Einwohner in 61 Wohnungen.

**Beschreibung der Flächennutzung[1]:**

Die Ortsteile Mohr, Neu Duvenstedt-Nord und Neu Duvenstedt-Süd, Schulendamm sowie die Einzelgehöfte Schlagbaum, Hegenholt und Heidberg sind charakteristisch für die landwirtschaftlich geprägte Gemeinde.

**Anzahl der Einwohner der Stadt / Gemeinde[1]:**

128

**Gesamtfläche der Stadt / Gemeinde in qkm[1]:**

5,7

**Anzahl der Wohnungen in der Stadt/ Gemeinde[2]:**

61

**Gesamte Länge der kartierten Hauptverkehrsstraßen im Gemeindegebiet in km:**

1,2

**Geschätzte Zahl der von Lärm aller kartierten Straßen belasteten Menschen in der Gemeinde Neu Duvenstedt[3]**

| $L_{DEN}$ dB(A) (24 Stunden) | Belastete Menschen – Straßenlärm |
|---|---|
| über 55 bis 60 | 10 |
| über 60 bis 65 | 10 |
| über 65 bis 70 | 0 |
| über 70 bis 75 | 0 |
| über 75 | 0 |
| Summe | 20 |

| $L_{Night}$ db(A) (22 bis 6 Uhr) | Belastete Menschen – Straßenlärm |
|---|---|
| über 50 bis 55 | 10 |
| über 55 bis 60 | 0 |
| über 60 bis 65 | 0 |
| über 65 bis 70 | 0 |
| über 70 | 0 |
| Summe | 10 |

**Von Straßenlärm belastete Fläche (qkm) und geschätzte Zahl der Wohnungen, Schulen und Krankenhäuser in der Gemeinde Neu Duvenstedt[4]**

| $L_{DEN}$ dB(A) | Straßenlärm | | | |
|---|---|---|---|---|
| | Fläche (qkm) | Wohnungen | Schulen | Krankenhäuser |
| über 55 | 1,725 | 10 | 0 | 0 |
| über 65 | 0,384 | 1 | 0 | 0 |
| über 75 | 0,097 | 0 | 0 | 0 |

Fußnoten

1 Angaben der Gemeinde
2 Statistisches Amt für Hamburg und Schleswig-Holstein,Stand: 2011
3 auf die nächste Zehnerstelle gerundet
4 Die Zahl der Wohnungen wurde gemeindespezifisch aus der Zahl der Einwohner abgleitet.
Bei der Zahl der Schulen und Krankenhäuser wurde die Zahl der Gebäude der jeweiligen Einrichtung berücksichtigt.

*Figure 3: Municipality details, numbers of affected people and PDF download (excerpts)*

## 4.4. Documentation, upload and publication of action plans

Based on the environmental noise data the municipalities develop action plans in order to document noise reduction measures. The Noise Atlas offers modules for uploading action plans, for commenting it and to make the plans available for public download in combination with the municipality information presentation (see Figure 3). This service implements the reporting requirements defined by the Environmental Noise Directive. All PDF files documenting the action plans and additional remarks are managed by the database and protected according to access rights so that only released action plans can be downloaded by the public.

## 4.5. Administration module for maintaining address data

An administration module was developed in 2013 to support the State Agency in maintaining all data of municipalities and other authorities concerning the noise Environmental Noise Directive. For each reporting period for instance number of inhabitants, lengths of roads and railroads, mandated companies and similar details can be managed centrally.

## 4.6. Evaluation of action plans and municipal data with Cadenza

The in environmental informatics well-known evaluation platform Disy Cadenza is employed in order to analyse all noise related data mentioned in the previous sections as well as to fulfil reporting obligations. The noise evaluations are based on a central Cadenza installation which is already operated by the State Agency used by other departments. Cadenza supports direct access to the operational Internet database, so the data has not to be transferred into the State Agency's local network.

The evaluations include details about the municipalities' noise action plans concerning state of planning, costs and affected inhabitants but also various noise related data.

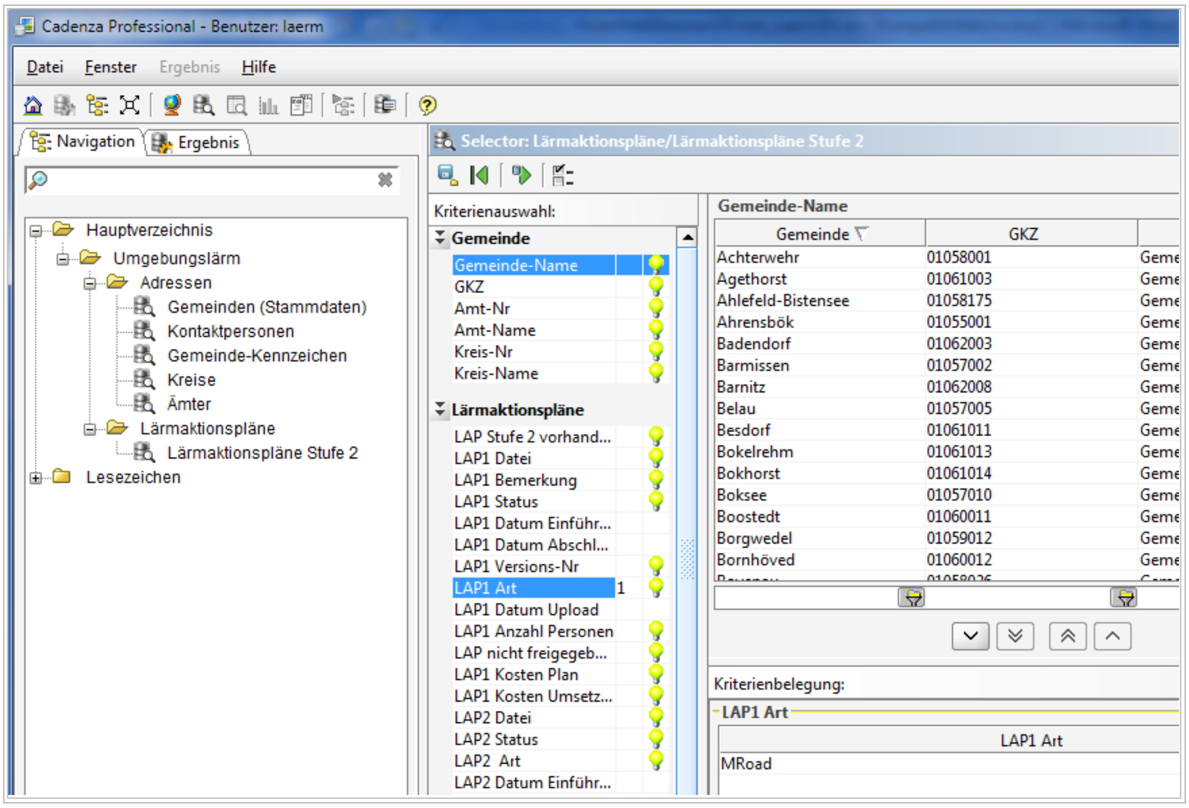



*Figure 4: Evaluation of environmental noise data using Cadenza Professional*

## 5. Conclusion and outlook

Since the first implementation steps were performed in 2007 in order to meet the requirements of the first period of the EC Environmental Noise Directive in Schleswig-Holstein, the "mapping service environmental noise" ("Noise Atlas") had been enhanced and expanded continuously. While the Noise Atlas was a helpful tool supporting the municipalities and state authorities preparing the first period, the application was further optimized since 2012 for the directive's second period.

Thus, all relevant data are managed consequently in the central Oracle database, while in the past Microsoft Access and Excel were used additionally. So, on the one hand all municipalities are provided with a common distributed web access to their data including editing functions while on the other hand the State Agency LLUR can perform administrative tasks and overall evaluations using Disy Cadenza.

During preparation of data for the second period the plausibility of the results and the noise maps were accepted by the municipalities much better than for the first period, because now they were provided with means to check and correct the input data. The State Agency had to deal with significant less inquiry and complaints regarding the noise data, which turned out to be a huge benefit.

Legal duties like publishing and reporting obligations could be achieved automatically and efficiently.

In future legacy data collected for the first period as well as quantities about affected people and similar data should also be made available for Cadenza utilising additional evaluation potential.

Some noise maps are already prototypically published as WMS service offering integration of these geodata to the municipalities and other interested people into their own GIS software in the future.

## References

[1] European Commission: “Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise”. 2002 Available: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:189:0012:0025:EN:PDF (last visit: 22nd June 2014).

[2] Görtzen, D.; Schneberger, S. & Rammert, U.: “Schleswig-Holsteins Environmental Atlas for the Public and for Special Interest Groups”. In: Minier, P. & Susini, A. (eds.): *Proceedings of the 18th Conference Informatics for Environmental Protection.* October 21-23, 2004. CERN, Geneva, pp. 634-640.

[3] Görtzen, D.; Rammert, U. & Bornhöft, U.: “Geo Data and Infrastructure provided by the Environmental Administration of Schleswig-Holstein”. In: Wohlgemuth, V.; Page, B. & Voigt, K. (eds.): *Proceedings of the 23rd on Environmental Informatics and Industrial Environmental Protection: Concepts, Methods and Tools.* Berlin, 2009, pp. 369-376.

[4] Rammert, U. & Hosenfeld, F.: “Dynamic and Interactive Presentation of Environmental Information”. In: Gnauck, A. & Heinrich, R. (eds.): *The Information Society and Enlargement of the European Union, 17th International Symposium Informatics for Environmental Protection*, Cottbus 2003, pp. 517-524.

## Links (in German):

Environmental Noise Directive in Schleswig-Holstein (Umgebungslärmrichtlinie in Schleswig-Holstein): http://www.laerm.schleswig-holstein.de/

Mapping service Environmental Noise (Kartenservice Umgebungslärm): http://www.umweltdaten.landsh.de/laermatlas/

# An Evolutionary Approach to Geo-Planning of Renewable Energies

Daniel Lückehe[1], Oliver Kramer[2], Manfred Weisensee[3]

## Abstract

Renewable energy sources are getting more and more important in many industrial nations. As their behavior and effectiveness often depends on their location, the employment of geo-planning and geo-optimization strategies improves their value. A geo-planning process must consider multiple aspects and different requirements resulting in a constrained optimization problem. In this work, we introduce a new optimization approach for geo-planning based on evolutionary strategies. For this sake, we adapt evolutionary operators and employ deterministic parameter control. We define an experimental setting for wind turbines with different potentials, constraints, and wake effects. In the experimental part of this work, we first show the behavior of the approach on toy settings. Extended settings with real-world geographical data, ground mounted solar power plants, and political conditions demonstrate the flexibility and extensibility of the approach.

## 1. Introduction

While many European countries increase their renewable energy resources, the requirements for geo-planning are becoming more and more complex. Old fossil power plants are replaced by smaller regenerative energy sources, whose behavior and effectiveness depend on their location. It becomes necessary to analyze and plan the participants in energy systems, e.g., strategies for generators, consumers, and storages in a smart way [1]. In order to reduce the load of power grids and to optimize output from regenerative energy sources, geo-planning has an important part to play. In particular, the increasing number of renewable energy sources leads to the requirement of their careful integration into the environment [8]. Therefore, many different parameters, which affect power output, have to be considered, e.g., wind potential for a wind turbine, wake effects, statutory frameworks, the development of an existing power grid, and the locations of consumers. The fast expansion of renewable energy sources is not the primary target. The German Federal Ministry for the Environment defined the objective to treat all participants of the energy system in an optimized and integrated way [4].

The objective of this work is to introduce a new optimization approach for geo-planning. Our approach should be able find optimal locations for various types of power plants. Therefore, the approach takes into account different criteria, e.g., environmental constraints, constraints between power plants, and varying power potentials at different locations. This work shows that evolutionary strategies (ES) can be a good approach for geo-planning that is able to consider different objectives.

This paper is structured as follows. In Section 2, we will give a general introduction to ES. Our geo-planning model will be illustrated in Section 3. In Section 4, an experimental analysis will show the capabilities of our approach. Conclusions are drawn in Section 5.

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## 2. Evolutionary Strategies

To find a location for new wind turbines, solutions can be evaluated w.r.t. different objectives, e.g., effects on the power grid or w.r.t. the wind potential. From this perspective, the problem becomes a multi-objective optimization problem. We call the function to evaluate solutions fitness function in the following. Which approach should be used to solve an optimization problem w.r.t. the fitness function depends on their characteristics. If the derivation of the fitness function is known, Newton-based methods like the Broyden-Fletcher-Goldfarb-Shanno algorithm are recommendable choices [11]. If the fitness function is non-differentiable or the computation of the derivation is too expensive, it is a good choice to treat the optimization problem as a black box. In black box optimization, no assumptions are made on the fitness function, allowing the employment of complex and combined fitness functions. For example, in a solution space that can be described by a simple fitness function like classic sphere function $f(x) = x^2$ the knowledge of mathematical description is a great advantage for finding the optimal solution. But the more complex the solution space is, the more difficult is a mathematical description and the search for an appropriate method to solve the equations. Treating the optimization problem as a black box problem has the advantage that the fitness function can have various characteristics, e.g., an equation, which models wind wake effects, the interpolation between discrete measurements of data or results of grid simulation programs. The ES is constructing a solution $x_i$, interprets the value of its fitness function $f(x_i)$, but does not require further knowledge of $f$. ES are a proven approach to solve black box optimization problems. They were developed independently in Germany by Rechenberg [13] and Schwefel [14] and in the United States by Holland [6]. Since their invention, ES were continuously further developed in various fields. Also in the field of wind turbine placement optimization, they are a highly modern method like shown by Tran et al. [15].

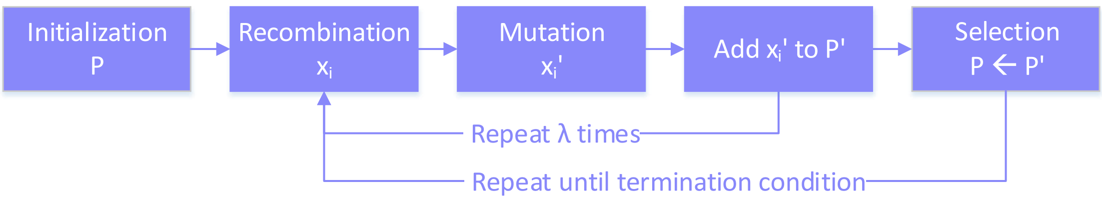


*Figure 1: Evolutionary Strategy*

Evolutionary strategies are inspired by the biological process of optimization, which is called evolution. The optimization process can be split into three main operators: recombination, mutation, and selection. Figure 1 visualizes the process of an ES. The first step is to initialize solutions $\{x_1, \dots, x_\mu\}$. These solutions are the initial population and will be called $\mathcal{P}$. Recombination will pick $\rho$ solutions from $\mathcal{P}$ and create a new solution $x_i$ by combining their parameters. There are numerous ways to accomplish this, e.g., for rational numbers the mean value can be calculated. The next step is to mutate solution $x_i$ to $x_i'$. For rational numbers a common choice is Gaussian mutation where it applies $x_i' = x_i + \sigma \cdot \mathcal{N}(0,1)$ while $\mathcal{N}$ is the Gaussian distribution and $\sigma$ is the step size. The mutated solution $x_i'$ will be added to new population $\mathcal{P}'$. Recombination and mutation will be repeated $\lambda$ times. So the size of new population is $\lambda$. Selection chooses the $\mu$ best solutions and replaces population $\mathcal{P}$ for the next generation. In a $(\mu + \lambda)$-ES, the best solutions can be chosen from $\mathcal{P}$ and $\mathcal{P}'$. In a $(\mu, \lambda)$-ES, they can only be chosen from $\mathcal{P}'$. To rank the solutions, the fitness function $f(x_i)$ is used. For a maximization problem, for the best solution $x^*$ it holds $f(x^*) \geq f(x)$ for every $x \in X$.

## 3. Geo-Planning Model

In this section, we introduce our evolutionary approach for geo-planning. First, the optimization problem is defined. For wind turbines, the turbine model, potential maps, constraints between turbines, and wake effects are specified. This setting is used in the experimental section for our wind turbine experiments. In the last paragraph the specification is extended to real world data from OpenStreetMap and simple models for solar power plants and political framework conditions. This extended setting shows the flexibility of the evolutionary approach when handling different objectives.

### 3.1. Evolutionary Approach

In our approach, we use a $(1+1)$-ES, i.e., the ES generates one offspring solution ($\lambda = 1$) in each generation and selects the better solution (offspring or parent, $\mu = 1$). A solution $x_i$ contains multiple elements $e$ and every element represents an energy source on a map in a defined location. In this work, we consider different types of energy sources, e.g., small and large wind turbines and solar power plants. For example, element $e_{wind(0,0,135)}$ represents a wind turbine placed at position $(0,0)$ with a turbine height of 135 meters. The solution, which only includes this wind turbine would be $x_i = [e_{wind(0,0,135)}]$. We define a solution that includes more than one energy source as $x_i = [x_{i1}, x_{i2}, x_{i3}]$ with the number of energy sources $N = 3$, e.g., $x_i = [e_{wind(0,0,135)}, e_{wind(2000,1000,78)}, e_{\text{wind}(3000,3000,78)}]$. Then, it holds $x_{i0} = e_{wind(0,0,135)}$ and $pos\left(e_{wind(0,0,135)}\right) = (0,0)$. A solution is evaluated with the help of a fitness function. The objective is to maximize power potential $P$, which depends on position $pos\left(x_{ij}\right)$. The value of fitness function is the sum of every energy sources potential. It holds:

$$f(x_i) = \sum_{j=1}^{N} f(x_{ij}) = \sum_{j=1}^{N} P(pos(x_{ij})) \tag{1}$$

In case of the population-less $(1+1)$-ES, recombination does not apply. In our approach, mutation of solution $x_i$ can add a new element $e_{new}$ to solution $x_i$ or change the position of an existing element $e$ of solution $x_i$. The position for a new element $e_{new}$ is chosen randomly anywhere in the defined area. For the change of a position Gaussian mutation is applied and the step size $\sigma$ is adapted deterministically. It follows the principle of starting with a large step size, which covers the entire area, and ending with a very small step size to fine-tune the solution. When changing the position of an element, the ES can also change parameters from element $e$, e.g., the height of a wind turbine, with chance $c$. In the first generation, this chance is set to $50\%$ and is reduced in the course of the optimization process. It holds:

$$\sigma(t) = 1.0 - \left(\left(1.0 - \frac{1}{T}\right) \cdot \frac{t}{T}\right) \text{ and } c(t) = 0.5 - 0.5 \cdot \frac{t}{T} \tag{2}$$

Where $t$ is the actual number of generation and $T$ is the total number of generations. At the beginning, the ES starts with an empty solution, which means initial population $\mathcal{P} = \{x_0\}$ with $x_0 = []$. In the geo-planning process, there are many constraints that have to be considered, e.g., laws and physical limits. In our approach, we employ a constraint handling method known as death penalty to enforce the fulfilment of constraints. That means every infeasible solution that has been created by mutation is discarded.

### 3.2. Wind Turbines Setting

The characteristics of the wind turbine E101 by Enercon is the basis of our approach. E101 is a very modern wind turbine. Further, we define that small turbines have a height of 78 meters, while large turbines have a height of 135 meters. The characteristics and power curves are taken from

Haack [5], Manwell et al. [10], and Gasch and Twele [3]. In real world data settings, interpolated data from the COSMO-EU model [2] are used for determination of the wind power potential $P(pos(x_{ij}))$. For every wind turbine, we define the constraint that no other turbine may be placed in an ellipse of a size that is five times the height of the turbine in the main wind direction and three times orthogonally to the main wind direction. In this work, the main wind direction is defined as coming from south west, which is a standard assumption for most places in Lower Saxony, Germany. The placement of a wind turbine affects the wind potential in the close neighborhood. These effect are called wake effects and are caused by complex physical principles. In our approach, we employ a simple wake model from Kusiak and Zong [9]. We modified the model focusing on the main wind direction of Lower Saxony with the simple model:

$$P_{wake}(\cdot) = \left(1.0 - \sqrt{\sum_j \left(\frac{1.0-\sqrt{1.0-c_T}}{1.0+\kappa\cdot(\cos(\alpha)\cdot\Delta x+\sin(\alpha)\cdot\Delta y)/R}\right)^2}\right)\cdot P(\cdot) \tag{3}$$

with $c_T = 0.8$ and $\kappa = 0.075$ as proposed by Kusiak and Zong. As we use the wind turbine Enercon E101 for wind, the rotor radius is set to $R = 55.5$. The angle $\alpha$ is the main wind direction and $\Delta x$, $\Delta y$ are the differences between the target position and the positions of wind turbines $e_j$. The index list $j$ contains indices of every element $e$ of solution $x_i$, for which it holds $R + \kappa \cdot dist(\Delta x, \Delta y, \alpha) + bd(\Delta x, \Delta y, \alpha) > 0$ and $R + \kappa \cdot dist(\Delta x, \Delta y, \alpha) - bd(\Delta x, \Delta y, \alpha) > 0$ and $dist(\Delta x, \Delta y, \alpha) > 0$ with the distance $dist(\Delta x, \Delta y, \alpha) = \cos(\alpha)\cdot\Delta x + \sin(\alpha)\cdot\Delta y$ and border $bd(\Delta x, \Delta y, \alpha) = -\cos(\alpha)\cdot\Delta x + \sin(\alpha)\cdot\Delta y$.

### 3.3. Extended Setting

The experimental wind turbine setting will be extended in this section. We add geographical information from OpenStreetMap [12] and define restrictions for areas around buildings and streets. It is possible to define various restrictions for different regions, e.g., residential zones and industrial parks. In this setting, we define a global minimum distance of 150 meters between energy sources and streets implemented with rectangles, as well 300 meters from sources to buildings based on circles.

Ground mounted solar power plants have an economical minimum size of approximately 30,000 square meters [7]. To demonstrate the possibility to integrate new features into an existing solution, we first generate a solution for wind turbines. After the wind-based optimization process, the wind turbine placement method will be reused to search for solar power plant locations. In this process, positions are chosen randomly, similar to the process for wind turbines. The width constraint for solar plants is also chosen randomly, while the length is computed depending on the width w.r.t. an area of 30,000 square meters. An interesting aspect is the integration of new features into the optimization process. We employ political conditions to illustrate this possibility. Along technical factors, political aspects are playing an important role in a real-world decision making process. For example, if the numbers of wind turbines are equal in two communities, both are assigned to the same trade taxes. We define a function $n_{region}(x_i)$ that returns the number of elements in a region for a solution $x_i$. Political objectives can be modeled in the optimization process based on restriction $abs(n_{communityA}(x_i) - n_{communityB}(x_i))$, which must be smaller or equal to One.

## 4. Experimental Results

In this section, we experimentally analyze the proposed geo-planning approach based on the $(1+1)$-ES with various settings like described in Section 3.

## 4.1. Wind Turbine Experiments

The left part of Figure 2 shows an example of a wind potential map with four optima, i.e., a scenario with four mountains and strong wind. Violet and white areas reflect the magnitude of wind potential, while violet stands for low and white for high potential. In this case white areas are covered by the turbines. Black squares with a wind turbine icon symbolize the wind turbines and are labelled with W1 to W4. The ES fulfilled the constraint to place only four wind turbines with a height of 135 meters. In all 100 experimental runs, the $(1 + 1)$-ES was able to find the global optima. The $(1 + 1)$-ES was run for 10,000 generations taking less than one second on a usual home computer. On the right of Figure 2, the wind potential is equally distributed without wake effects. The ES places wind turbines in the solution space without numerical limitations. The figure demonstrates that every turbine constraint has been considered.

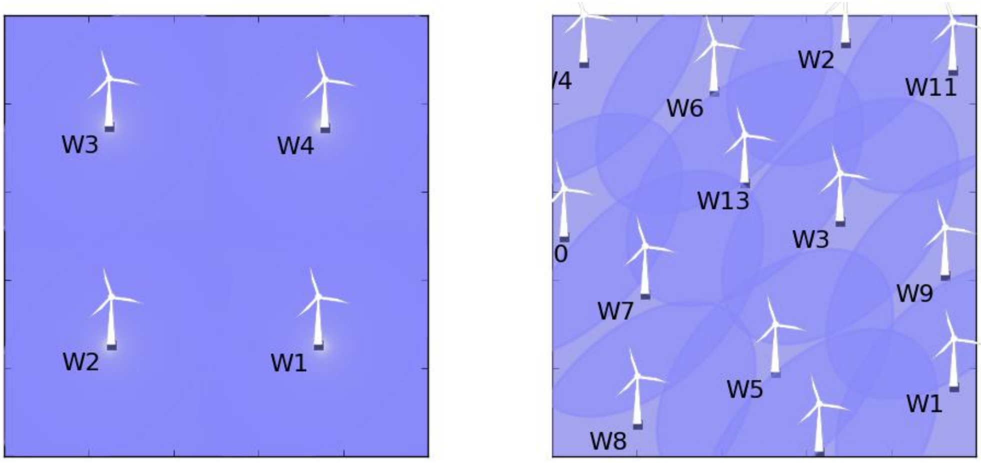


*Figure 2: Left: potential map with four optima and four wind turbines, right: result of ES with many wind turbines*

In the following experiment, wake effects are considered and visualized. Again, we are using a potential map with four optima. But in this case, the size of optima are increased. The ES can choose different positions within the optimal regions, which all belong to a global optimal solution. The optimum in the upper right corner has been increased to allow the placement of two wind turbines. As shown in the left part of Figure 3, the upper right optimum can be affected by wake effects.

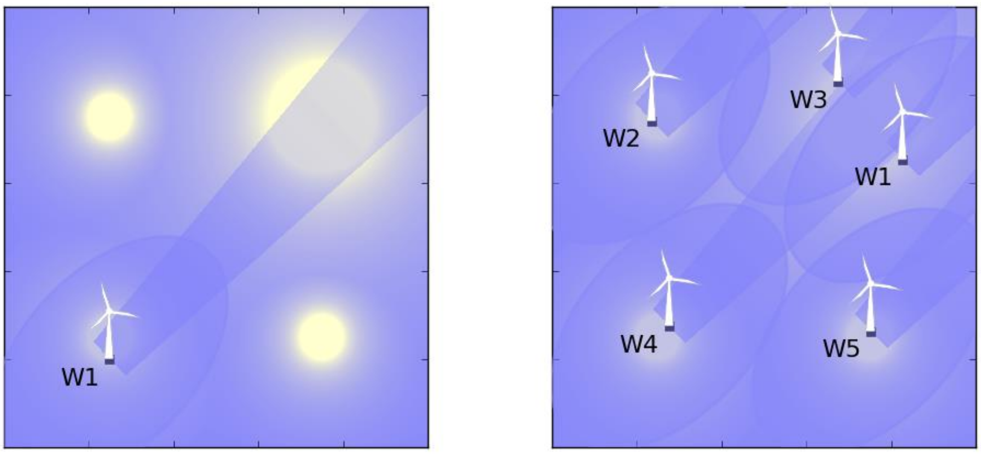


*Figure 3: Left: one turbine with wake effects, right: five turbines with optimal solution*

In this setting, the task is to place five turbines. The experiments show that the $(1+1)$-ES is able to find the optimal solution, which is depicted in the right part of Figure 3. Turbine W4 has been placed in the middle of the optimal region w.r.t. the perspective of the main wind direction. As a consequence, Turbines W1 and W3 can be placed in the optimal region without being affected by wake effects of W4. Turbines W2 and W5 are placed arbitrarily in the other optimal regions. Because of local optima situations, the $(1+1)$-ES was not able to find the global optimal solution in every test run. Preliminary experiments have shown that this issue can be solved by special mutation operators that will be subject to our future work.

In the last experiment for wind turbines, we are going to show the capability of $(1+1)$-ES dealing with turbines of different heights. Larger turbines have a higher power potential than smaller ones. Hence, an algorithm that optimizes the power potential will probably prefer larger turbines. In real world scenarios, small turbines are cheaper. Modelling financial aspects is possible, but not yet considered. For this reason, we define a power potential relative to costs in this scenario. In the left part of Figure 4, the relative potential prefers large turbines, while it prefers small turbines on the right hand side. In this experiment, the potential is at the same level on the map. On the diagonal, it is slightly higher. So it applied $P(\cdot) = 1.0 - abs(x-y)$ with $abs(x-y) \ll 1.0$. This is due the fact that in real world scenarios, the wind potential will also not be equal on the whole map.

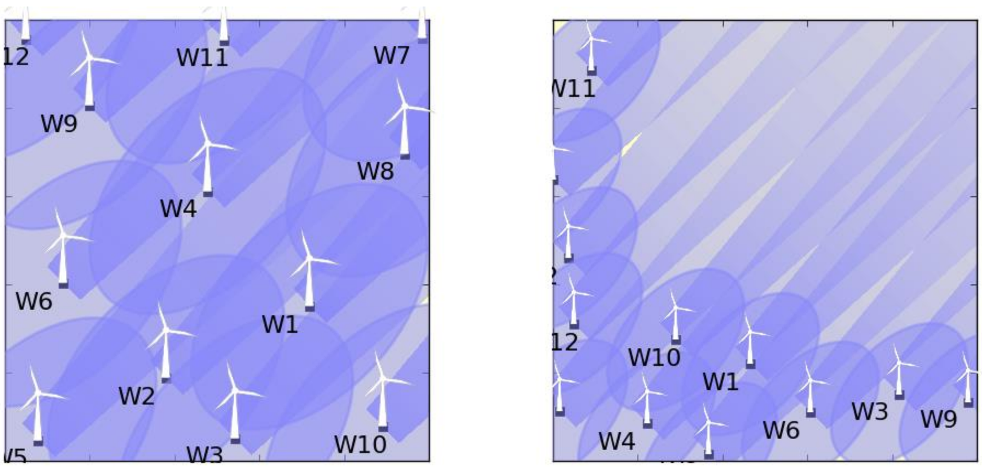


*Figure 4: Left: placement of 12 large turbines, right: 12 small turbines*

In the last experiment, the task is to place 12 turbines. With placing large turbines, see left part of Figure 4, some turbines have to be placed at locations that are affected by wake effects of other turbines. The $(1+1)$-ES minimizes these effects and places the wind turbines on the opposite side w.r.t. to the main wind direction. The turbines are also placed in lines orthogonally to the main wind direction. On the right hand side of Figure 4, a solution with many small wind turbines is shown. As smaller turbines can be placed closely together, it is possible to place all turbines without being affected by wake effects. The $(1+1)$-ES is able to find these solution, as shown in Figure 4. But again the search process can fail to find the global optimal solution due to local optima.

### 4.2. Extended Experiments

On the left hand side of Figure 5, two solar power plants are placed in a tiny real world setting. Like in all following plots with information from OpenStreetMap [12] yellow lines represent streets. Grey lines symbolize buildings. The constraints around streets and buildings are shown in red. The Figure illustrates that all constrains were considered. The regions for the solar power plants have been shaped to fit into the setting by the $(1+1)$-ES.

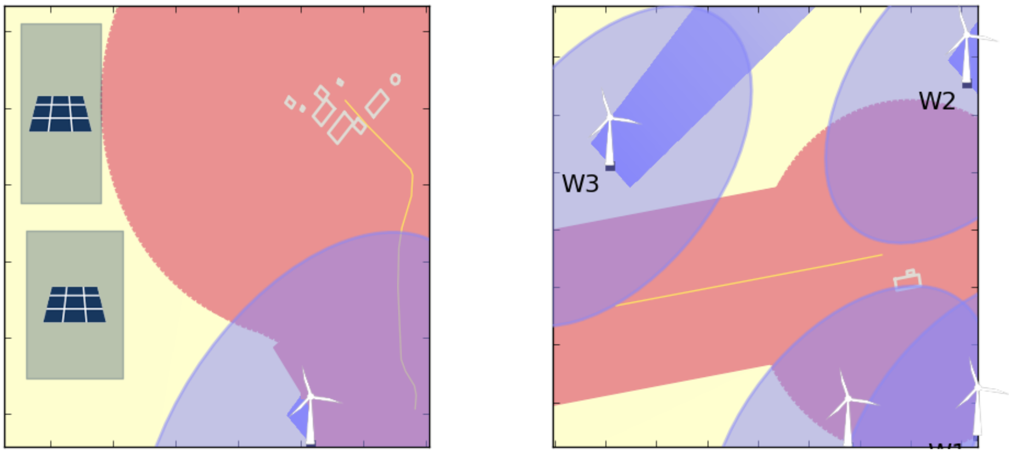


*Figure 5: Left: placement of two solar power plants in a setting with buildings, streets, and a wind turbine, right: placement of four wind turbines, equally distributed above and below a street*

On the right in Figure 5, the $(1+1)$-ES places four wind turbines with the political objective to place the turbines equally distributed above and below the street in this setting.

The last experiment is shown in Figure 6. In this setting, a village in Lower Saxony was chosen. It contains 139 buildings and 95 streets that consist of 454 parts. The computation of 50,000 generations takes less than thirty seconds on a usual home computer. The $(1+1)$-ES considers all constraints and places all wind turbines without being affected by wake effects, e.g., Turbine W5 is placed as close as possible to Turbine W3 without avoiding the minimum distance between turbines and being affected by wake effects. The gap between Turbines W1 and W2 has exactly the size of the wake effects of turbine W4 at location of W1 and W2.

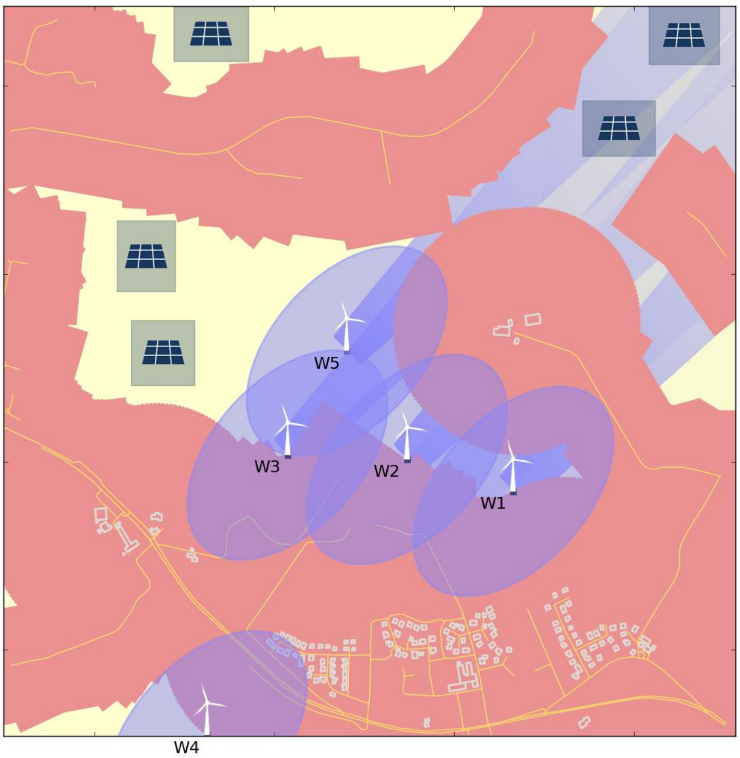


*Figure 6: Five turbines and five solar power plains placed in a setting with a village*

## 5. Conclusion

In our work, we have introduced an evolutionary approach for geo-planning that optimizes power potential and considers various kinds of constraints. We define a wind setting, where we use a turbine model based on a modern turbine, employ wind data from the COSMO-EU model, and add restrictions between turbines and wake effects. In our experiments, the $(1 + 1)$-ES considered all aspects and evolved valid solutions. Although the $(1 + 1)$-ES was demonstrated to find optimal solutions, there are still situations, when local optima can prevent finding the global optimum. In an extended setting, we employed geographical data from OpenStreetMap and also considered ground mounted solar power plants as well as political conditions. Again, the $(1 + 1)$-ES was able to handle all these aspects and demonstrated its flexibility.

In our future work, we will focus on leaving local optima with specialized mutation operators. Further, initial tests have shown promising results by optimizing multiple energy sources at once instead of only one. We also plan to add more features into the settings, e.g., more detailed solar power plant models and energy grid simulations.

## Acknowledgements

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# Using Interlinked Thesauri for INSPIRE-Compliant Metadata Management

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## Abstract

As part of the eENVplus project about infrastructures for the INSPIRE implementation, a Thesaurus Framework (LusTRE) is being developed which allows to interlink different environmental domain thesauri and offers access to them as one virtual integrated linked data source – which shall support better metadata compilation and metadata discovery for describing and finding INSPIRE data and services. Further, a Web Service infrastructure is being provided (the LusTRE Exploitation Services, LusTRE-ES) that allows to make optimum use of the knowledge contained in LusTRE for improving existing metadata tools. In this paper, we give an overview of LusTRE and present important aspects of the LusTRE-ES: its architecture and design principles, the REST interface, the list of services / service modules under development, and the way how these services shall improve existing metadata tools.

## 1. Overview

The EU-FP7 CIP-PSP pilot project eENVplus ("eEnvironmental services for advanced applications within INSPIRE") develops – within ten INSPIRE/SEIS pilot-implementation testbeds – an ecosystem of software services for comprehensively supporting all aspects of interoperable environmental information services. As part of eENVplus, a thesaurus framework (LusTRE) is being developed and exemplarily filled which allows interlinking of different domain thesauri. In this paper, we present the eENVplus thesaurus exploitation services: Web services exploiting the domain knowledge contained in the interlinked thesauri for the purposes of metadata creation and maintenance and for resource discovery. The services can be used by different tools such as metadata editors, metadata validators, CSWs, information portals or specific application solutions. Some exemplary use cases:

- The eENVplus thesaurus exploitation services can deliver to a search engine synonymous, broader, narrower or related terms from several interlinked thesauri or controlled vocabularies which facilitates cross-domain, cross-corpus, cross-boundary and multilingual search.

- For a user who is less experienced in some domain and who has to create or maintain metadata, the visualization service as well as visual browsing through conceptual spaces of several interlinked thesauri together with term explanations and term translations can help to better understand and use the provided thesauri, controlled vocabularies and code lists.

- The automated cross-walking service between terms from different interlinked controlled vocabularies supports easier working beyond the scope and limitations of a single thesaurus or controlled vocabulary alone.

The paper is structured as follows: In Section 2, we sketch the eENVplus Linked Thesaurus Framework for the Environment (LusTRE). Section 3 is about the LusTRE Exploitation Services, showing the software architecture, the REST interface and the list of exploitation service modules under development. Section 4 is about how to use LusTRE-ES and explains use cases and application

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scenarios with the help of some application mock-ups. Section 5 concludes the paper with some information about commercial use and about the current implementation status.

## 2. The Linked Thesaurus Framework for the Environment (LusTRE)

Although different directives (e.g., INSPIRE - Infrastructure for Spatial Information in the European Community) and policy communications (e.g., SEIS - Shared Environmental Information System) have been launched at European-scale with the objective of improving the management of heterogeneous environmental data sources, an effective sharing of these resources is still part of the desiderata, also due to the intrinsic multicultural, multilingual and multidisciplinary nature of the environmental domain. Terminological resources such as thesauri are widely employed as common ground enabling communication among the different communities working in environment-related domains: they allow users to share and agree upon scientific/technical terms in the target domain and to express them in multiple languages. In the recent years several thesauri have been deployed by different communities having a large spectrum of competencies. They have been created embodying different points of view based on different ways of conceptualization. Their development reflects different scopes and implies quite a range of levels of abstraction and detail. All these thesauri are precious and their reusability is pivotal within a Spatial Data Infrastructure (SDI) for providing more homogeneity in data description (metadata compilation) and data discovery.

In eENVplus, we are developing a multilingual, pan-European infrastructure of Knowledge-Organization Systems (KOS: thesauri, taxonomies, ontologies, ...) for the environment considered as a set of interlinked/interoperable terminologies distributed on the Web together with the the services needed for their management and usage. The LusTRE infrastructure addresses the needs of different user communities in sharing digital information at cross-border level, i.e. concept interoperability and concept-availability in multiple languages as it is needed in metadata compilation and information discovery.

In particular, we are building a software framework that allows combining existing thesauri to support the management of environmental resources. It considers the heterogeneity in scope and levels of abstraction of environmental thesauri as an asset when managing environmental data, so it exploits linked data best practices [3, 4] to provide a multi-thesaurus solution for INSPIRE data themes related to the environment. The LusTRE framework extends the common thesaurus framework for Nature Conservation [5] resulting from the NatureSDIplus project (http://www.nature-sdi.eu/). It is based on existing KOSs encoded in the SKOS ontology (Simple Knowledge Organization System) and represented in the RDF data model (Resource Description Framework). LusTRE provides an integrated view on different available terminologies. It is an open environment where it is possible to add, assemble and share in a frame general-purpose KOS as well as domain-specific terminologies. The framework has to be a dynamic environment in the sense that a new KOS may be added or a thesaurus within the framework can be extended easily. For this purpose, the following requirements were considered when building LusTRE:

- **Modularity**. Each KOS should be intended as a module plugged in the set of thesauri included in the framework. In particular, modularity should be preserved in order to eventually include future updates for existing terminologies.
- **Openness.** Each KOS should be easily extendable, in order to possibly add (as separated modules) new concepts and terms keeping separated the original terminology/thesaurus.
- **Exploitability.** Each KOS should be encoded in a standard and flexible format, in order to encourage the adoption and the eventual enrichment from third party system.
- **Interlinking.** Terms and concepts in existing KOS should be interlinked in order to harmonize the term usage from a multicultural point of view.

Altogether, the technology in the Semantic Web field aids to meet these requirements: Hence, the standard model SKOS (Simple Knowledge Organization System) is employed to encode each KOS and Linked Data principles are employed to expose, share, and connect thesauri via Uniform Resource Identifiers (URI) that can be looked up on the Web. In particular, the resource translation to SKOS enables the modularity property, whereas the resource accessibility according to linked data is a key aspect to meet the requirements of openness and exploitability.

At this stage of development, LusTRE is already available as linked data[3], it already includes differrent SKOS/RDF resources such as the **Thist** thesaurus for geology, the **EUNIS** Species and Habitat types, the Digital map on EU Ecological Regions (**DMEER**) and the Environmental Application Reference Thesaurus (**EARTh**) which is adopted as backbone thesaurus in the framework. Besides, it includes *intra-thesaurus interlinks* between Habitats and Species, DMEER and EARTh, as well as an *inter-thesaurus linkset* from EUNIS Species to official EUNIS species provided by the European Environmental Agency, and from EARTh to **GEMET**. Further inter-thesaurus equivalences have been added recently [1]. GEMET's outgoing links to **AGROVOC**, **EUROVOC**, **DBpedia** and **UMTHES** have been imported into EARTh by working out GEMET's *skos:exactMatch* relationships. Unfortunately, links obtained by this procedure only pertain to the subset of concepts that EARTh shares with GEMET. In order to complement that set and find out a more complete connection among EARTh and GEMET's linked datasets, a two-step process has been put in place: First, SILK[4] has been applied to discover new links, then the SILK results have been validated by experts in order to verify the accuracy of the links and to identify the most suitable types of interlinking property (i.e., *skos:exactMatch* or *skos:closeMatch*). The joint exploitation of *skos:exactMatch* transitive closure and the manually validated SILK link discovery have almost triplicated the number of outgoing links available with respect to the previous EARTh releases. In particular, about 7171 links have been discovered relying on the transitive closure, 465 have been generated deploying SILK. This new release paves the way for a combined exploitation of LusTRE with GEMET, AGROVOC, EUROVOC, DBpedia and UMTHES (about 33% of the EARTh concepts have a link to other thesauri) enabling LusTRE adopters in taking advantage of their respecttive strengths and complementarities.

## 3. An Architecture for Exploiting LusTRE Knowledge

### 3.1. Architecture of LusTRE Exploitation Server

Figure 1 illustrates the overall idea of how to make use of the thesaurus knowledge provided by LusTRE in order to improve metadata compilation, harmonization and data discovery, e.g. in geo portals: One one hand, we have end users, who typically create, edit or search metadata which describe spatial data sources or spatial data services. We cannot expect that all users should switch to a metadata management tool (geodata portal, CSW tool, etc.) provided by eENVplus; instead, we offer highly configurable services with standards-compliant interfaces and, in that way, allow all users to extend their existing client software with functionalities exploiting the LusTRE knowledge. This means, "client" in the figure below could be any existing (or new) tool for creating, processing or searching geo metadata. On the other hand, we have the different environmental thesauri which are – through the functionalities of the LusTRE Thesaurus Framework – bound together to a large, multilingual and multidisciplinary conceptual space. The knowledge contained in this conceptual space can, by technicians, be accessed through LusTRE's SPARQL endpoint. However, instead of directly addressing this SPARQL endpoint, the LusTRE

[3] http://linkeddata.ge.imati.cnr.it:2020/

[4] http://wifo5-03.informatik.uni-mannheim.de/bizer/silk/

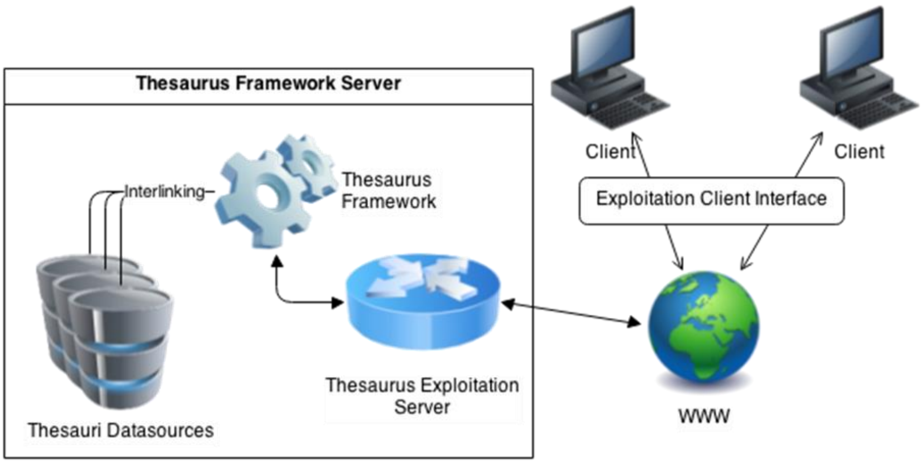


*Figure 1: Overall Usage Scenario for Interlinked Thesauri*

Exploitation Server (LusTRE-ES, Figure 2) manages all interactions with clients.

For better expandability and flexibility, the LusTRE-ES is designed as shown in Figure 2: It consists of an (i) HTTP Server that offers a REST interface; (ii) a Service Manager; and (iii) a non-empty set of Service Modules. The main task of the **Service Manager** is to delegate requests from the HTTP server to suitable Service Modules based on their exposed capabilities, to collect returned *Callables* from Service Modules, to orchestrate the execution of the *Callables* and route back the query results to the HTTP server.

The **Service Modules** provide the core functionalities of the system. They implement the various exploitation-functionality logics, practically by translating an end-user request in a (set of) SPARQL query/ies. The Service Modules are the only points of contact between the thesaurus framework back-end and the rest of the exploitation layer. The modules are like pluggable cartridges for the system engine, each of which enhances the behaviour of the system in certain domains or criteria. The architecture of the system allows these modules to be totally independent from each other, to focus on the one and only task they have: "perform a specialized query from the TF". For each request type supported by a Service Module, it must offer a separate interface that has a public method which returns a *Callable<T>* as result. Each Service Module can be developed in a single class which must implement at least (but not limited to) one of the request type interfaces. It must include an implementation of all the public fields and methods of the request type interface. The

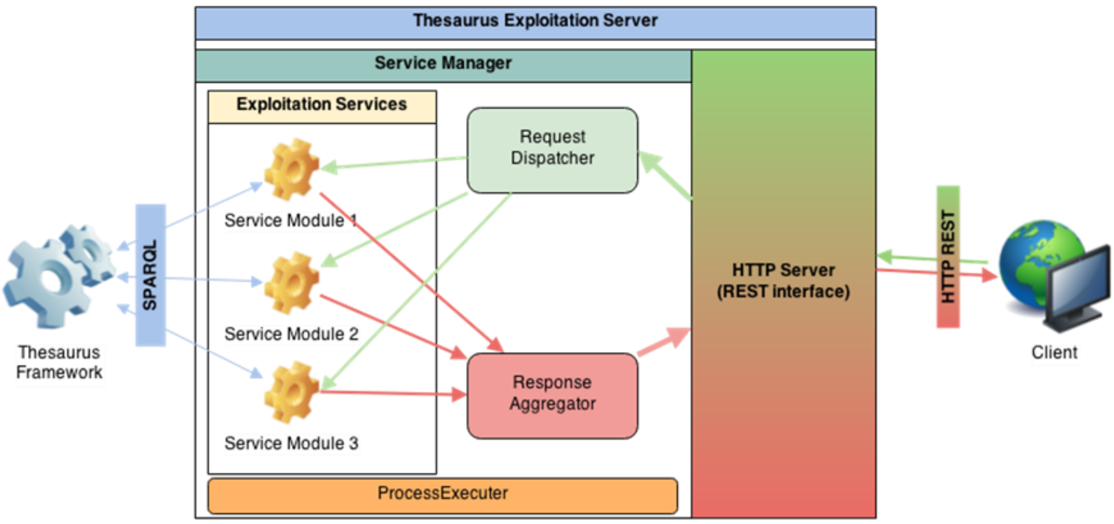


*Figure 2: Components of LusTRE Thesaurus Framework Exploitation Server*

rest of the logic, as well as any number of private methods and fields, can be freely defined and developed by the developer to address the task the service module have to carry out. Following our Service-Module design guideline, a uniform interface for all the Service Modules can be maintained. The advantage of such a design is that every Service Module includes *only* the solution logic for the task at hand, and the Service Manager can orchestrate the execution of the processes.

## 3.2. REST Interface Operations

The REST interface foresees one operation to be offered by all Service Modules and by the Service Manager, namely the *GetCapabilities* operation as the starting point for every client to gather the basic service information as well as a capabilities catalog as a guide to the available operations and resources. Further, there are two operations (*DescribeConcept, ResolveThesaurus*) that shall be answered by exactly one Service Module (see below). But the most often used operations for accessing thesaurus knowledge may be interpreted differently by different Service Modules.

- The purpose of the *GetSuggestions* operation is to suggest matching thesauri concepts upon receipt of a lexical keyword, or a part a lexical keyword. The matching logic and the actual criteria for matching the thesauri concepts depend on the active Service Modules in the system.
- The purpose of the *GetSynonyms* operation is to query for all concepts which are considered to be synonyms to the input concept. The equality logic and the actual criteria for finding the synonymous concepts depend on the active Service Modules in the system. For example, some module might deploy cross-walking through different thesauri in order to include inter-thesauri synonyms by considering also synonyms *(skos:altLabel)* and preferred labels *(skos:prefLabel)* coming from the interlinked *skos:conceptScheme*.
- The purpose of the *GetRelatives* operation is to query for all concepts related to the input thesaurus concept. The relationship logic and the actual criteria for finding the relative thesauri concepts to the given concept depend on the active Service Modules in the system.

## 3.3. List of LusTRE Exploitation Services Under Development

The following Table 1 includes the list of service modules and their respective capabilities currently being developed for the eENVplus project.

| **Service Module Name**<br>**Capabilities** | **Description of operation execution** |
|---|---|
| **KeywordCompletion**<br>*GetSuggestions* | Given a series of characters as part of a keyword, this module will query the thesaurus framework and return a list of thesauri concepts.<br>Selection logic: based on *prefLabel* and *altLabel*. |
| **KeywordExplanation**<br>*DescribeConcept* | Given a concept URI, this module will return the complete SKOS concept record. |
| **KeywordTranslation**<br>*GetSynonyms* | Given a concept URI, this module will return all the thesauri concepts that are considered synonyms and/or *exactMatch* to the selected concept in any given natural language available for the framework. The functionality includes also cross-walking through the interlinked thesauri to consider the mapped concepts from other thesauri. |
| **ThesaurusResolution**<br>*ResolveThesaurus* | Given a concept URI, this module will return the originating thesaurus to meet TG Requirement 16 of the INSPIRE Metadata Implementing Rules - Technical Guidelines. |
| **QueryReformulation** | Given a concept URI, this module will return all the thesauri |

| | |
|---|---|
| *GetSynonyms* | concepts that are considered synonyms to the selected concept in any given natural language available for the framework. (also through cross-walking, respectively through thesauri interlinking) |
| **AnnotationNormalization**<br>*GetSuggestions* | Given a concept URI, this module will return the best fitting thesauri concept, respect to the agreement of a literal text input and the preferred label of a concept. |
| **SemanticExplorative Search**<br>*GetRelatives*<br>*GetSynonyms*<br>*DescribeConcept* | Given a concept URI, this module will return all related concepts and needed information, for example, to populate a semantic visualization. |

*Table 1: eENVplus Service Modules and Capabilities*

Please note: (1) Some of the Service Modules offer a number of parameters to further describe the requests (for instance, a maximum number of suggested keywords, a limitation to specific natural languages or thesauri, etc.). (2) We usually allow to exchange so-called *KeywordObjects* as operation input and output that contain no only lexical terms, but also the concept URI, if available.

## 4. Use Cases for LusTRE Exploitation Services

Practically, we consider three basic use cases further explained in the subsections below.

### 4.1. Metadata Compilation

When an end user creates, harmonizes, or actualizes metadata, several LusTRE-ES services may be useful: Of course, **KeyWordCompletion** may always save time and reduce error possibilities, it may also increase the level of cross-indexer homogeneity. Using **KeywordExplanation** and **KeywordTranslation** may also help to better understand the offered indexing terms and their correct use – in particular, if one is not working in his mother language or preferred domain topic. Seeing broader, narrower and related terms, also from different thesauri (offered by **KeywordExplanation** or by **QueryReformulation**) may provide further help. A **KeywordValidation** module could even (semi-)automatically provide a „normal form" for a given (set of) metadata record(s) that contains only preferred labels, etc. Such a validation procedure could also be run in batch-mode as a metadata transformation services applied to legacy metadata.

### 4.2. Metadata Discovery

Figure 3 illustrates a possible intended way of using the LusTRE-ES to improve resource discovery based on metadata. Assume a user typing some characters in the search field of his CSW, the LusTRE **KeywordCompletion** could offer a number of potential word extensions (1), maybe even

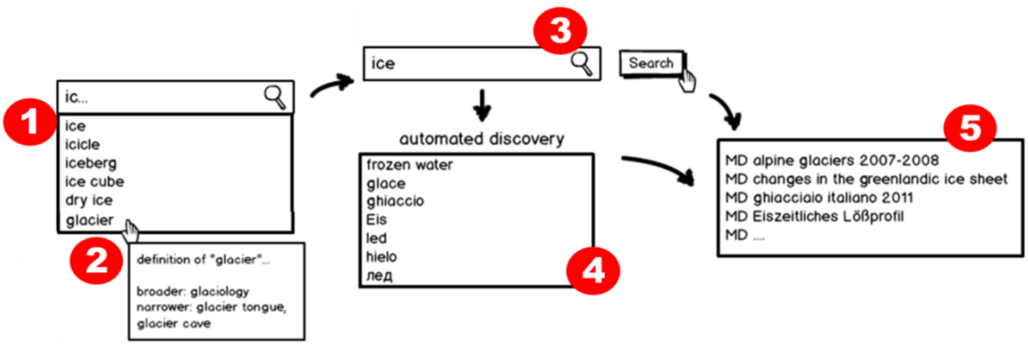


*Figure 3: Mock-Up of Metadata Discovery Use Case*

ones that only match at the conceptual, not at the lexical level (like glacier). Using **KeywordExplanation**, background knowledge about terms could be offered for tooltips (2). If the user decides for some search term (3) and starts the query, the **QueryReformulation** could provide an extended list of search terms such that also synonymous, translated or closely related terms could be included in the search (4), finally leading to a more complete result set (5).

### 4.3. Semantic Explorative Search

The third use case can be combined both with metadata creation and with resource discovery. Our so-called **SemanticExplorativeSearch** module provides the "conceptual neighbourhood" of a given keyword which allows building up an interactive, browsable concept map which helps an unexperienced user to better understand a concept in all its facets and relational contexts. Figure 4 illustrates the idea in a mock-up. Here, the term "Soil" is shown with its GEMET broader term and narrower terms as well as access to its definition and its translation. Further, there are navigations to related GEMET terms and one inter-thesauri link to the *skos:exactMatch*, namely "Soil" in EarTH – that has, e.g., completely different broader and narrower terms since it represents a different perspective on the topic.

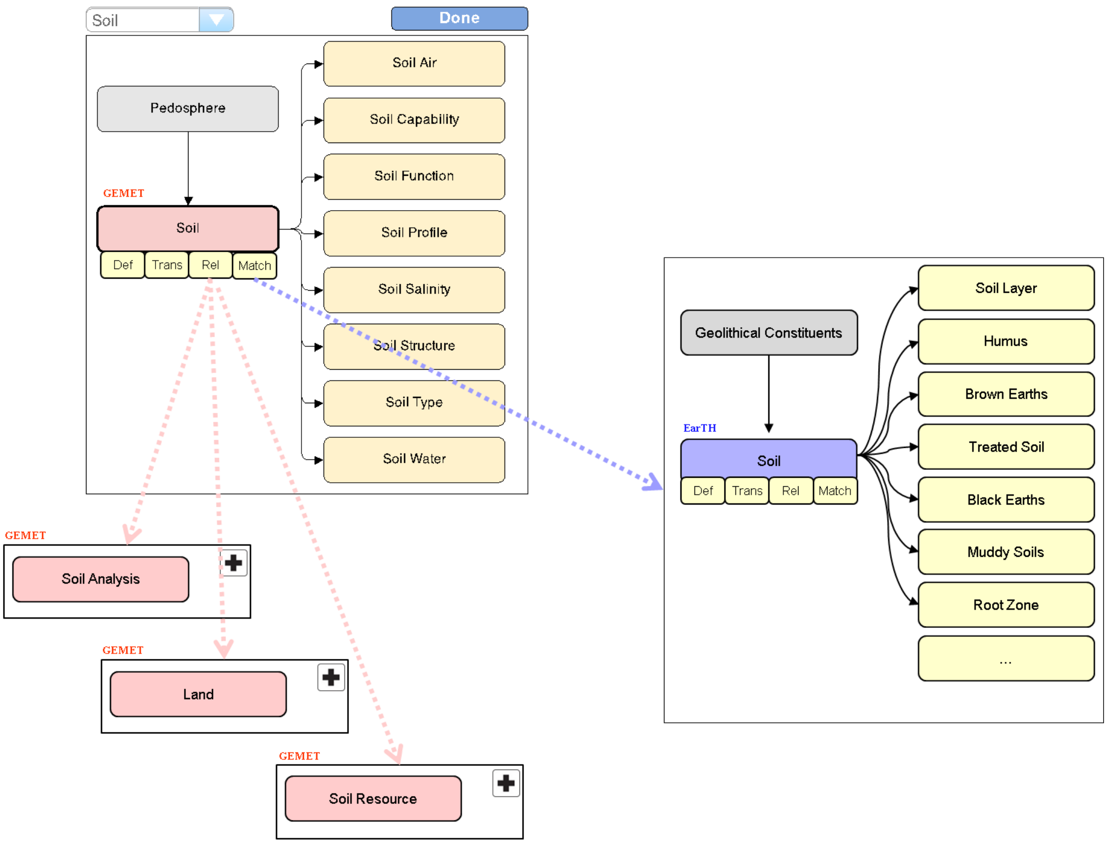


*Figure 4: Mock-Up of Semantic Explorative Search Use Case*

## 5. Conclusions

When writing this paper, the LusTRE is already publicly accessible. The LusTRE-ES architecture is running and will stepwisely be populated by Service Modules during summer and autumn 2014. The integration with different clients is being tested. The service usage will be prototypically implemented by integration with (1) the eENVplus metadata tool under development, (2) the JRC geoportal developer version and (3) with the commercial metadata management tool Disy Preludio.

The **Preludio metadata management system** supports editing, managing and searching for meta

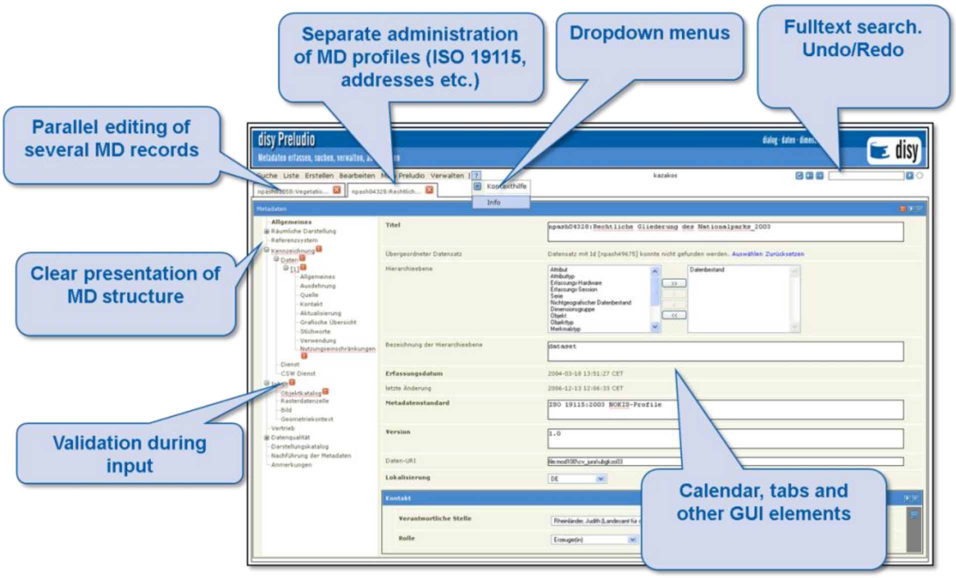


*Figure 5: Some Preludio GUI Design Principles and Functionalities*

data that describe data and services in a spatial data infrastructure. Preludio is compliant with INSPIRE, OGC and ISO standards 19115/19119/19139. It implements a metadata server following the Catalog Web Services standard CSW 2.0.2. ISO API 1.0. Preludio has a Web application similar to the MS Windows GUI principles, with a full-text and extended search, as well as an integrated map viewer. A main design goal for Preludio was user-friendliness and usability, putting much emphasis on a clear presentation of the metadata structure. It allows parallel editing of several metadata entries and provides manifold mechanisms for automated validation during the input. Such mechanisms comprise specification of default values for metadata fields, default values depending from the actual input, automated validation against schema and INSPIRE implementation rules, as well as calling the German GDI-DE INSPIRE test suite. The metadata is stored in a relational database. Both the metadata schema and the system GUI can be freely configured. One application can simultaneously support several metadata profiles. Preludio allows the integration of external Web Services. Preludio is widely used in German environmental agencies.

First integration experiences will be available during late 2014. A full integration with Preludio is planned for mid of 2015. Conceptually, one of the more promising upcoming challenges is an understandable, yet powerful GUI design and interaction design for the visualization tool working with the **SemanticExplorativeSearch** module.

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# A Sensor and Semantic Data Warehouse for Integrated Water Resource Management

Andreas Abecker[1], Torsten Brauer[1], Babis Magoutas[2], Gregoris Mentzas[2], Nikos Papageorgiou[2], Michael Quenzer[1]

## Abstract

The goal of the EU-FP7 project WatERP is to achieve more interoperability of software systems along the water-supply chain. A central element to achieve that is the WatERP Water Data Warehouse which shall act as a central data-exchange platform between different software systems. The WDW shall be able to store and provide sensor, measurement and forecasting data, as well as semantic knowledge about the water-supply chain. It shall be as standards-compliant as reasonable and shall offer query and reasoning facilities over sensor data, spatial information and ontological knowledge. In this paper, we show the basic architecture of the WDW and shortly discuss its main design decisions.

## 1. Motivation

A holistic view on the way of a drop of potable water, starting with a precipitation in a river catchment area or with a deep-well to an aquifer, and ending with a private household, an industrial or agricultural consumer, reveals a whole bunch of administrative, commercial and societal actors and stakeholders that altogether create the drinking-water supply chain or value-network, or have some interest in it. Depending on the respective regulatory, administrative and economic system in a country, the specific form of this value-network differs significantly from country to country. Nevertheless, it is always composed of a number of different actors (if we also consider private consumer households, even a huge number) with significantly differing ways of working, depending on their place and their role in the water-supply chain. Such actors can be, e.g., bulk-water suppliers, dam administrations, local or regional utility companies, large industrial consumers, private households, but also environmental agencies, NGOs, etc. Seen from the legal perspective, these actors comprise also different kinds of organizations, public authorities, administration unions, special-purpose associations, private companies, public-owned enterprises, public-law institutions, private persons, etc. Also the tasks related to the water-supply chain are not restricted to providing water to consumers, but also affect constraints and secondary goals, like energy production, flood protection, environment protection, and – of course – quality control and quality assessment of the delivered drinking water.

It is a nearby hypothesis that some of the activities in such a multitude of actors, actions and objectives could gain efficiency or effectiveness if there was a comprehensive and prompt exchange of data between different stages in the supply chain. For instance, when optimizing the water distribution in temporarily droughty areas, an early estimation of the upcoming water yield of a bulk-water supplier at a given interconnection point together with a good short-term/mid-term estimation of the different competing consumers' demand could facilitate the reduction of causes of conflict. Furthermore, economic incentives (like flexible water tariffs), organizational measures (timed coordination between different industrial consumers), motivational activities (giving information or appeals to the citizen) or regulations (setting of quotas) – as methods of *Demand*

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*Management* – could be better coordinated. Or, in the case of a foreseeable peak-demand, the water production can be controlled more efficiently (operation management of deep-wells, water works, reservoirs, etc.). But also in water-rich areas, optimization potentials can be expected, in particular with respect to the energy consumption and/or energy costs (in the case of flexible energy tariffs) needed for operating the water-distribution network (pumps for filling elevated tanks and for keeping the water pressure), if one takes into account more exact demand forecasts and/or more actual consumption data or if one coordinates the consumption-plans of large industrial customers.

However, such a systematic, comprehensive and real-time data and software interoperability throughout the whole water-supply chain is not given at all, at the time being. Typically, if there is communication/coordination between two actors, then it is between two immediately subsequent stages in the value-chain, it is done for the immediate usage in a work process, and it is often realized with simple, often tailor-made, technical means, and not always refers to most actual data.

In order to improve this situation, the EU-FP7 project **WatERP** ("Water-Enhanced Resource Management – Where Water Supply Meets Demand") [1, 2]

- on one hand, realizes forecasting and decision-support tools for optimizing the whole water-supply chain (tools for demand forecasting, for energy-optimized network operations, for demand management, etc.), and
- on the other hand, implements a data-exchange platform through which the different actors in the water-supply chain can share their observation data, forecasted values, and management decisions.

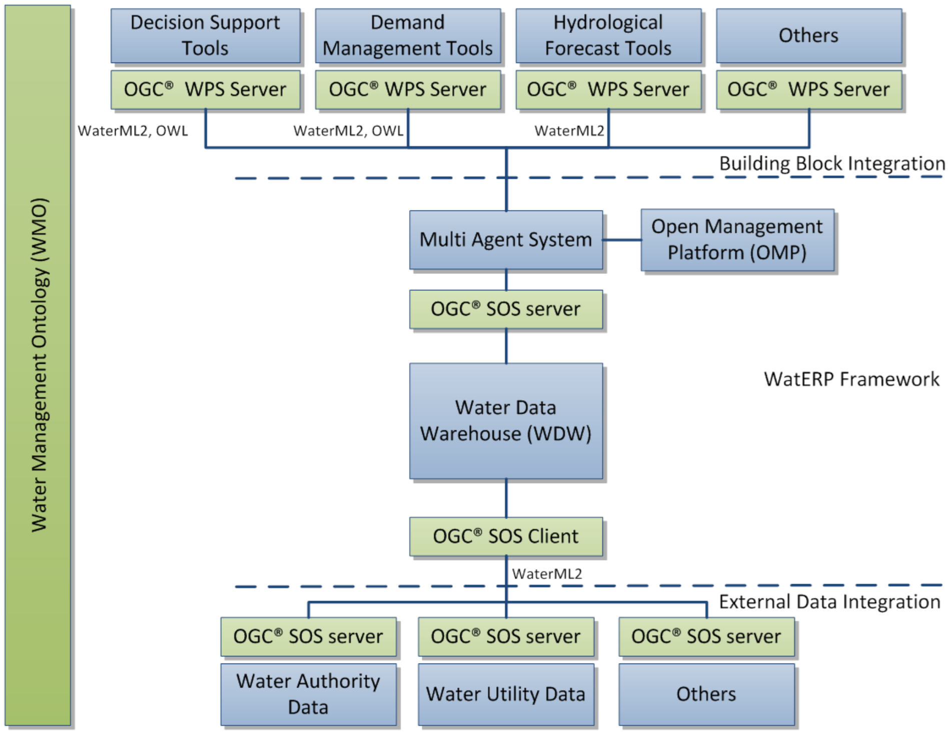


*Figure 1: Overall WatERP Software Architecture*

Here, it should also be noted that optimization potentials do not necessarily need to span *different* organisations; often enough, there are already interoperability deficiencies between the software systems of only *one* actor.

The main element of the WatERP data-exchange platform is the so-called **WatERP Water Data Warehouse (WDW)**. In the WDW, different kinds of data, information and knowledge created in

the water-supply chain is centrally collected and stored and is provided for different tools and purposes in different views, formats, aggregations, etc.
Figure 1 gives an overview of the overall WatERP software architecture: The WDW stands at the center of the system. It is fed by data-producing systems linked to the WDW through OGC SOS interfaces exchanging WaterML2.0 data. The data-consuming, decision-support tools realize a Service-oriented Architecture (SOA), enabled by the OGC WPS (Web Processing Service) protocol for communication, and facilitated by a Multi-Agent Systems which helps to find appropriate services and orchestrate complex processing workflows. The conceptual backbone of the system is the WatERP Water Management Ontology (WMO) which represents all decision-relevant aspects of the water-supply chain as an OWL knowledge base (see also [1, 2]).
This paper is structured as follows: In Section 2, we describe the overall architecture of the WatERP WDW and introduce some main design decisions. In Section 3, these design decisions are discussed with some more detail. Finally, we conclude with Section **Fehler! Verweisquelle konnte nicht gefunden werden.**.

## 2. Architecture of the WatERP Water Data Warehouse

The Water Data Warehouse copies data from operational systems and offers them in optimized views, aggregations and formats for analysis purposes. Typical functionalities of a Data Warehouse comprise data harmonization, measuring fault assessment, data cleansing, as well as purpose-specific selection, view and aggregation mechanisms. Figure 2 sketches the WDW architecture within the overall project context. One major design decision was to devise **two separate storage areas**:

- **Mass data** (time series describing sensor measurements about hydrology, network operation, meteorology, …) is typically highly repetitive, very simply structured, but coming in large volumes. Large amounts of this kind of data can easily and efficiently be managed with "conventional" database technologies, in our case, an *object-relational storage area* (*PostGIS* database). These data populate a data schema which is based on the structure of the OGC / ISO conceptual model „*Observations and Measurements*"[3] and on OGC *WaterML2.0*[4], respectively.
- On the other hand, in order to describe all decision-relevant aspects of a water supply chain comprehensively – which might be needed to allow interoperability of formerly isolated systems responsible for specific complex tasks – one might have a need to describe more irregularly structured knowledge, **complex relationships** between objects, definitions of technical terms or interrelationships of them, or generic relationships which abstract away from specific facts (like rule-based knowledge or arithmetic relationships). For expressing such more complex issues, computer science has developed knowledge-representation languages for expert systems which have been consolidated and standardized through "Semantic Web" technologies. In the Semantic Web area, so-called triple stores have been introduced for storing and processing complex knowledge. More recently, *triple stores* have been extended towards geospatial reasoning which allows drawing logical deductions that also include also simple notions of spatial relationships and spatial deductions. For instance, sensors could be geo-referenced and the system could, if appropriately modelled, find all sensors in a given administrative district or in the state which comprises this district; or all sensors situated on the rivers that a given public authority is responsible for. So, the second main storage area of the WatERP WDW is a triple store enabled to do geospatial reasoning (*OWLIM* triple store with

[3] http://www.opengeospatial.org/standards/om
[4] http://www.opengeospatial.org/standards/waterml

*SesameAPI* together with the *uSeekM* library to add geospatial search functions and geospatial reasoning through the *GeoSPARQL* query mechanism).

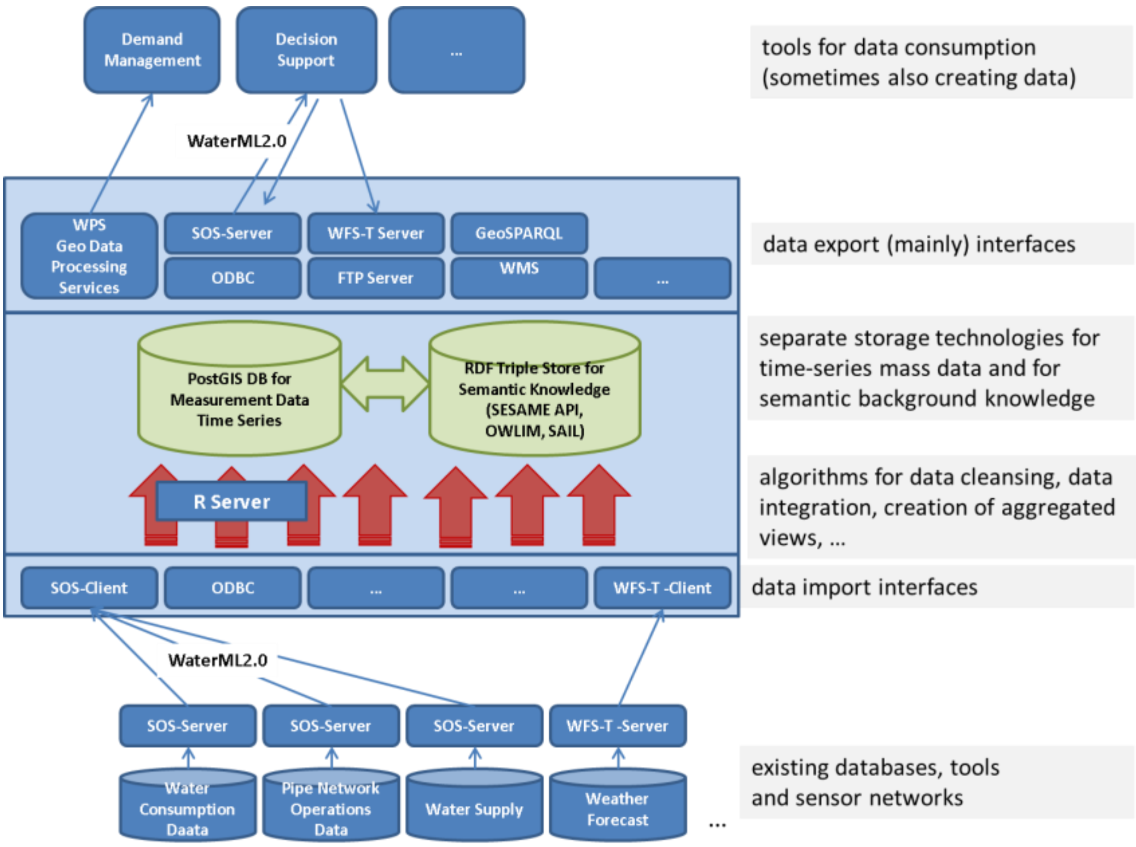


*Figure 2: Simplified Architecture of WatERP Water Data Warehouse*

A second important design decision was to base all developments to the most possible and reasonable extent on the **open standards of the Open Geospatial Consortium (OGC)** which is the most important data and software interoperability organization in the geodata area. Hence, all sensor and measurement transmission activities as well as the internal organization of the time-series PostGIS database follow the OGC WaterML2.0 specification.

Thirdly, it should be noted that many data pre-processing steps can excellently be realized through the **R**[5] **statistics software** which has also extensions to directly interoperate with SOS sensor data streams.

All these three design decisions are explained with some more detail in the following section.

## 3. Discussion of Specific WDW Design Aspects

### 3.1. WaterML2.0 and SOS

All sensor and measurement transmission activities follow the **OGC SOS protocol** with **WaterML2.0 as data schema**. The internal organization of the mass-data storage also implements a simplified and tailor-made data schema based on the OGC WaterML2.0 data specification. For implementation, we employed the 52°North SOS Server.[6] All data sources are linked to the WDW through SOS – except for the meteorological forecasts where we considered WFS/WFS-T more

[5] http://www.r-project.org/

[6] http://52north.org/communities/sensorweb/sos/

suited for representing the structure of the data. Of course, time-series data are also offered through SOS/WaterML2.0. In our practical experience, up to now, the existing infrastructure works stable and reliable. Regarding parallel processing of many sensors, the solution seems to work very well. We discovered one problem of the 52°North SOS Server in the situation that one would try to send as one large package a huge number of observations (> 1 Mio) with the full WaterML2.0 metadata. Of course, this is not the usual use case for SOS (where a data stream comes in package-wise step-by-step), but it could happen in the case of importing a larger legacy observation database. In such a case, the server would probably crash. But, of course, dividing the database into smaller packages or loading as a CSV file would help. In general, the OGC SOS protocol with the WaterML2.0 data format turned out to be a powerful and stable infrastructure in our experience.

### 3.2. Semantic Knowledge Base and Geospatial Reasoning

The incorporation of a semantic knowledge base follows the current trend to empower modern software solutions by knowledge-based components, to increase interoperability through ontologies and to provide data with *Semantic Web* methods according to the *Linked Open Data* paradigm. However, a complete "semantification" (representation, storage and processing of all aspects with Semantic Web methods and tools) of all data in WatERP seemed not feasible and promising to us, especially regarding the measurement data. Instead, the time-series data and the semantic knowledge complement each other and could together be exploited for powerful analyses and queries about the considered water supply system. For instance, the structured relationships in the triple store might be used to logically describe a water-distribution network and its geospatial aspects, as well as some background knowledge, for instance, about measurement methods for assessing water quality. Then, specific water-quality measurements could continuously be fed as time series into the PostGIS database. The metadata for measurements would have references into the knowledge base. This allows making complex queries which combine time-series sensor data and semantic background knowledge. For instance, one could ask for all measurements made in a certain geographic area and using an analytical sensor technology with certain characteristics; or, about all sensor data from a certain point on in the water supply chain which make statements about a certain group of related chemical or biological pollutants. Analysing the answers could help to find upstream dischargers responsible for a contamination and take appropriate counter-measures, or it could help to identify endangered spots further downstream and take suitable protection or purification measures.

It should be noted that, as a side-effect of the overall architecture, the simultaneous evaluation of quantitative, measurement-data based and qualitative, knowledge-based conditions in *one* query cannot be done *within* the WDW framework. So, if one would like to find, for example, all sensor observations coming from a certain administrative area (spatial reasoning) and made with a certain type of sensor technology (structural reasoning) which are above a certain threshold (sensor value), this would have to be implemented as a query agent outside the WDW that merges the query results of the SOS sensor-data query and the logic-based query.

Figure 3 shows the implementation of the WDW geospatial reasoning which is based on the uSeekM und Sesame Java libraries in combination with the PostGIS geodatabase and the Sesame-based RDF triple store OWLIM. **Sesame**[7] is a Java framework for the implementation of RDF stores that offers an extensible API on top of which other stores can be built. OpenSahara **uSeekM**[8] is a Java library which realizes spatial indices and spatial queries as an extension of Sesame Java based triple stores. uSeekM creates a separate R-Tree index for spatial data. It catches

[7] http://www.openrdf.org/

[8] http://www.w3.org/2001/sw/wiki/USeekM

GeoSPARQL[9] queries and rewrites them as a combination of queries against the spatial index and the RDF triple store. Different triple stores can be used, as far as they support Sesame Sail. The **Sesame Sail** API allows for functional extensions of RDF stores as a low-level system API for RDF stores and inference engines which abstracts from implementation details and so allows to use different stores and inference engines. In WatERP, we employ **OWLIM**[10] as an RDF store that allows reasoning over an OWL ontology, such that, altogether, the WDW Triple Store allows combined reasoning over ontological and spatial knowledge.

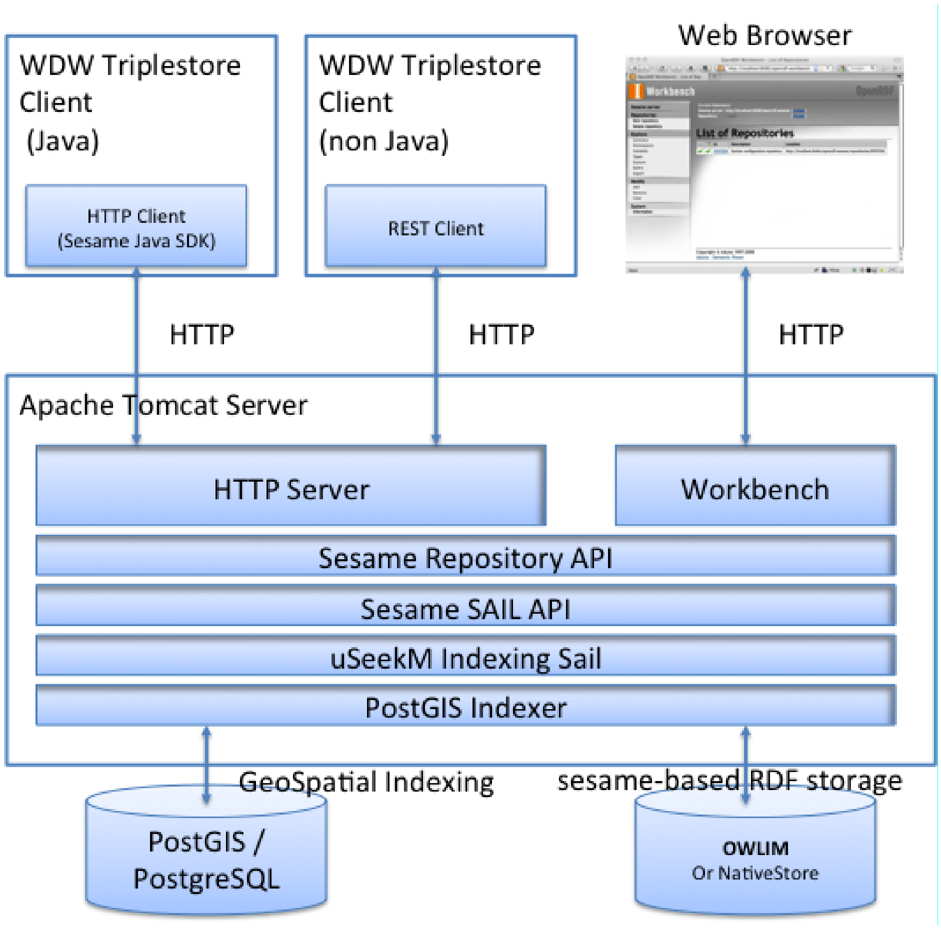


*Figure 3: Semantic Reasoning Architecture within the WDW*

### 3.3. ETL Processes and Aggregations

A typical functionality of a Data Warehouse is the provision of so-called ETL processes *(Extract – Transform – Load)* in order to pre-process incoming data, for instance for data cleansing or for data integration. Moreover, it is often useful to create certain (spatial, temporal or topical) data projections, views or aggregations and store them explicitly for more efficient further processing. In WatERP, we employ the R software workbench for realizing such pre-processing algorithms because R offers already a huge number of efficient implementations of statistical and geostatistical data-processing routines. There is also already a connection between R and SOS. Figure 4 indicates how we integrated R routines into the WDW architecture: As soon as an SOS sensor receives new data, this may trigger predefined processing steps. Such a processing step is defined by the R script to be run and its appropriate parameters. The result of the script-application is a modified

[9] http://www.opengeospatial.org/standards/geosparql

[10] http://www.ontotext.com/owlim

measurement-data time-series which is then stored in the SOS server as a “derived SOS sensor”, i.e. a virtual sensor.

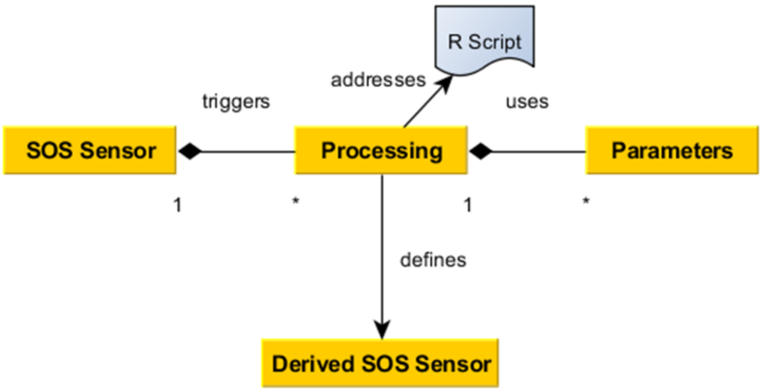


*Figure 4: Integration of R Pre-Processing Scripts into the WDW Architecture*

## 4. Conclusions

**Status and real-world impact.** At the time of preparing this paper, the first fully working prototype of the WDW is up and running and is actually being filled with real-world test data of the two WatERP pilot users, the *Catalan Water Agency* (Agencia Catalana de l'Aigua / ACA, Barcelona, Spain) and the water utility of the city of Karlsruhe (*Stadtwerke Karlsruhe* GmbH, Germany). In the ACA case, e.g., Integrated Water Resource Management is supported such that, through the WDW, the water supply measurements are connected with a Water Demand Management System and a Decision Support System. The interoperation of these different tools and the data exchange between different parties shall help to more efficiently distribute the water resources stored in reservoirs among different utility companies working with one bulk supplier and also among the different competing kinds of water usage (agriculture, industrial use, domestic use).

Although first estimations in the project suggest that water savings in the dimension of 8% in the ACA pilot and energy savings in the dimension of 5% in the Stadtwerke Karlsruhe pilot may be achievable through more integrated and smarter software, it would be dubious to make such promises at this point in time. First, we deliver and test a technical solution. The concrete impact of applying such solutions highly depends on the exact usage situation and the exact way of usage. But we hope to gain more insights about that in the piloting phase 2014/15. In general, the success of many specific use cases will also highly depend on non-technological issues, like the regulatory framework, the incentive systems for data exchange, etc. It might also be the case that for an operational roll-out of a WatERP-like solution, a very strong privacy and data-protection layer would have to be integrated because stakeholders might not send their data to a central system if it was not ensured that unauthorized access is impossible.

**Scientific-technical contribution.** The main contribution consists in the engineering and the proof-of-concept implementation of the WDW architecture with its different kinds of data and knowledge and different kinds of reasoning possible. This concerns, on one hand, the stability and usefulness of the selected and integrated elements (52°North SOS server, SOS protocol, WaterML2.0 data schema, R server, OWLIM, uSeekM, …) and, on the other hand, the way of integration (separate storage areas for measurement data and semantic knowledge, defining R processing results as derived sensors, …). In general, we believe that such a combined solution of a standards relational data warehouse with a powerful spatial-reasoning enabled technology is unique.

**Limitations and next steps.** Technically, this prototype is not yet suitable for processing many high-frequency data streams in (near)real-time (for instance, continuous gauge values from thousands of metering points in a flood-endangered river catchment area, or continuous smart-meter data about water consumption of thousands of households). Instead, both pilot application scenarios can live with considering several hundreds of domain objects (water-transmission points between stages in the supply chain, deep-wells, water works, reservoirs or elevated reservoirs, head pipes, pressure zones, …) and a data actualization interval in the dimension between an hour and a couple of days. Scaling-up our solution towards a more real-time and more fine-grained data-collection mode would certainly create new challenges regarding performance and software architecture. Here, recent methods from *Big Data* processing could be employed. Nevertheless, already the current approach offers manifold potential benefits to our end users. It is not obvious whether and when they would technically and organisationally be able to create and reasonable employ huge, high-frequency data streams.

To sum up, the main emphasis of the last project phase in Autumn 2014 – Autumn 2015 will be the piloting in the two test beds. Technically, this could raise some additional work with respect to software usability, stability and efficiency. Also, the integration of the WDW with the complex WatERP overall infrastructure and its deployment in the real-world scenarios will not be trivial. Nevertheless, we are confident that we can provide functional and stable technical prototypes. The next interesting question will be whether the expected benefits for the pilot users can be realized. Within the area of water supply, there are certainly further additional potential benefits from increased data exchange between different parties that were not yet considered in depth. For instance, leakage detection and long-term pipe-network planning could be improved. Further, we expect that the technical solution of WatERP for multi-stakeholder data exchange can be applied far beyond the scope of water resource management, e.g. in the general broader scope of *Smart Cities.*

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# Orchestration of Geospatial Processes with RichWPS – a Practical Demonstration

Dennis Ziegenhagen[1], Jörn Kohlus[2], Rainer Roosmann[1]

## Abstract

Distributed geospatial data and services can be used to form Spatial Data Infrastructures (SDI). Current technological developments enable SDI to process large amounts of geospatial data. In this context, Web Processing Services (WPS) can be used as an open interface standard for accessing and executing geospatial processes. Since many SDI are based on Service-Oriented Architectures (SOA), the orchestration of services is enabled by composing existing services. The results are higher services, e.g. complex geospatial applications. The RichWPS research project focuses on analysing and providing practical approaches of web service orchestration. For this, software components are developed to build a modular orchestration environment. Real-life examples of geospatial processing are analysed and divided into simpler, reusable sub-processes. Using the RichWPS environment, the sub-processes are implemented and arranged as workflow models, which are deployed to an extended WPS server and interpreted by its orchestration engine. This enables workflows to be executed by WPS clients. This paper presents the RichWPS environment and one of the analysed real-life scenarios. The example scenario “Macrophyte Assessment” contains the assessment of water plants in order to report on the water’s qualitative status. This meets requirements of the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) of the European Union. The scenario is analysed in order to identify elementary processes. With the use of RichWPS components these processes are orchestrated to form an executable assessment procedure.

## 1. Introduction

With the current developments in Geographic Information Systems (GIS), Spatial Data Infrastructures (SDI) offer opportunities to distribute and process spatial data [1]. SDI implementations are mainly based on the Service-Oriented Architecture paradigm (SOA) and offer access to shared geospatial data and applications [2]. Therefore interoperability and a uniform service access are necessary. Both aspects are supported by open web service standards. In the scope of geospatial services, the Open Geospatial Consortium (OGC) defines widely used standards, commonly referred to as OGC Web Services (OWS).

This paper focuses on OGC’s Web Processing Services (WPS) to enable a modular orchestration of distributed geospatial processes and data. In terms of the SOA paradigm, *service orchestration* is a method to design higher services by composing existing services [3]. As the web services technology has matured in the past years [4], it meets the requirements of distributed geospatial systems. Thus, web services are able to form the technological basis of geospatial infrastructures and enable further research on web service application and opportunities for future extensions.

### 1.1. The RichWPS Research Project

RichWPS is a research project funded by Germany’s Federal Ministry of Education and Research[3]. It focuses on inspecting and improving the practical use of WPS inside distributed geospatial

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systems like Spatial Data Infrastructures (SDI). Research results are compared to existing solutions, e.g. web service orchestration using the Business Process Execution Language (BPEL) together with the Web Services Description Language (WSDL).

To achieve and analyse the desired project results, multiple software components are developed which together form a comprehensive OWS orchestration environment. The development is done by Osnabrück University of Applied Sciences[4] and Disy Informationssysteme GmbH[5]. The environment includes a WPS 1.0.0 implementation conforming to OGC's standard. To increase the practical functionality, the implementation also picks up ideas of transactional WPS (WPS-T) and other aspects of the forthcoming standard version WPS 2.0. The aim is to enable an easy creation and use of complex geospatial processing applications for a large domain of users.

Real life use cases and example scenarios are provided by the project partners, Schleswig-Holstein's Government-Owned Company for Coastal Protection, National Parks and Ocean Protection[6] and Germany's Federal Waterways Engineering and Research Institute[7]. The scenarios contain applications of geospatial processing with the potential to be described as a workflow arrangement of less complex processes. Hence, the initial scenario processes are divided into functional units and each of these units is made available as a WPS. The aim is to extract simple processes which can be utilised as widely reusable building blocks for geospatial applications.

With the RichWPS environment, data and services like the described processing units can be arranged to form workflow models. Loops, conditional forks and other control structures allow dynamic and flexible workflows. Arranged models can be validated, tested and finally deployed onto a server which enables workflows to be executed by WPS client applications.

## 2. The RichWPS environment

To build a flexible and modular orchestration environment, three main software components and a domain specific language (DSL) are developed. Creating, testing and deploying workflow models are tasks of the *RichWPS ModelBuilder*. It uses the *RichWPS SemanticProxy* as a directory service to look up and receive semantically enriched information about available OWS. Validated workflow models are translated into the *RichWPS Orchestration Language* (ROLA). This DSL is used to transfer workflow descriptions to the *RichWPS Server*, which interprets the ROLA document and uses it to set up the orchestration engine. After a workflow has been deployed to the server as a new process, it is able to be executed via the server's WPS interface. A visual representation of the environment, including the connected components, is shown in Figure 1.

### 2.1. ModelBuilder

With the ModelBuilder, the task of service orchestration is abstracted and simplified in a graphical and interactive way. Creating a model of the desired workflow hides technical orchestration details and enables editing and adjusting workflows without directly applying changes on a deeper level (e.g. to the server or the orchestration engine). Workflow models are also easy to share with other users and can be used as a base for new workflows to build on.

[3] Bundesministerium für Bildung und Forschung, http://www.bmbf.de

[4] http://www.hs-osnabrueck.de/

[5] http://www.disy.net/

[6] Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz des Landes Schleswig-Holstein, http://www.lkn.schleswig-holstein.de

[7] Bundesanstalt für Wasserbau, http://www.baw.de

Target users of the core modelling tool are experts in geospatial domains. Therefore the user interface and provided functionality should be intuitive and easy to understand. Knowledge of technical details and the underlying systems is not necessarily needed to create complex processing workflows. A simple and well-structured interface design supports the usability. Dynamic visual hints and textual messages provide helpful feedback without distracting users from their tasks.

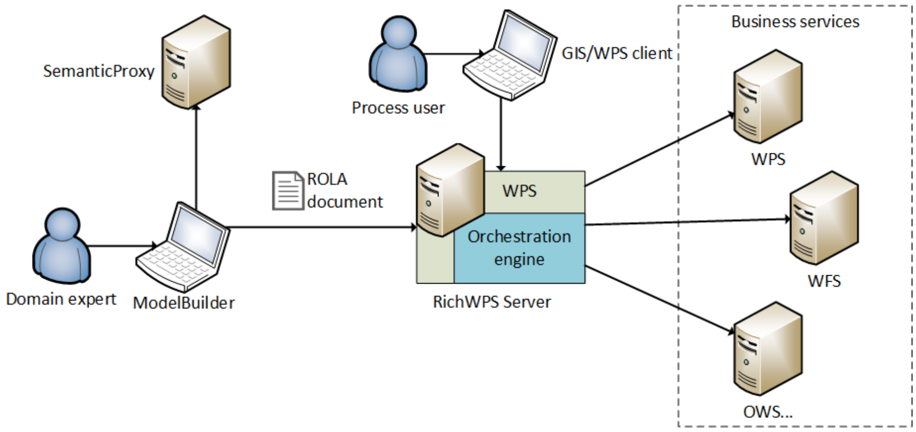


*Figure 1 RichWPS environment*

The ModelBuilder's main window (Figure 2) is divided into four areas. The tree view on the left contains a hierarchically structured list of available modelling elements like services and data sources. Modelling elements can be added to the editor in the window centre via drag and drop gestures. Using the mouse, compatible input ports (green) and output ports (blue) of modelling elements can be connected. Single characters inside input and output ports represent the used data types which are defined by the WPS standard [5]. For example, "L" is *LiteralData* and "C" represents *ComplexData*.

All elements, including connection lines, can be moved and arranged as needed. Additionally, an auto-layout mechanism is provided. The example model shown in Figure 2 also contains explicit input ports (yellow boxes at the top) and output ports (black box at the bottom) which will be the inputs and output of the resulting WPS after deploying the workflow onto the server.

Further information of selected modelling elements is shown in the properties view on the right side of the window. Users are also able to enter necessary input data in the properties view, e.g. literal numbers or strings.

Status information, error messages and other hints are displayed and organized in multiple tabs at the window's bottom. Each tab contains messages belonging to a specific component: SemanticProxy, model editor or RichWPS server. New and unread messages are highlighted.

Other functionality like workflow deployment and process lifecycle management is accessible via the window's menus and toolbar. Helping information is consistently provided for all GUI elements and enables users to easily find the desired function.

In addition to the modelling elements shown in the example, loop and control structures can be used to create more powerful and dynamic workflows. For example, conditional forking elements allow the execution of processes only if a given condition is true (e.g. if specific geometries intersect). This is comparable to *if*-statements in programming languages. Accordingly, an *else*-fork of the condition exists, in order to execute other processes if the condition is not true.

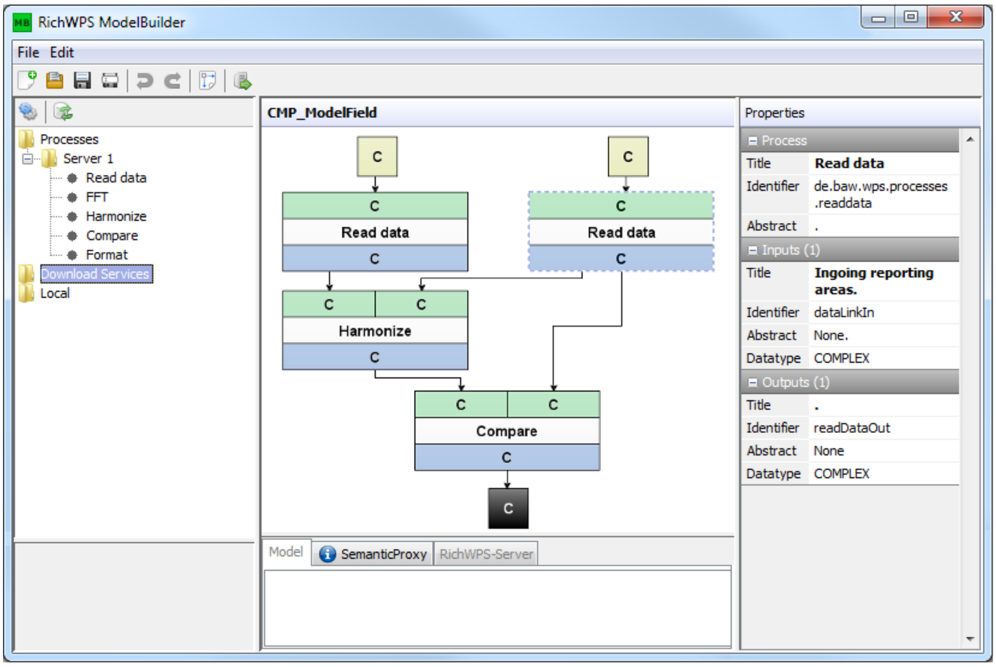


*Figure 2 RichWPS ModelBuilder*

## 2.2. Semantic Proxy

The ModelBuilder receives information about available OWS by connecting to the SemanticProxy. Hence, the SemanticProxy is designed as a directory service which can be searched via a RESTful interface. Information about available OWS is stored in a database and follows the Resource Description Framework (RDF) specification [6].

RDF enables a simple but flexible enrichment of service descriptions with semantic information. For database interaction and modification small client applications are implemented. Their functionality is also integrated into the ModelBuilder to create a bundled core application inside the RichWPS environment.

## 2.3. RichWPS Server

Being based on the 52°North WPS server[8], the RichWPS Server's WPS implementation is extended by a custom orchestration engine. The server's WPS-T interface enables the ModelBuilder and other client applications to deploy workflow descriptions via ROLA documents. These are interpreted by the orchestration engine in order to offer a centralised, controlled execution of the workflow and the involved processes and services.

Additionally, the server provides extended mechanisms for client communication and interaction. They allow ModelBuilder instances to monitor workflow executions and to receive details on the execution status and occurring errors. It is also possible to pause or stop running workflow executions.

The combination of the ModelBuilder and the RichWPS Server forms a comprehensive setup to test and debug workflow models. Test results can be used to improve workflows and to decide on which processes are to be used or preferred.

8 http://52north.org/communities/geoprocessing/wps/index.html

### 2.4. RichWPS Orchestration Language ROLA

ROLA documents are transferred from the ModelBuilder to the RichWPS Server and contain a textual translation of the workflow. They can also be considered as a pre-processing towards the technical orchestration. Thus, ROLA is a domain specific language having a strict syntax that can be interpreted by server components. But it is designed to be still human readable and understandable by choosing appropriate keywords and grammar rules.

## 3. Example Scenario: Macrophyte Assessment

Macrophytes are aquatic plants growing in or near water. The assessment of macrophyte occurrences is one of the real life use cases which are used to analyse and proof the RichWPS concept. The following section describes the use case itself and its implementation using the RichWPS environment.

### 3.1. Scenario Description

The Water Framework Directive (WFD) [7] instructs European Union (EU) member states to achieve good quality status of waters. States are directed to assess and report ecological quality values of rivers and seas. Another important directive for the marine sector is the Marine Strategy Framework Directive (MSFD) [8]. Its main objective is to achieve the Good Environmental Status (GES) of waters by observing and controlling improvements of the marine environment’s quality.

Frequent quality measurements and reports are required by both, the WFD and the MSFD. The EU demands automated reporting systems which deliver the results via web services to the European Commission. This meets requirements of the INSPIRE directive [9] and includes processing large amounts of data in the fields of chemical and biological quality components.

Implementing WFD and MSFD instructions for Schleswig Holstein’s Wadden Sea is inside the scope of Schleswig-Holstein’s Government-Owned Company for Coastal Protection, National Parks and Ocean Protection. This includes the reporting areas “Northern Frisia” and “Dithmarschen”. The presented example scenario covers the creation of macrophyte assessment reports for these areas.

The occurrence and the percentage of the macrophytes *seagrass* and *green macroalgae* is considered as an indicator for the quality of waters [10]. As a simplified summarisation, the quality status of the Wadden Sea is “good” if it contains more seagrass and less macroalgae. The assessment is based on five quality parameters, each evaluated within one of five categories that range from “0 - bad” to “4 - very good”. Combined with the categories, the parameters form an assessment matrix which is used to get the resulting quality status based on the evaluated parameters [11]. The final report contains assessment status for the relevant years: a specific reporting year and additionally the past six years.

### 3.2. Processes and Orchestration

An implementation of the described assessment process as a single WPS has already been done by Wössner [12]. The evaluation process is a chain of filtering and GIS operations. The technical environment for analysing and reporting is defined through the rules of the Marine Spatial Data Infrastructure (MDI-DE), a SDI [13].

In the presented example scenario, this process is divided into reusable and less complex sub-processes. For the assessment, specific input data is necessary, for example the year of assessment, reporting area geometries and raw data of macrophyte occurrences according to the MSFD.

Table 1 contains the resulting sub-processes after splitting up the functionality of the existing assessment process. Each process is implemented as a single WPS, indicated by the green data input ports at the top and the blue output ports at the bottom.

The workflow model shown in Figure 3 uses the processes *SelectReportingArea* and *Intersect* multiple times to demonstrate the desired reusability. Executing the workflow delivers assessed quality status for the reporting areas as ComplexData.

| Process | Description |
|---|---|
| C \| L<br>**SelectReportingArea**<br>C | Returns the reporting area geometry which corresponds to a literal input ID (e.g. "NF" for Northern Frisia) |
| C \| L<br>**MSRLD5selection**<br>C \| C \| C | Gets raw data for algae, seagrass and relevant years from existing MSFD data which is relevant for the given year[9] |
| C \| C<br>**SelectTopography**<br>C \| C \| C | Selects topography based on existing topographies and relevant years |
| C \| C \| C<br>**Intersect**<br>C | Returns the intersection of reporting areas, topographies and relevant years |
| C \| C \| C \| C \| C \| C<br>**Characteristics**<br>C | Returns the reporting area assessments based on the input data |

*Table 1 Example Scenario Processes*

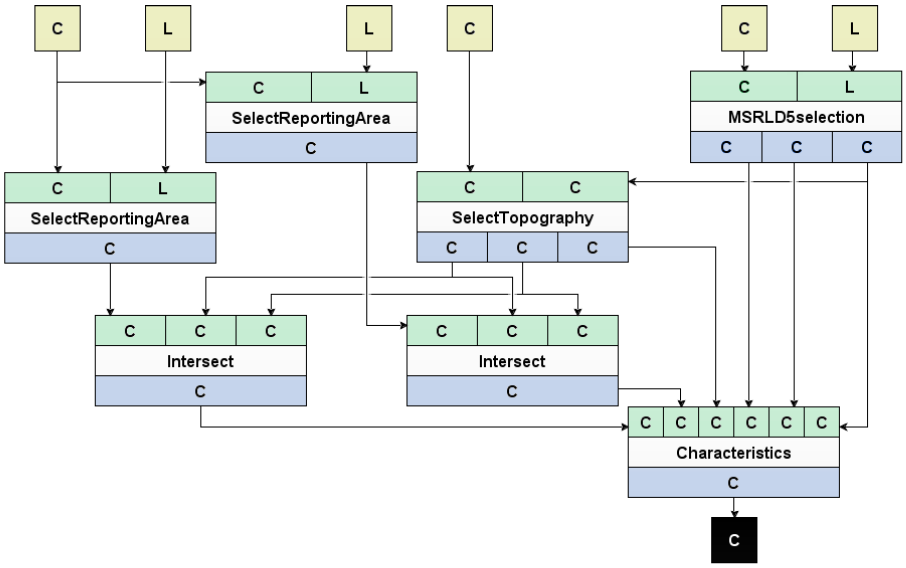


*Figure 3 The Assessment Process as a Workflow Model*

After implementing the single processes as WPS, information about the processes is stored and provided by the SemanticProxy. Using the ModelBuilder the processes are connected and arranged to model the workflow as shown in Figure 3. The modelling result is translated to ROLA and deployed onto a RichWPS Server. After the successful deployment the server's orchestration

[9] MSRL (Meeresstrategie-Rahmenrichtlinie) is the German translation of MSFD, D5 means descriptor 5 which is defined by the MSFD

engine allows executing the workflow by one single WPS *execute* call. This also enables a black box view on the workflow as a covering process as shown in Figure 4. Because of the server's implementation of the WPS 1.0.0 standard, execution calls can be done by any WPS client. The new process is also communicated to the SemanticProxy and thus can be used as a modelling element for other workflow models.

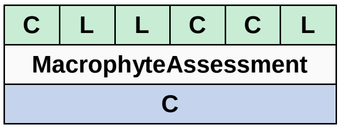


*Figure 4 Black box View of the deployed Workflow*

## 4. Related Work

Web service orchestration inside SOA-based infrastructures is discussed in [14]. At first, the paper summarises relevant technologies, requirements and opportunities. It then focuses on increasing the interoperability of published workflows by introducing the WPS-T standard which the RichWPS project uses.

Re-using distributed geospatial web services to form a business logic component has been demonstrated in [15]. It offers an interface between users and the geospatial data inside SOA infrastructures. Additionally, applications of the WPS standard are demonstrated.

Orchestrating web services using BPEL has been demonstrated in [16]. Mentioned are the advantages of using graphical tools over a hard-coded service orchestration. The use of WSDL is necessary to bring web services together with BPEL. The article states this circumstance's potential of danger to BPEL-processes (and thus to the whole orchestration).

Different software tools for graphical workflow modelling are available. They either focus on a specific subject or offer a comprehensive functional range as Taverna Workbench[10] does. An example for WPS orchestration using Taverna Workbench can be found in [17]. In the example, WPS instances require WSDL descriptions and, instead of the often chosen BPEL, the Simple Conceptual Unified Flow Language (SCUFL) is used.

## 5. Conclusion and Outlook

In early project stages, comprehensive researches and analyses have been done to gather the technical state of relevant technologies and existing approaches. Thus, the project's scope and basic conditions could be specified in detail to precisely prepare the software engineering.

At the time of writing, the software development is advanced and integrating the components to form the environment has been tested. During the development, the example scenarios have partly been implemented to test the components. First results proof the RichWPS environment approach and show the practical usability.

Currently a main task is to continue the integration in order to completely implement the scenarios. This will allow a closer research to get the desired project's results.

## 6. Acknowledgement

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# Collaborative Environmental Data Management Framework for Microsoft Excel

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## Abstract

In many companies Microsoft Excel is often used as a CEMIS for managing environmental data. In collaborative scenarios this single-user application often causes problems. In this article, the multi user framework Quexolver is presented, which supports the simultaneous processing of environmental data in Excel by multiple users. The multi-user capability is provided by introducing a role and rights management concept for Excel users and a client server architecture with a central database. The use of web services provided by the framework (server) enables the communication between the individual Excel applications (client) and the database. First experiences with Quexolver based on a case study from the environmental protection are also described.

## 1. Introduction

The need to detect and evaluate environmental information using IT-systems in companies is constantly increasing. One the one hand, this is due to in stricter laws, standards and guidelines [3]. On the other hand, companies want to access potential to increase efficiency [11] and enhance environmental awareness to prove their reputation among their customers [4]. Unlike tasks in companies which are absolutely necessary, such as human resources and accounting or technical-specific deeds, special software called “Corporate Environmental Management Information Systems” (CEMIS), made for the care and treatment of environmental data, is only used seldom applied [9, 11]. Instead, Microsoft Excel is often used for this task [7]. This is due to the simplicity in collecting and analyzing data, as well as the various methods available for presenting it.

However, the many advantages of Excel are offset by some disadvantages. The collection of data from several sources by multiple users leads to an effort that grows disproportionately with the number of users. For this purpose, either additional communication between users or a central data consolidation is needed. Excel does not support versioning, concurrent acquisition of data and has no role concept. When a spreadsheet is used by multiple users, the complex dependencies of data are often not recognizable and will be thereby in many cases destroyed.

This is where Quexolver enters. The framework was developed to use the advantages of Excel, particularly in the case of data analysis, and to support the collection of data by multiple users. Therefore, Quexolver extends the functionality of Excel by its ability to refer data from respectively transmitted data to a central database. Excel acts as a frontend, through which data can be entered, processed and presented in the usual ways. With Quexolver, necessary functionalities in a multi-user client-server infrastructure are provided: multi-user capabilities, network capability, versioning, roles and rights concept and consistent data storage in a relational database.

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This paper describes the architecture of Quexolver (chapter 3), explains the methodology to develop Excel applications through the use of Quexolver (chapter 4) and refers first experiences from a pilot scheme on corporate environment protection (chapter 5). The paper concludes with a summary and an outlook on further research (chapter 6).

## 2. CEMIS and Excel – Related work

In scientific literature the use of Excel as a CEMIS is rarely discussed. Some authors include Excel as an example for a CEMIS in their definition, e.g. [13], while others explicitly exclude Excel from being a CEMIS, e.g. [6], because of its missing collaborative capability. In practice, Microsoft Excel is in fact widely used as a CEMIS because of its availability, ease of use and capabilities for data processing, analysis and visualisation. Approximately 70% of the industry is using programs for spreadsheet analysis, such as MS Excel, to handle environmental information [1] and to support the various tasks of corporate environmental protection.

CEMIS very often provides respective interfaces to import from or export data two Excel [13]. These interfaces only support one-way communication, which does not allows collaborative work. Data is either imported or exported (e.g. for reporting or visualization), but not both at the same time. It is not possible to edit and update exported data and save changes in the original system.

The file-based single-user solution Excel supports rudimentary collaborative work scenarios by using the shared-workbook feature and placing the file on a network location. But only the user who opens the file first can edit and save data. Other users can only work with a copy of the original file, what leads to several copies of the original file with different data and the need to manually bring changes together.

To be able to use Excel with multiple users collaboratively, different approaches are now created, but each with their own specific disadvantages. Although w*eb-based file server* (file server) (e.g. SharePoint) has shares and rights concepts, they are file-based, and changes are not synchronized (without synchronization). *Synchronized network drives* (e.g. DropBox) synchronize user changes, but are also file - based and do not allow the collaborative editing of the document (without editing function). *Repository -based* approaches (e.g. Kivo) support the ability work collaboratively on a document with common version control, but do not allow simultaneous work on an Excel document in real time.

In contrast, so-called *online spreadsheets* (eg Google Drive, EditGrid, Zoho Docs, Microsoft Office Web App) allow collaborative spreadsheet processing in a web application. These allow collaborative work, but they do not reach the scope and speed of Excel for data processing and analysis. In addition (apart from Office Web App), users cannot use the familiar Excel environment but must instead learn to use a different system. Microsoft's own online spreadsheet "Excel Web Access" supports collaborative work in real time, but provides only a part of the original functionality of Excel.

The Business Intelligence Suite "Jedox base" of the company Jedox upgrades Excel with a MOLAP server. This allows editing Excel-worksheets simultaneously by several users in real time. Furthermore, the commercial suite "Jedox Premium" offers web capability, support for mobile devices and the possibility of integrating SAP.

Except for Jedox all solutions just discussed have only a part of the instruments that feature a multiuser system, such as network capability, versioning, a rights and role concept and consistent data storage in a relational database.

## 3. Architecture of Quexolver

The multi-user capability of Excel is made possible by the Quexolver client-server architecture, which is described in this chapter.

### 3.1. Main components

The architecture of the framework consists of three key components: database, backend and Excel-add-in (Windows/Mac). The communication between Excel and the database is accomplished by means of web services. The implementation of web services is triggered by the respective user. The available web services (with consideration of the roles and right concept) are listed by the Quexolver Excel add-in to the user.

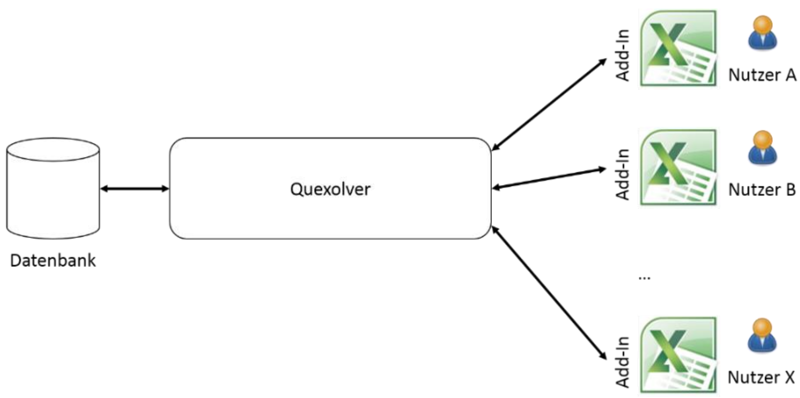


*Figure 1: Excel multi user mode with Quexolver*

The data in an Excel spreadsheet are stored in a central database. Communication between Excel and the database is carried out by web services. The execution of said web services is triggered by the respective user. Considering the respective role and rights, a Quexolver add-in (Windows / Mac) in Excel presents the executable web services to the user.

### 3.2. Interface to the database - Hibernate and DAO

Quexolver, however, is not just an implementation of web services. The interface between the web services programmed in Java and the database is realized through a data access object *(DAO)*[12]. By using DAO it is possible to separate the logic of the program from data storage. This means that the used database system (DBS) is exchangeable. The recent experiences (see chapter 4) with Quexolver are achieved using the open source DBS PostgreSQL.

If a certain web service is triggered by the user (e.g. "show me the values of all environmental indicators from the year 2012"), a request is sent to the database. The database system provides the query results as a table. For the further processing of the data by the Java based web service, the result table has to be converted into objects (Plain Old Java Objects - POJOs). This conversion is done automatically in Quexolver by Hibernate. Hibernate is a persistence framework program written in Java which converts and returns objects in data tables and vice versa (Object-relational mapping, ORM) realized [2].

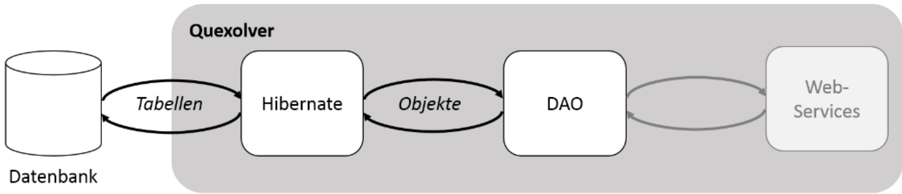


*Figure 2: Interfaces between database and web services (Hibernate and DAO)*

Hibernate does not only realizes the mapping of the data tables to objects. It also serves as a so-called persistence layer and implements the persistence of processed objects. Data to be stored from Excel into the database is persistent from the moment on once it is processed by Hibernate.

### 3.3. Data processing between Excel and DAO

At first, apart from the multi-user mode, the list of objects in the DAO interface must be associated with information about concerning at which point they shall be presented in an Excel worksheet. The objects are enhanced with the corresponding cell information[5]. The so-called converter, another component of Quexolver, is responsible for this operation. Each web service interacts with a converter. In the direction of the data flow from the database to Excel, cell information is added to the objects as described. In the opposite direction of data flow from Excel to the database (data storage), the cell information is removed from the objects before they are stored for reuse.

Another Quexolver component is necessary due to the simultaneous processing of data by multiple users. It is the so-called merger. The merger compares the local copies of data in the Excel spreadsheet with the objects stored in the database. There are two ways of changing data. First, the user may want to save new data that he has entered via Excel in the database. The merger checks, if data have been added, modified or deleted and refers them back to the web service, which can now save the updated dataset. This ensures that not all data is stored, but only the added, modified or deleted data.

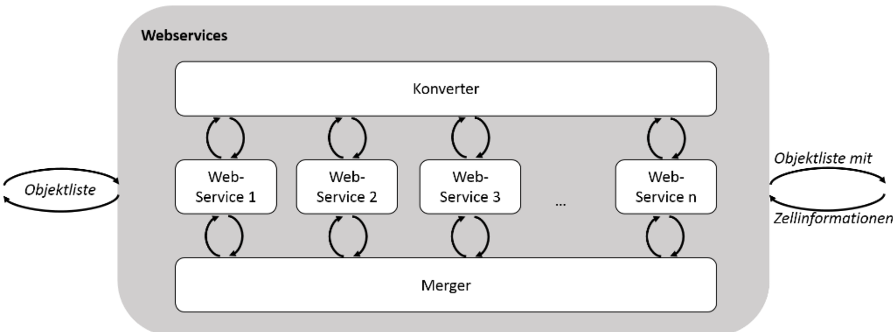


*Figure 3: The use of converter and merger by web services*

The second option is the change of data by another user, who works at the same time on the same data. This is realized by Optimistic Locking (Optimistic Concurrency) [10] realized. It is preferably used in applications, where the data is mostly accessed in read-only mode. The user who makes the first changes to the data record is privileged. If another user changes the same record, he will receive a notification of the change of data.

## 4. Configuration and use of the multi-user operation

For the single user, there are almost no changes in the daily work routine caused by the use of Quexolver, as he can use the well-known user interface of Excel and its full capabilities as usual.

[5] A cell is a place for data in an Excel worksheet.

Additionally, there is the new advantage due to the possibility of simultaneous editing of the same worksheets by multiple users. Time-consuming, error-prone data consolidation is thus avoided. The following describes the procedure for simultaneous editing of the same data by multiple users and how to adapt Quexolver to the respective business requirements.

## 4.1. Quexolver in multi-user mode

Each user logs in to the system with his name and password. The login screen is part of the Quexolver add-ins for Excel and visible in the right column within the Excel user interface. In Quexolver a role is defined for each user. Each role is assigned with certain rights, which grant access only to selected web services. These web services appear similar to a list of links on a web page at the right side of the Excel interface (see Figure 4). The user can execute the selected web service by simply clicking on it.

The execution of a web services causes the appearance of one or more worksheets with data in Excel. The user can now enter additional data, change or delete it, or perform analyses and evaluations, thereby using familiar Excel environment.

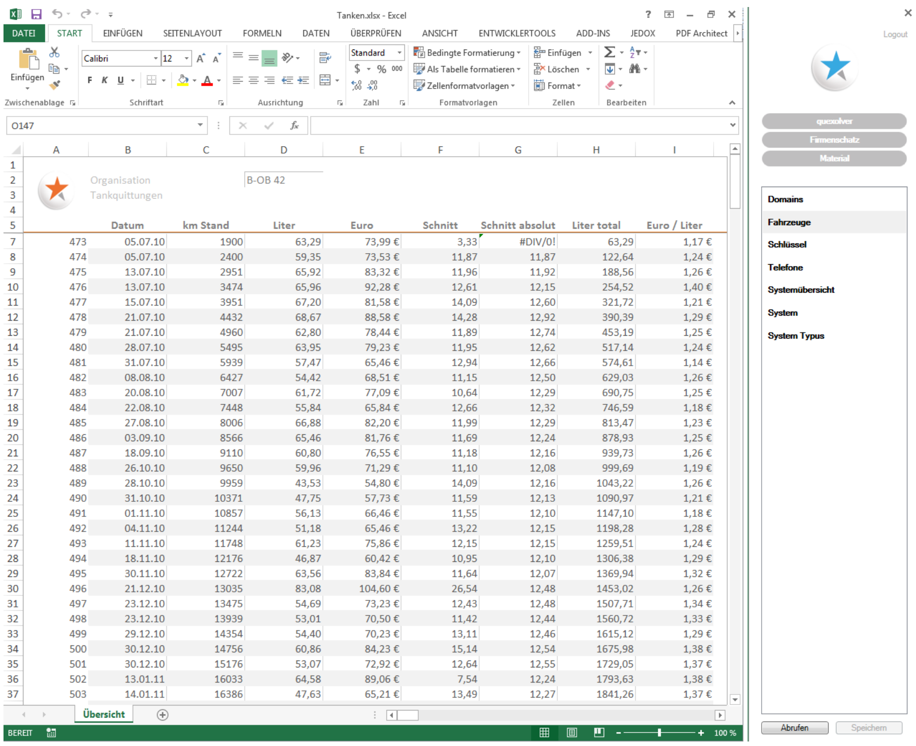


*Figure 4: User Interface (Quexolver add-in right column)*

If data is entered, changed, or deleted by user A, these changes appear in real-time in the worksheet of any user currently working on the same data user B. By saving changes, these are persistent and active for all other users.

The Merger ensures that effective changes are only incremental. This means that only the changes (inserts, updates, deletes) are stored and never all the work. This provides the possibility of a simultaneous processing of the same worksheets by multiple users without losing any data due to overwriting. For example, if data in the same worksheet from multiple data sources (that means by multiple users) is inserted into the database, the entire data is stored successively through the users's saving. Changes are visible even in real-time for all users during processing.

The use of Quexolver is characterized by two features: first, the user remains in the familiar environment. The addition of the login screen and the list of usable web services that are executed by a simple mouse click to the well-known Excel interface are intuitive to use and do not require any training. Second, the concurrent recording of data by multiple users is possible without requiring additional work processes. Instead, it eliminates even the manually merging of same Excel files. This is, unfortunately, in larger institutions with multiple data sources is currently still common and carries a high error rate during data acquisition.

### 4.2. Configuration of Quexolver

The configuration of Quexolver for a new application is possible in various ways. Usually, the starting point is an existing Excel file, which is either copied and sent to different users to be filled with data and later manually consolidated via copy and paste into a single file or sent from user to user to collect the data. To configure Quexolver, this Excel template is used to create a so-called entity-relationship model of the central database. By means of this model and generative software development techniques the Hibernate persistence layer and database are automatically generated.

Now the data in the database is mapped to the objects (Plain Old Java Object - POJO) and can be forwarded by the generic DAO interface to the web service for further processing (Data Access Object , see chapter 2.2).In the converter, another mapping of data to the cells, in which they should appear in the Excel worksheet is stored. Moreover, these web services are implemented, which accomplish the processing of the data. Therefore, typical web services are used. This includes querying a full data table from the database into an Excel worksheet, storing of changed or added data, as well as filtering and combining different data attributes in preparation for further data analysis.

An extension to the usual work with Excel is the combination of data entries with documents. This is useful, for example, if invoice data is stored with the corresponding invoice document. The documents are also saved in a database. Clicking on a date that is linked to a document corresponds to a web service that loads the corresponding documents from the database and opens them.

## 5. Application of Quexolver

Quexolver has already been used prototypically in different professional environments. An example of this application in the operational environmental protection is described in the following.

### 5.1. Case study: Extension of an existing Quexolver solution for the integration of environmental aspects

The existing ERP system of a company in the service industry should be extended to collect the relevant environmental information due to the introduction of a voluntary environmental management system. Since the existing solution is already a Quexolver solution, its data model must be extended. A particularly relevant indicator for the environmental performance of the company's environmental aspects is the consumed fuel by business trips using the company's own motor vehicle and the resultant $CO_2$ emissions. In the first step, the derived environmental indicator "annual mileage" has been implemented.

To include the environmental information, the existing data model has been extended. For this, the required attributes have been added to the respective entities. On the functional level, the input of the data was implemented for specific roles, which led to consistent data management. This ensured, on the user level, that only users with the appropriate qualifications could enter and change master and environmental data. The environmental data can be viewed by all users. For the company’s employees, this shall lead to an increased awareness about the environmental impact.

The environmental information was processed along with the master and vehicle-specific data, accumulated for a year and, furthermore, over all years. The comprehensibility of the information from the aggregated annual values to the individual data of the relevant vehicle is ensured via drill-down. In terms of data consistency, missing or invalid data is communicated to the user at any level and is also comprehensible via drill-down to the (environmental) master data.

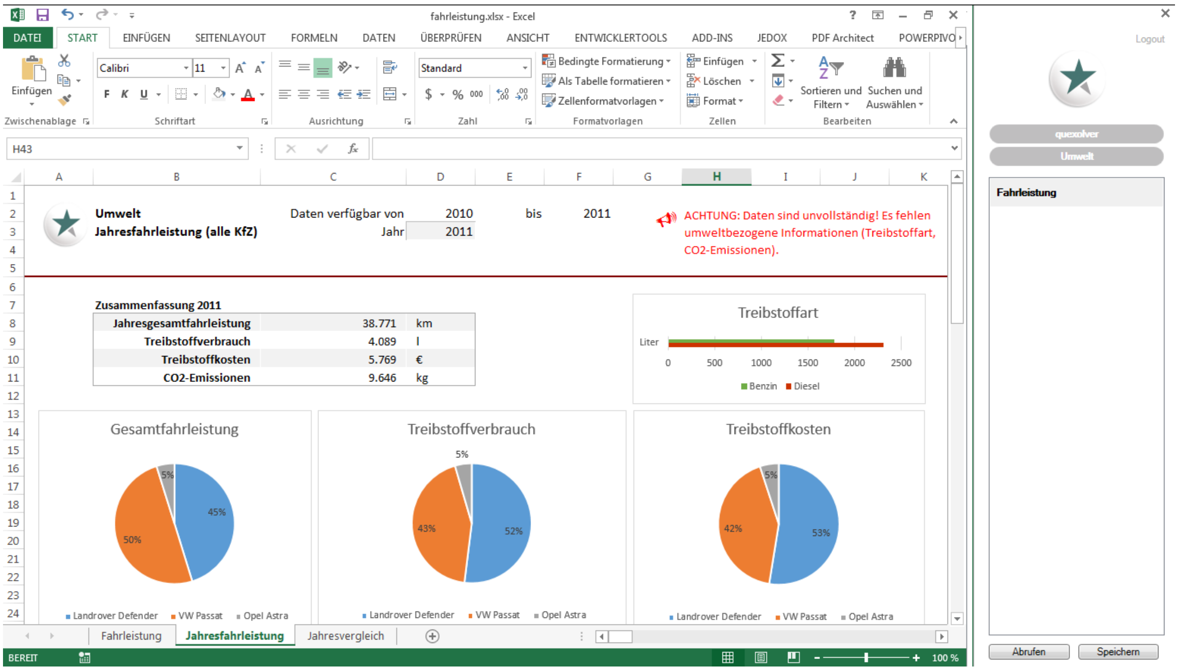


*Figure 5: Excel front-end for visualization of the environmental indicator "annual mileage"*

## 6. Summary and Outlook

Despite intensive research so far, continuous adoption and diffusion of CEMIS could not be achieved in practice [11]. Therefore, more recent research does not deal with universal CEMIS solutions and the general availability of CEMIS, but often with the analysis of existing CEMIS solutions in organizations [5, 14]. Thus, the specific design challenges and design factors can be more focused. In the context of corporate environmental protection, the research object of this paper, Microsoft Excel was the most frequently used standard software Microsoft Excel. This makes it possible to analyse and design the specific design requirements and factors of a widely adopted and diffused artifact.

Excel is a standard part of the Microsoft Office software used in most businesses and institutions. It is used in various applications as software for both the resource and project planning. The many advantages of Excel are offset by the disadvantages associated with the lack of multi-user capability. The experience with the presented tool Quexolver has shown, that addition of the multi-user capability and maintaining the familiar Excel environment at the same time is a promising approach to ensure a rapid and easy integration of the new tool in everyday work processes.

In particular, for processes, where many decentralized users collect data from various sources, the introduction of Quexolver leads to a simplification of these applications. Due to better automation of the consolidation and aggregation of data from various sources, the error rate is reduced significantly by Quexolver. The high flexibility of Excel as well as the service orientation of Quexolver, allows one to simplify and automate very specific technical processes.

Work is in progress to generalize the configuration of Quexolver for new technical applications and, thus, to simplify the framework. In another case study at the Federal Environment Agency of

Germany, further experience is gained with Quexolver in the scope of environmental management in order to incorporate further improvements of the framework.

## 7. Acknowledgements

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# Simulation and Optimization as Modular Tasks within a Framework on High-Performance-Computing-Platforms

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## Abstract

In the context of the project „Effizienter Flughafen 2030" separate, autarkic models simulating the different processes at an airport have been coupled to build an integrative over-all model. For scenario analysis and to identify the relevant model parameters for the over-all behavior it was postulated to fit input parameter values automatically with regard to a certain optimal behavior of the coupled system. To solve this task, a framework approach had been developed using soft-computing optimization methods. Independently of its original motivation and application, this approach can be applied to all complex optimization problems, if an encapsulated specification of the model components and the optimization is provided. The soft computing approach has the advantage to be able to deal easily with typical phenomena known in the area of environmental modeling such as lack of definition, non-linearity, or incomplete data. On the technical level it was a quite natural step to transfer the concept of the model coupling to the complete framework including the optimization component and to implement the complete functionality as a web service. For the prototype introduced in this paper genetic algorithms are selected for the optimization module. The architecture of the genetic solver demonstrates the general framework approach and is able to use high-performance-computing platforms to produce considerable speedups without demanding high bandwidths or low latency interconnections for the platform used.

A simple application example will demonstrate the interfaces for the model and the genetic solver that have to be provided to encapsulate these components for usage in the framework. The outlook deals with the optimization of the parameters of the genetic solver itself and proposes to interpret the black-box web-service interface of the solver as a model itself such cascading two genetic solvers: the inner one to optimize the simulation model parameters and the outer one to optimize the genetic algorithm parameters of the inner one.

## 1. Introduction

One of the main task for a modelling and simulation approach is to optimize the behaviour of the system under observation. Therefore, the relation between the two modules "simulation model" and "optimization algorithm" is well developed since a long time (see e.g. [19]). Mostly however, there will be problems with the calculation effort to solve the coupled simulation-optimization problem. In general, the simulation model will have input parameters of different types (int, float, bool, double, …) to vary for the simulation runs. The simulation-based optimization has to find a set of values for these inputs in regard to a given objective function. This function evaluates the simulation run in a certain way and delivers a measure for the quality of the current set of input parameter values.

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A very simple optimization problem might be to find optimal values for two integer parameters in the interval of 0 to 19. The first approach to solve the problem would be a parameter variation algorithm that finds all possible combinations, runs for all these (400) input vectors the model, calculates the objective function, and thus determines the optimum by a “brute force”-approach. The problem for practical use is that the number of combinations grows up exponentially with the number of input parameters. If we increase the number of inputs in this example from 2 to 4 there would be 160000 runs be necessary instead of the 400 runs for 2 inputs.

For real problems more efficient search strategies are used. Often used are the tree-search algorithms on the one hand, and the so called genetic algorithms on the other hand. For a typical example where both optimization strategies are applied successfully and compared in a realistic air traffic context see [7].

In this paper, the focus will be on the genetic algorithms because of an already existing implementation of this strategy type in connection with the framework introduced. Using these algorithms, the problem of the exponential relation between the number of inputs and the number of combination between them (all representing an individual simulation run) still exists, but the setting of the problem allows an easy parallelization of the independent simulation runs necessary and thus, nevertheless, leads to feasible runtimes. However, the technical problem how to manage this parallelization task still remains and that is exactly the initial situation for this paper.

Thus, a short introduction how to increase the computing power by high performance systems will be given in the next section. Then, the architecture of the optimization framework is introduced and will be exemplified by a textbook-example.

## 2. High-Performance-Computing and Cloud-Computing

We will not focus on a distinctive definition of high-performance-computing in this section, because the value of “high performance” always will depend on the current state of the technique and available hardware platforms. But one main characteristic of all the approaches is the support for parallelization. First a symmetrical multi-processor (SMP) system could be used that typically offers a high communication bandwidth and supports shared-memory access. However, the number of processors for such a symmetrical multiprocessor system is limited.

The further extension of such a SMP system are cluster systems with cluster nodes consisting of SMPs. The necessary communication between the nodes may be realized e.g. by a message passing interface (see [10, 15-16]) if there is a demand for fine granular communication and/or synchronisation. In comparison to SMP systems the number of processors is increased, but in return, fast shared-memory access will be restricted on the level of the cluster nodes.

One currently developed type of high-performance computing is the so-called “cloud-computing” allowing to rent via the internet the amount of computing power required and for exactly the time interval needed to solve a problem. A typical example for such a cloud environment is the Google Compute Engine [6]. An alternative to the offer of Google [9] is Amazon [1] with the Amazon Elastic Compute Cloud (EC2) and the Amazon Web Services. To give an impression of the pricing for such services: the costs for a machine with 8 virtual CPUs – comparable to 8 Hardware-Hyper-Threads of a current Intel-Server-CPU – are about 0.49 € per hour at Amazon [2]. The administration of the virtual cluster is managed by a browser-based management console, the access is realized by remote-desktop clients (for Windows) or ssh (for Linux). Additionally, there are Graphics Processing Units (GPU) offered and the user has the possibility to configure his cloud dynamically according to the currently needed load profile.

Thus, the main advantages of cloud computing lie in zero efforts for maintaining the hardware and the option to rent exactly the amount of computing power needed. This however is exactly the typical situation for every modelling and simulation study: after a long period of model development on standard PCs comes a phase of intense experimentation for parameter variation and/or optimization with numberless simulation runs and strong demands concerning computing power. How the simulation has to be adapted to benefit from the offer of a compute cloud will be shown in the next section.

## 3. Concept of the Optimization-Framework

As already mentioned, one of the main tasks during a simulation study is optimization, i.e. the fitting of free parameters within the model description to the model data or the search for an optimal behaviour of the modelled system during the simulation period. It is nearly impossible to apply analytical methods for optimization because

- the system generally has a large number of free parameters, and
- there is no analytical and explicit junction between the free parameters and the value of the objective function. This is the reason for the use of simulation: the simulation model itself represents the connection between input values and resulting value of the objective function and therefore has to be evaluated for each setting of the inputs individually.

The use of optimization methods and simulation models should be structured as independent as possible to fulfil the postulation of encapsulation and modularisation. Fig. 1 shows the general concept and the architecture of the optimization framework in some more detail.

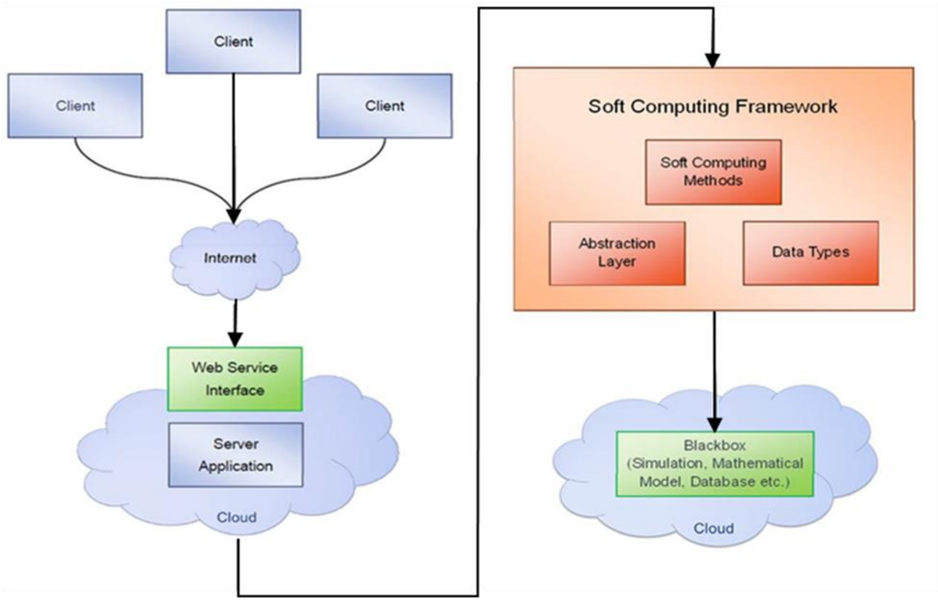


*Fig 1. Overview over the Framework-Architecture*

The special feature of the framework proposed is that there is no need to know anything about the simulation model or the mathematical model. The system to optimize appears as a real black-box activated by an easy to define web-service-interface. This allows flexible hosting of the simulation models in the cloud.

## 4. Prototype

The basis of the implementation are Web Services (WS) [21] and the use of XML-standards for exchange of structured data.

Fig. 2 shows the architecture of the genetic solver as one implementation of the optimization framework concept. The input parameters of the client (upper left) are transformed to internal structures (WSF Staff-Framework [23] and possible alternatives, see in [12]). In the middle the core of the optimization is figured, calling the simulation to determine the objective function for the different chromosomes in parallel and distributed as web-service requests by the load balancer (lower part of the figure).

The main benefit of the architecture proposed lies in the fact how the interfaces between these different levels are designed and especially in their independency from a specific simulation model and the optimization algorithm used. The following example will demonstrate, what a user of the framework has to specify to get the whole system running.

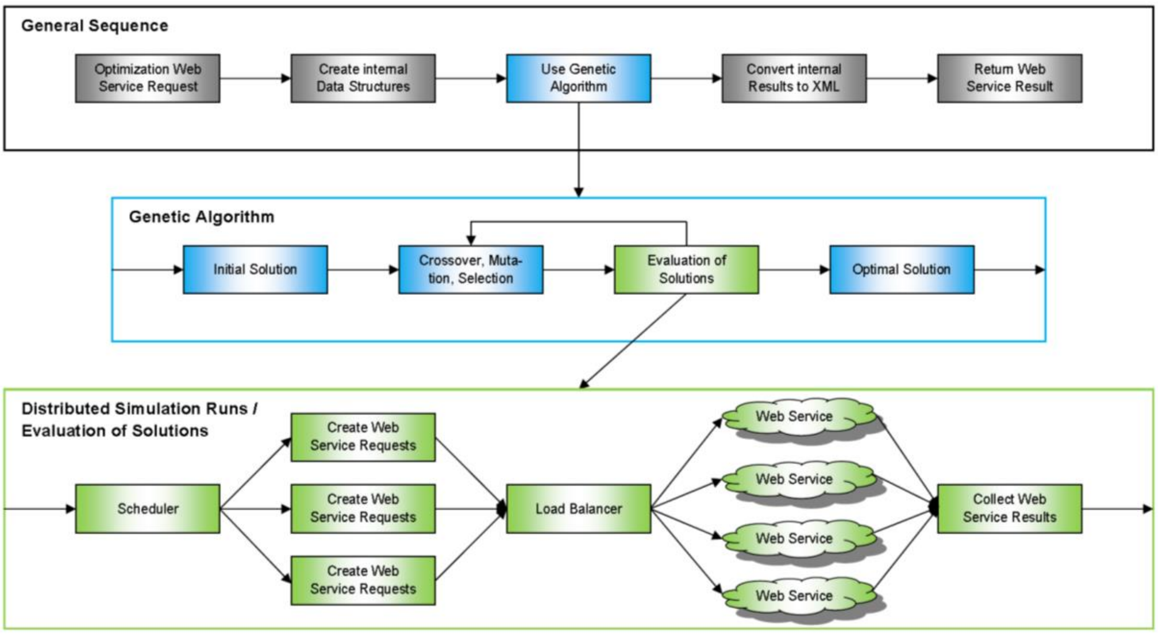


*Fig. 2. Architecture of the Genetic Solver*

## 5. An Example

To show the elements of the framework and the additional work for the user to encapsulate the relevant elements, a very simple textbook example is implemented: Fig. 3 shows the problem dealing with the production numbers of two products under the restriction of machine capacities (from [18]).

The objective function to maximize is given by the earnings for the two products without exceeding the capacities of the machines. Concerning the interface, the inputs are the numbers for A and B to produce and the machine capacities. The output is the value for the overall profit.

The framework architecture demands from the user to transform this interface as follows:

1. Defining the interface as a web-service interface (see Fig. 4)
   The simulation model is transformed to a black-box-component by the web-service interface. The model could be of arbitrary complexity that is hidden behind the input-interface and the encapsulation. For the example, the model just calculates the over-all earnings and represents just a placeholder for the general functionality.

2. Implementing the simulation as a web service (see Fig. 5)
   Here an implementation by C++ using the WSF Staff-Framework is used. The total earnings are calculated and returned; in case of a violation of the restrictions the earnings are cut to 0.

3. Configuring the optimization algorithm as a web service (see Fig. 6a)
   Here the solver interface is depicted on the highest level of its XML Schema description [22]. By the *SolverConfigurationType* the typical parameters are set. Of special interest is the entry *SimulationServiceURLs* that indicates a list of servers in the compute cloud providing identical copies of the simulation model and thus being prepared for a parallel execution of several runs.

4. Configuring the simulation as a web service (see Fig. 6b)
   The configuration of the simulation execution defines the name of the simulation function and kind of objective evaluation selected (e.g. minimize or maximize value). In addition, the input- and the output parameters of the simulation model are specified. Even structured parameter types may be used as it is natural for XML and Web Services.

5. Formatting the output of the optimization algorithm (see Fig. 7)
   The result of the solver is given here as a typical XML formatted output extracted from a protocol. The XML-representation of the output contains all the information given in the *SimulationConfiguration* when calling the web service, such as *isModifiable* for the free parameters. To simplify and by the hope to shorten the optimization the range of parameters of this type may be restricted by the user (e.g. *countA* may not exceed a value of 150 (limited by max. capacity of Machine II), and *countB* may not exceed a value of 60 (limited by max. capacity of Machine III).

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | **Maximizing the Profit (considering a 1 month period)** | | | | |
| 2 | | | | | |
| 3 | | **Product** | **Product** | | |
| 4 | | **A** | **B** | | |
| 5 | **Sales Price** | **1,000 €** | **3,000 €** | | |
| 6 | **Production Costs** | **700 €** | **2,500 €** | | |
| 7 | **Profit per Unit** | **300 €** | **500 €** | | |
| 8 | | | | | |
| 9 | | | | | |
| 10 | **Required Machine Hours per Product** | | | **Capacities Used** | **Max. Capacities Available** |
| 11 | **Machine I** | **1** | **2** | **170** | **170** |
| 12 | **Machine II** | **1** | **1** | **110** | **150** |
| 13 | **Machine III** | **0** | **3** | **180** | **180** |
| 14 | | | | | |
| 15 | **Production Numbers** | **50** | **60** | | |
| 16 | **Profit per Product** | **15,000 €** | **30,000 €** | | |
| 17 | | | | | |
| 18 | **Overall Profit** | | | **45,000 €** | **<- Optimum?** |

*Fig. 3. The Textbook Optimization Problem*

Web Service Request

```
<soapenv:Body>
  <calculateProfit>
    <countA>50</countA>
    <countB>60</countB>
  <calculateProfit>
</soapenv:Body>
```

```
<soapenv:Body>
  <calculateProfitResult>45000</calculateProfitResult>
</soapenv:Body>
```

Web Service Response

*Fig. 4. Encapsulating the Simulation by the Web-Service Interface*

```cpp
int MyExcelSimulationImpl::calculateProfit(int countA, int countB)
{
// limits machine I - III
    if (countA + 2 * countB > 170) return 0;
    if (countA + countB > 150) return 0;
    if (3 * countB > 180) return 0;

    return 300 * countA + 500 * countB;
}
```

*Fig. 5. Implementation of the Simulation Model as a Web Service in C++*

```xml
<complexType name="SolverConfigurationType">
  <sequence>
    <element name="mutationProbability" type="double"></element>
    <element name="crossoverProbability" type="double"></element>
    <element name="competitors" type="int"></element>
    <element name="populationSize" type="int"></element>
    <element name="generations" type="int"></element>
    <element name="SimulationServiceURLs" type="URLsType"></element>
  </sequence>
</complexType>
```

*Fig. 6a. Solver Web Service (XML Schema Fragment for Configuration of the Genetic Algorithm)*

```xml
<complexType name="SimulationConfigurationType">
  <sequence>
    <element name="name" type="string"></element>
    <element name="simulationFunction" type="string"></element>
    <element name="evaluationFunction" type="string"></element>
    <element name="inputParameters" type="ContainerType"></element>
    <element name="outputParameters" type="ContainerType"></element>
  </sequence>
</complexType>
```

*Fig. 6b. Solver Web Service (XML Schema Fragment for Configuration of the Simulation)*

```xml
<result>
  <wsFunction name="calculateProfit">
    <parameters>
      <int32 name="countA" isModifiable="true" minValue="0" maxValue="150">
        130
      </int32>
      <int32 name="countB" isModifiable="true" minValue="0" maxValue="60">
        20
      </int32>
    </parameters>
    <resultType>
      <int32 name="calculateProfitResult">
        49000
      </int32>
    </resultType>
  </wsFunction>
</result>
```

Solver Configuration:
mutationProbability: 0.05
crossoverProbability: 0.2
competitors: 3
populationSize: 500
generations: 10

*Fig. 7. Output (Example) of the Genetic Solver*

As one can see, all the interface tasks are managed in just one page of code. The code segments are easily understandable and (especially if they are marked for the unexperienced user as blocks to edit within the whole code file) easily to fill, too. The user just has to specify the objects of the interfaces of simulation and solver such as parameters, restrictions, and paths at the position indicated within the prepared code blocks. This is just the specification level the user is acquainted with.

## 6. Conclusion and Outlook

Based on the assumption of the need for high-performance computing for optimization tasks in connection with simulation studies, the paper proposes a framework-approach for platforms like the Amazon Elastic Compute Cloud. The example using genetic algorithms as optimization solver and an encapsulated simulation based on a textbook problem shows the feasibility and the level and design of a possible user interface. It shows, that this approach is well suited to provide a high-performance-solution as „Simulation Computing as a Service“ in analogy to the so called „Everything as a service“ [3] with low level effort for implementation and low investment costs for hardware.

The use of genetic algorithms seems to be ideally suited for the modularisation because

1. there is no internal knowledge about specials of the model and/or simulation necessary and the interface can be reduced on the typed input-/output-parameter set, and
2. the search can be easily parallelized by parallel simulation runs each of them evaluating the fitness of one chromosome under observation.

On the side of simulation, models in C, C++, Java, and especially MatLab-models can be encapsulated as shown for the example and realized as web-services. There are already implementations running for these types of model implementations. Any other simulation system may be integrated as well if it can be controlled externally by an Application Programming Interface (API).

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# Management of Meteorological Mass Data with MongoDB

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## Abstract

The remote sensing of atmospheric trace gases investigates dynamic, microphysical and chemical processes in the Earth's atmosphere, with the goal to understand, quantify and predict its natural variability and long-term changes. Accurate measurements of atmospheric trace gases from various observational platforms (ground-based stations, air craft, balloons, satellites) provide the data that are required for the modelling of atmospheric processes. The instrument GLORIA (Gimballed Limb Observer for Radiance Imaging of the Atmosphere), developed by KIT/IMK and FZ Jülich, an Infrared Spectrometer, which measures atmospheric emissions, was engaged in several measurement campaigns on board of HALO (High Altitude and Long Range Research Aircraft) and provided a large amount of data, which has to be managed efficiently for processing and visualisation. This paper describes the system background and the use of MongoDB for the provision of measured and processed mass data.


## 1. Introduction

The observation of the atmosphere is still one of the most important subject areas to obtain the necessary knowledge about meteorological and chemistry phenomena which influence climate change or greenhouse effect. Several remote sensing campaigns are performing worldwide and a huge amount of data is gathered and processed. In order to enable efficient processing and visualisation of the collected data, sophisticated and effective methods and tools are necessary. Although a lot of powerful databases and storage tools are available, which allow the management of big data, the best solution for this is to assemble best fitting tools.

This paper describes the system background and the use of MongoDB for the provision of measured and processed mass data collected by the remote sensing instrument GLORIA (Gimballed Limb Observer for Radiance Imaging of the Atmosphere) on board of the aircraft HALO (High Altitude and Long Range Research Aircraft). The processing of the data leads to chemical information (correlations and distributions) about trace gases in the atmosphere.

### 1.1. The instrument GLORIA

The Gimballed Limb Observer for Radiance Imaging of the Atmosphere (GLORIA) is a recently developed unique atmospheric remote sensing instrument that bridges the gap from scanning to imaging in the infrared spectral domain. This is realized by the combination of a classical Fourier transform spectrometer (FTS) with a 2-D detector array tailored to the FTS needs. Imaging improves the spatial sampling by an order of magnitude in comparison to state of the art limb scanning instruments. In addition to the limb mode, the instrument can also perform Nadir


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measurements. GLORIA is designed to operate on the high altitude research platforms aircraft [6] and stratospheric balloons [4]. Figure 1 shows a graphic of GLORIA and an image of HALO which carries GLORIA as one of several instruments. GLORIA is attached underneath the fuselage of HALO (white arrow).

GLORIA is a joint development of the two national research centres of the Helmholtz Association Karlsruhe Institute of Technology (KIT) and Forschungszentrum Jülich (FZJ). Detailed information about the instrument is presented at [5].

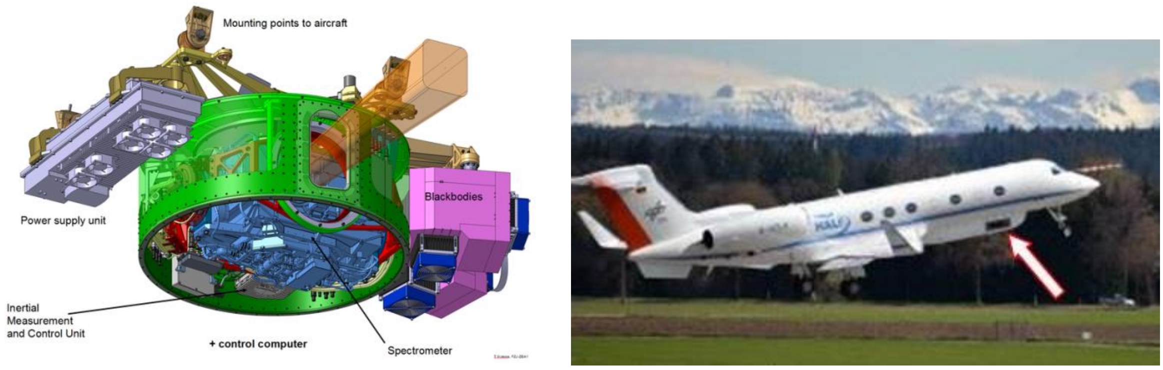


*Figure 1: The instrument GLORIA and the HALO aircraft (arrow: the location of GLORIA).*

### 1.2. The GLORIA data structure

The GLORIA data consists of three major parts: the pre-processed measurement data, the processing configuration data, and the final result data (spectra, trace gas distributions, etc.). The first objective is to store the pre-processed data which is the base for further processing and visualisation.

Figure 2 shows the data structure of a pre-processed GLORIA dataset provided by the measurement campaigns on board of HALO [6]

A flight delivers a dataset and may take several hours. The files of a dataset are called "cubes" and contain a measurement sequence of about 3 to 12 seconds. A measurement sequence is a sequence of recorded "images" (slices). A single slice is delivered in a time period of 15ns-300ms by a detector field with 256x256 pixels. Depending on the scientific needs, only a subset of the full detector array is used for performing the measurements.

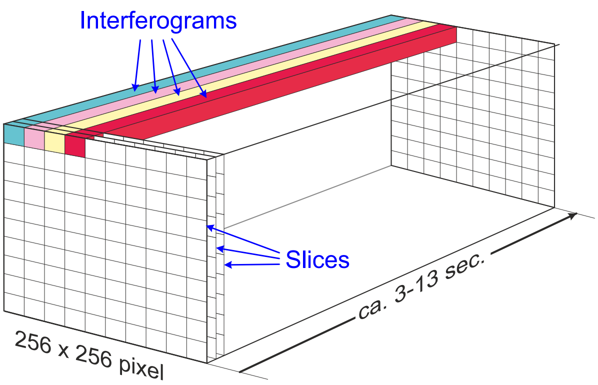


*Figure 2: The structure of a GLORIA dataset (GLORIA cubes)*

The chronological order of each value of a given slice pixel leads to an interferogram. The size of a dataset varies between 100 MB and 8 GB, depending on the GLORIA recording mode and the measurement duration. A standard dataset of the last campaigns contains approximately 74.500 slices for a detector sub array of 128x48 pixels and has the size of 1 GB.

A HALO flight in 2012 took 12 hours and produced about 11.500 datasets (≈ 2.2 TB). Scientists are particularly interested in processing interferogram data. Since the GLORIA dataset files contain the ordered list of slices, the datasets must be converted to be stored in MongoDB based on the resulting interferograms.

### 1.3. The data management and processing environment

The Large Scale Data Facility (LSDF) at KIT is a data centre for large scientific data from several data intensive disciplines [3]. The LSDF provides petabytes of storage accessible via the protocols NFS, CIFS, and GridFTP. In addition, the LSDF consists of a Hadoop cluster including a Hadoop Distributed File System storage, and an OpenNebula cloud environment. LSDF serves as storage backend for multiple iRODS instances and for the NoSQL database MongoDB.

The MongoDB instance for GLORIA data runs on a dedicated hardware server with 12 physical CPU cores and 128 GB RAM. The cluster file system GPFS of LSDF is attached via a 10G ethernet connection. The operating system is a 64 bit Linux (CentOS 6). As of writing this paper, the version of the MongoDB server is 2.4.8.

In Figure 1, the setup of the database infrastructure is depicted. The MongoDB server provides data stored on LSDF to various clients (Processing, Loader and Visualization). So far, a single instance of MongoDB was sufficient to handle all data, but in order to scale out the infrastructure so-called sharding is being investigated. This allows splitting the data based on a shard key and distributing them to several instances. In addition, replica sets provide a mechanism to replicate data to many redundant instances in order to increase the reliability of the system.

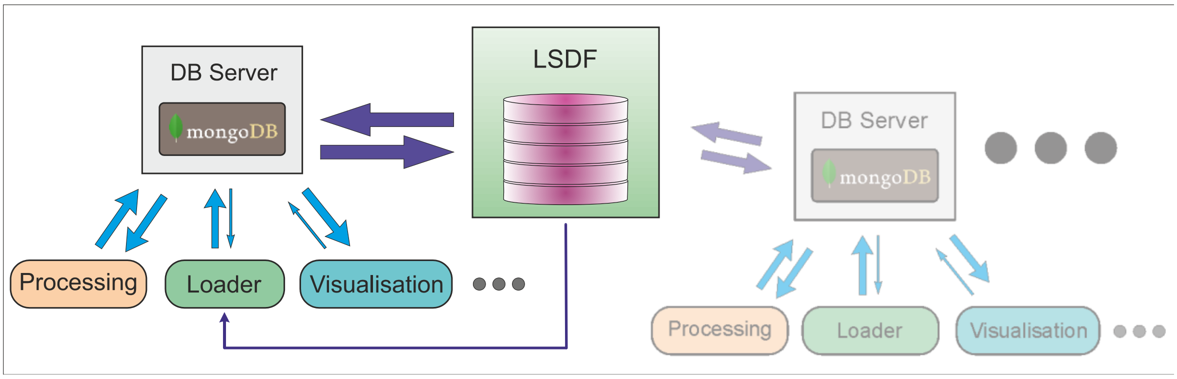


*Figure 3: The database server MongoDB provides data to processing, loader, and visualization clients. The Large Scale Data Facility serves as storage backend. Additional instances of MongoDB are foreseen*

### 1.4. The GLORIA data processing

One central issue is the processing workflow of GLORIA's data. The process chain consumes the measured data and metadata to generate the calibrated spectra (Figure 4). Due to the detector properties, each pixel has different sensitivity and nonlinearity behaviours. Experiments under laboratory conditions are performed to determine a set of parameters describing the nonlinearity. The first step is to use this set of parameters to perform a nonlinearity correction. The frames (slices) in the cube are measured at an equidistant time grid. The spectrum is based on an equidistant spatial grid.

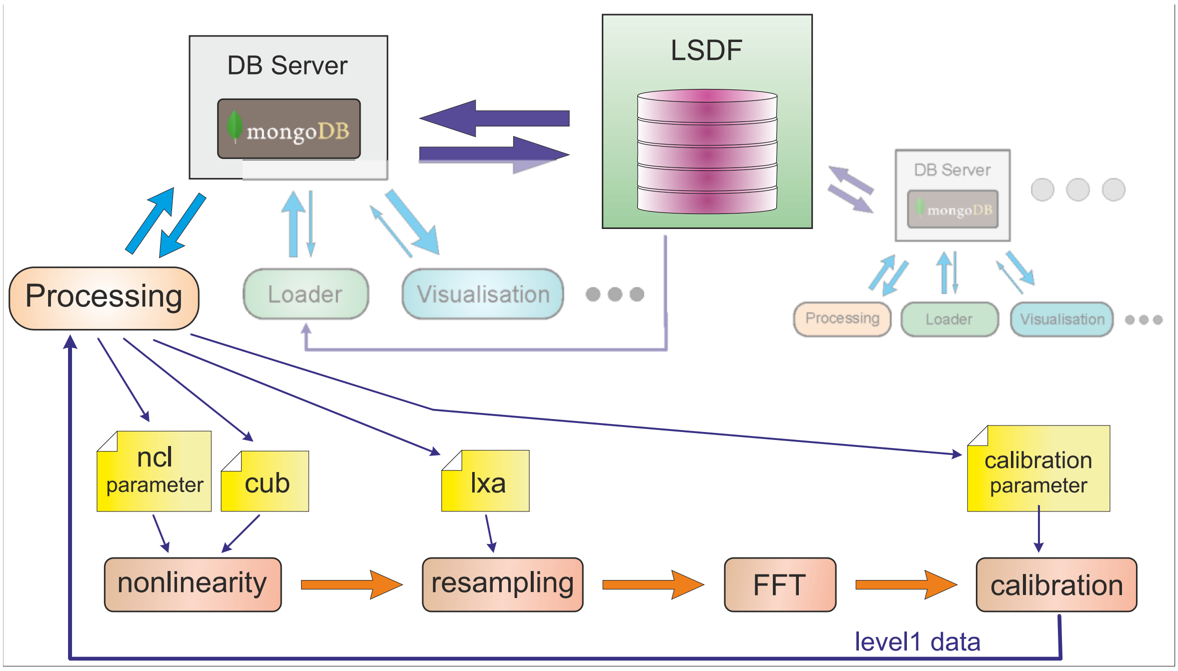


*Figure 4: The Data Processing Environment*

During the measurements, an equidistant spatial grid is defined by using a reference laser with a known laser wavelength. At every zero-crossing, an event sets a timestamp. With this timestamps, a tuple of time and space points are created. Performing a Whittaker-Shannon interpolation

$$I(x) = \sum_{n} I_n sinc\left(\frac{x - n\Delta T}{\Delta T}\right)$$

where x is the target point in space, $I_n$ is the n-th measurement and T is the time difference, the measurement is resampled from a time grid to a equidistant space grid. After the Fourier transform, the spectrum needs to be calibrated. Before the actual processing, the calibration parameters for each sequence are generated and stored in the Database. The data for the calibrations consists of blackbody measurements where the radiance is known and also measurements looking in the deep space where a minimum of trace gases are expected. The computation of this parameter sets requires the combination of different measurements at different times to increase the signal-to-noise ratio on the one hand and to generate a continuous set of parameters for every measurement on the other hand. In order to access various combinations of measurement data, the used database must provide facilities for complex queries. After the computation with the loaded parameter set, the calibrated spectra (*level1 data*) are stored in the database with an easy to access interface for further analysis.

## 2. Why MongoDB?

MongoDB is an open-source database used by companies of all sizes, across all industries and for a wide variety of applications. It is an agile database that allows schemas to change quickly as applications evolve, while still providing the functionality that developers expect from traditional databases, such as secondary indexes, a full query language and strict consistency [9].

The first approach to manage the GLORIA data was reuse of the software environment of its predecessor instrument MIPAS which is available on aircraft, balloon and for ground-based measurements. Furthermore, MIPAS provided a huge amount of data as one instrument aboard the European environmental satellite ENVISAT.

The software environment for the MIPAS aircraft and balloon experiments is based on Firebird, a free parallel development of Borland's™ relational database Interbase. The database manages the metadata of the measurements with links to the data files which reside on the file system.

The data generated by GLORIA is approximately hundred times the data produced by MIPAS. For this reason, the data management has to be reconfigured. Additionally, several fundamental new requirements exist for the data management which must be fulfilled by the new environment. The most important requirements are:

- Access to data and metadata within one single database query
- Usage of a free database which can be managed easily
- The data schema should be open for enhancements and modifications
- Fast access to large quantities of data
- Horizontal scalability
- Provision of powerful interfaces (drivers) for Java, Python, C++, etc.
- Possibility of array-oriented storage of datasets

### 2.1. Access to data and metadata within one single database query

The first important requirement for the new environment was access to data and metadata within one single database query, i.e. one query should provide the metadata as well as the underlying measurement data. Therefore, it is possible to get complete big datasets via the internet without multiple accesses to the database. Only few relational databases provide such an access mode. For instance Oracle™ offers its BFiles which are external BLOBs stored in files on the file system. The BFiles can be read similar to standard column types.

### 2.2. Usage of a free database which can be managed easily

In order to perform experiments and various different performance and access tests with large data sets, it is necessary to install and manage the database without big effort. The creation, deletion and modification of databases, database users and access permissions are mostly performed automatically by use of script files or via interfaces.

### 2.3. Free data schema for enhancements and modifications

On demand frequent changes is part of nature of scientific software development. These changes are applied based on experiences gathered during the development or based on technical innovations and enhancements of the measurement system. Therefore, changes on the data schema are often necessary. A very easy way to modify the structure of data storage is the use of schema-free NoSQL databases, a relatively young database type [10]. The most popular representtatives of about 150 NoSQL databases are HBase, CouchDB, and MongoDB. While HBase is a so-called Wide Column Store database, CouchDB and MongoDB are document-based, i.e. the entries of a document collection are documents, which represent a list of key-value pairs in any order. Search indexes can be created for singular and combined keys. Several performance tests concerning the type and amount of data as well as the usability of desired interfaces showed that MongoDB would meet our requirements better than other NoSQL databases.

Figure 2 shows the basic difference between the relational database and a schema-free document database structure. While the tables in a relational database have a fixed format and fixed column order, a MongoDB collection can contain entities of different types in any order. The entities are grouped in a "document" which resembles a relational table row but with variable length. The element *dbRef* allows the creation of an explicit reference to another document in the same database or in another database on another server.

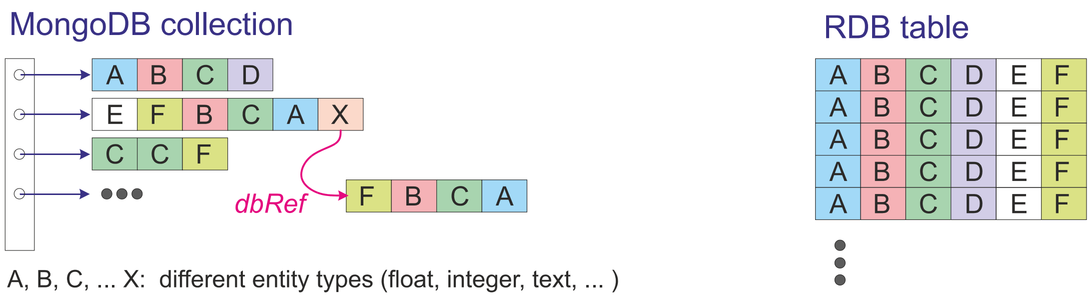


*Figure 2: The basic data structure of MongoDB and a Relational Database*

### 2.4. Fast access to large quantities of data

The fixed table structure of relational databases facilitates the recognition of the stored element types. This advantage is compensated by the ability of MongoDB to allow additions to collections and documents without restructuring the schema. A fast access to desired documents must be realized via indexes on the identifying key names. Several tests showed that the search for documents for given keys in large databases must be based on explicit indexes for the desired keys to find the data in a fast way. Without indexes the search took an unexpectedly long time.

Based on current experience and several performance tests with about 57 million documents, MongoDB is able to fulfil the access requirements for large quantities of data. Powerful caching and indexing mechanisms support the search in big data stores. A typical query scenario needs about 1-2 seconds (see subsections 3.3 and 3.4).

### 2.5. Horizontal scalability

This requirement is based on the importance to access big datasets from different locations. The GLORIA project covers a lot of scientists at different scientific organisations which must have a fast access to the data. MongoDB is built for scalability, performance and high availability, it is scaling from single server deployments to large and complex multi-site architectures. MongoDB's native replication and automated failover enable enterprise-grade reliability and operational flexibility. MongoDB features like auto-sharding and replication support the realisation of this requirement. There are some tests scenarios still in progress to check the availability and performance of a sharded system.

### 2.6. provision of powerful drivers

The GLORIA software environment uses different approaches to compute the given measurement data. Results are interferograms, spectra and trace gas distributions. To address these challenges, different tools based on different programming languages are used. Like other databases, MongoDB offers a lot of drivers. For the most important languages in the GLORIA project, C++, Java, and Python, powerful drivers are available.

### 2.7. Possibility of array-oriented storage of datasets

The GLORIA data is mostly structured as value arrays (see subsection 1.2). Experiences with big satellite data showed that databases offering array elements are particularly suitable for this use case. Only a few databases provide this kind of element type (e.g. Oracle™, Firebird, MongoDB) whereas a powerful support for array elements is given with Oracle and MongoDB. While Oracle allows the definition and management of nearly every primitive (short, int, float, etc.) or complex element type, MongoDB offers arrays only for its standard BSON types [1, 9]. Both databases provide convenient methods to access the arrays within database queries.

## 3. Experiences with GLORIA data on MongoDB

Most of the tests have been performed to examine the usability and reliability of MongoDB for the given requirements. The major challenge is to test with big data, because the cube data has to be converted before being stored (see section 1.2).

For the test scenario, loading, converting and storing the data of a selected HALO/GLORIA flight took about 34 hours for 2 TB. Therefore, some important configuration and structural decisions have to be taken before loading the complete data. The following subsections describe some essential aspects regarding the usability of MongoDB for the given test scenario.

### 3.1. Installation and maintenance

The download and installation of a MongoDB server is very easy to perform. Like other databases, MongoDB provides a shell environment to access the database. MongoDB offers an interactive JavaScript shell. The creation of users, databases, collections, indexes and access permissions is done very easily and quickly. Simple and complex queries can be performed easily, too.

For each database, MongoDB creates an “unlimited” number of 2 GB database files and creates a journaling directory. The maximum document size is 16 MB, larger documents can be stored in so-called GridFS files, a kind of BLOB file which is referenced by database objects.

### 3.2. MongoDB BSON types and conversions

MongoDB stores documents on disk in the BSON serialization format [1]. BSON is a binary representation of JavaScript Object Notation (JSON) documents, though it contains more data types than JSON [7]. The 'smallest' BSON type is a 32 bit integer, but majority of GLORIA data is of type short (16 bit interferogram values). Therefore, if the data would store without conversion, the storage of this data using 32 bit integer arrays would duplicate the storage size unnecessarily. Therefore the *short* arrays are converted to binary arrays before storing them into MongoDB.

In the beginning of the project, there was a request that the interferogram-based datasets should be queried for selected slices (see subsection 1.2). MongoDB offers direct access to selected array elements, which must be BSON types. An option is the Binary type, an object that carries a byte array. Due to the fact that the storage and retrieval of Binary arrays is considerably time-consuming, the interferograms are stored as a pure byte arrays with the consequence to renounce the direct array access.

The small number of BSON types for small elements ((unsigned) int and short, float, etc.) turned out to be obstructive in some scenarios.

### 3.3. Indexing and searching for data

MongoDB offers a powerful indexing mechanism that allows the fast retrieval of data for a large amount of documents. If a document has to be found by given attributes, an index should be created for each desired attribute and/or combination of attributes. The interferogram collection contains about 57 millions of documents with the major attributes *cubeID* (e.g. “20120926_060047 “) and their coordinates on the detector field. A repeated search for all interferograms of a selected cube needs less than one second to get the resulting database cursor to the data. Note: the time to get the cursor does not imply the download of the data but only the result of the search inside the index file (size of 9 GB for the test scenario). Arbitrary queries can be performed via the MongoDB shell or via a driver using a JavaScript syntax with MongoDB extensions (less or greater than, contains, etc.). In contrast to SQL, the attributes, which has to be excluded within a query, must be listed explicitly.

### 3.4. Loading and retrieving data - caching mechanisms (observations)

During the tests it turned out that the retrieval of data stored in MongoDB does not only depend on common caching mechanism (whether the data was already accessed before), but also on the order the data was inserted into the database. A complete cube data is read much faster than the data resulting from a query for all interferograms of a given detector field coordinate of the whole flight. Although the data size is comparable, the download time differs considerably.

## 4. Conclusions

The storage of GLORIA data for the given requirements is a big challenge to any database. The underlying test scenario comprises a GLORIA/HALO flight with about 11.500 cubes and 57 million of interferograms and a resulting data size of 2,2 TB. With MongoDB a suitable way is found to manage the data. The utilisation of MongoDB for the storage of GLORIA data shows the following advantages and some disadvantages during the performed test:

- Easy and fast installation of MongoDB, simple creation of users, databases, and collections
- Fast access, the attributes together with the interferogram data can be retrieved within one single query
- All required drivers with rich functionality are available for the integration in applications
- Rich query features are available using JavaScript via a command shell and via drivers
- Open-source application
- Good indexing and caching mechanisms are provided
- The lack of small primitive BSON data types is negative for the scenario

Up to now, the basic tests are completed. The next step will be the conversion and storage of all other available GLORIA data which will lead to a resulting estimated size of 30 TB. Further tests have to be performed exploring the performance difference when using several instances or one single database instance for all flights.

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# An expert system-based approach for energy-efficient processing of natural raw materials

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## Abstract

This paper presents an approach aiming to reduce the energy consumption during the processing of natural raw materials. Natural raw materials are processed with more energy than they actually need. This is due to uncertainties on material and energy flows and to a lack of process flexibility and inappropriate machine configuration. The proposed approach combines techniques like artificial intelligence (expert systems) with technologies for data processing in order to create real-time "action plans" containing energy reduction suggestions for compound feed manufacturers. These suggestions are based on the correlation between energy consumption, product quality and process control by influencing the grain size, the steam amount and machine parameters. Through the application of expert systems the energy consumption in energy-intensive processes could be reduced and seen as an efficient way leading to lower $CO_2$ emissions. At the end of the paper current results are detailed and future work is presented.

## 1. Introduction

In today's competitive business environment, production managers are constantly called upon to make decisions that directly influence operations and therefore profitability. The growing demand for customized products and complexity of raw materials processing have changed the face of production practice for compound feeds. Staying competitive in any field of business requires the ability to adapt to an ever changing and dynamic environment [8]. Producers in the feed sector are required to ensure higher efficiency, greater flexibility, better product quality, greater satisfaction of customer's expectations and especially lower cost and less energy consumption. A great challenge for producers in the feed sector is not only how to adapt to this changing business environment but also how to draw a competitive advantage from the way in which they choose to do so [1]. As a basis to achieve advantages towards reducing energy consumption, producers have started to seek to optimize the operation of their production systems. Production scheduling and machine configurability are the most critical parts of a production system. If a company requires operating existing machinery and maintaining same configuration, another company needs to be able to make mandatory decisions and take actions. It is, therefore, important to have accurate information in a timely manner in order to make effective decision [5].

The authors present an IT approach helping producers in feed sector to deal with uncertainties on material and energy flows. These uncertainties are resulting significantly impact on the energy consumption during the processing of natural raw materials. Natural raw materials are processed with more energy than they actually need. This is due also to a lack of process flexibility and inappropriate machine configuration. The interpretation of these uncertainties is mandatory and will facilitate the better understanding of energy problems. For the benefit of the readers who may be unfamiliar with the processing of natural raw materials and with and potential technologies, an analysis of the process and the key concept of these technologies are briefly explored first. A systematic methodology for the

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development of the approach is then introduced. An on-going prototype system development that concerns compound feeds production is then discussed.

## 2. The compound feed production process

Producers in the feed sector edit natural resources to a mixed feed with constant and controlled quality. For all that fluctuating proportions of the components, the animals receive exact amount of nutrients such as proteins, fats, trace elements and vitamins that they daily need. Not only the ingredients but also the consistency of the feed has a significant impact on the usefulness and the health of the animals. Every delivered batch of raw materials must be individually assessed and analysed to certain product parameters. The product range goes from customer-specific products over special daily produced main products. Figure 1 shows an example of product varieties in compound feed production.


*Figure 1: a) mealy feed, b) feed as pellet, c) crumb feed*

The compound feed production process (Figure 2) could be divided into four energy-intensive process steps. This includes at first the incoming of different natural resources like wheat, barley, rye and so on which are delivered by trucks, discharged into collecting vessels and short-term stored in silo compartments. The production process starts with the scaling and sieving process. After that follows the milling process by hammer mills or roller mills and the mixing process by high-speed mixers[4].

The use of different mills leads to different grain structures which have an effect on the following process step: the compactor process. This step produces the pellets (Figure 1.b) with high-quality and physical impacts against pressure, abrasion and critical strength. The quality of a pellet must have a uniform length, hardness and has to be resistant against all strains. The particle size through the milling process influences the compactor process which includes the conditioning, pelletizing, cooling and crushing process steps. Based on the grain size (too fine or too rough) of the mealy material the electric and thermal energy consumption can wary extremely.

In many plants the product quality is correlated with the energy consumption. The products are produced with more energy than they actually need. This is due to the fact machines (e.g. steam conditioner) are usually configured on behalf of high production tolerances. This means that for the conditioning process more steam is applied than necessary in order to guarantee the expected product quality. The result is a significant increase of energy usage and therefore product price which leads to the fact that the producers are forced to optimize the energy consumption.

An issue of concern is related to the variation of grain size in lots. A lot is defined as 4.000 kg of natural raw materials. The extreme variation of the materials influences the energy consumption during the pelletizing process. Figure 2 outlines the fluctuation of the grain size. The arithmetic mean of the grain classes of a batch with 3 lots of 4000 kg with four samples per lot varies strongly across the sieve classes.

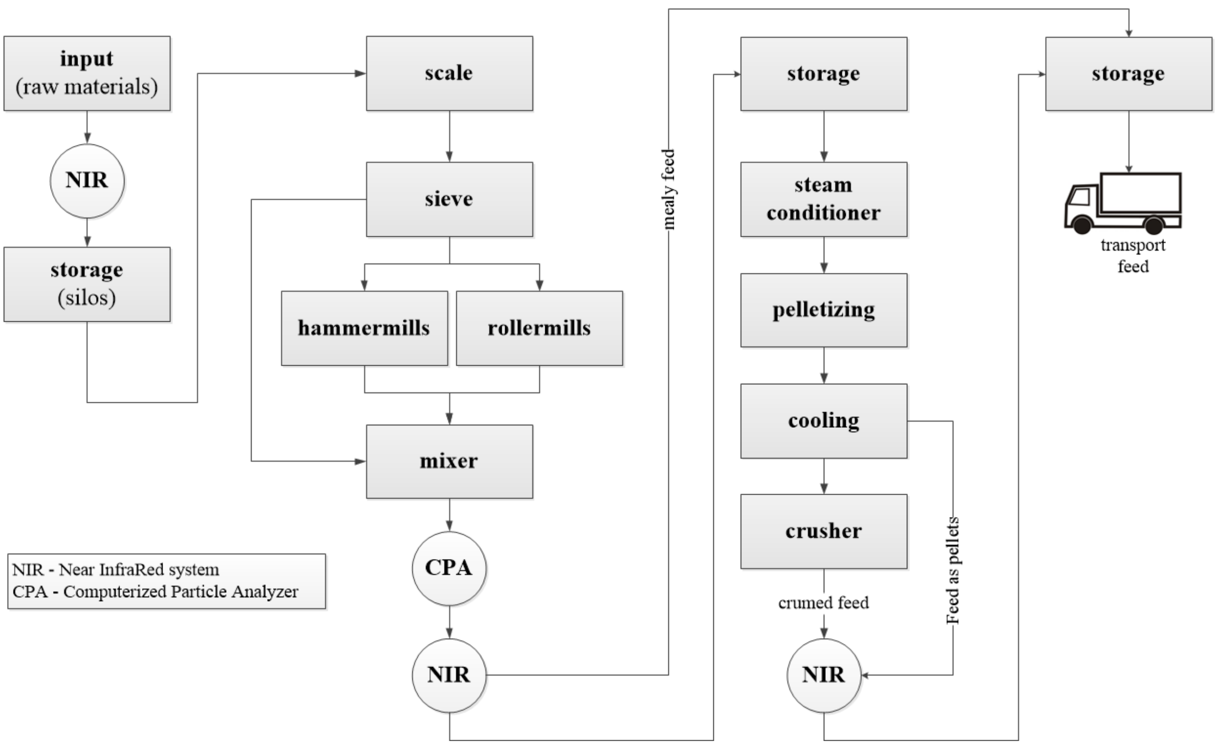


*Figure 2: Process flow of compound feed production*

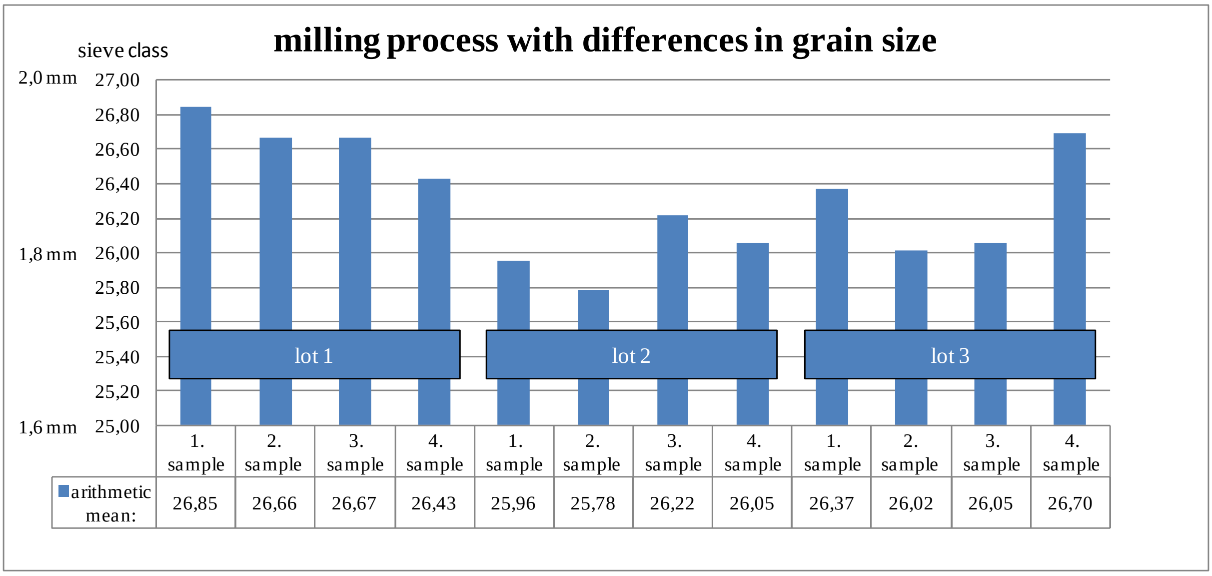


*Figure 3: Fluctuation of grain size by producing one product with 3 limited lots*

The grain size could be seen as critical aspect for the production process. The variation of the grain size within the sieve classes influences the pelletizing process and leads to significant difference in product quality and higher energy consumption, if no adjustment (rising or reducing) of the steam quantity are made. The seasonal fluctuation leads to different moisture content in raw materials and impacts therefore the process steps. Today's production processes get no information about the moisture content and can´t adjust the conditioning and pelletizing process automatically. Another important point is the uncertainties of the production process concerning the moisture content in raw materials and in mixed mealy materials.

## 3. Approach and prototype development

Based on the presented process analysis, producers in the feed sector have to deal with the presented uncertainties. The interpretation of these uncertainties will support the better understanding of the problems and therefore to generate action plans [9] that an employee (expert) may perform. This could be realized using existing technologies that are able to emulate the decision-making ability of a human expert [2] and to solve complex problems by reasoning. In particular the envisaged system should suggest recipe dependent machine parameters to the raw material properties and also give the necessary modifications towards process and machine configuration. In order to increase the energy efficiency for the processing of natural raw materials, a new approach has been worked out which is mainly based on artificial intelligence. This consists of the use of expert systems in combination with technologies for data acquisition, processing and storage. The envisaged solution will serve to the selection of the best available process configuration for the addressed production sector. For the benefit of the readers who may be unfamiliar with and expert systems, this chapter will briefly explore additionally the key concepts of expert systems.

In artificial intelligence, expert system can be regarded as a series of computer programs [10]. The key idea behind expert systems is that some problems are best solved by applying knowledge about the problem domain, knowledge that only people/experts very familiar with the domain are likely to have. It is a system that emulates the decision-making ability of a human expert. This naturally creates a need to represent that knowledge [3]. The knowledge needed to solve a problem rarely includes the exact answer to particular instance of the problem. Instead, the expert system has to take the knowledge that it has and infer new information from it that bears upon the exact problem it is solving. This means that these systems solve a problem by reasoning about knowledge, like an expert, and not by following the procedure of a developer as is the case in conventional programming. As illustrated in **Fehler! Verweisquelle konnte nicht gefunden werden.** a mature expert system is made up of three main components: the knowledge base, inference engine and the user interface[6]:

- Knowledge base is the core of the expert system in which the rich experience and knowledge of experts (e.g. workers) is conserved to solve a specific problem. The knowledge may be in the form of facts, heuristics (e.g. experiences, opinions, judgments, predictions, algorithms) and relationships usually gleaned from the mind of experts in the relevant domain. Knowledge can be represented using a variety of representation techniques (e.g. semantic nets, frames, predicate logic) but the most commonly used technique is "if-then" rules, also known as production rules.

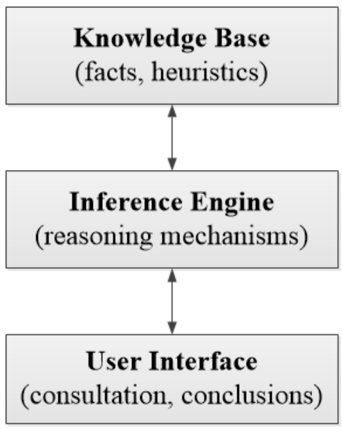


*Figure 4: Main components of an expert system*

- The inference engine is a way of using knowledge and can be regarded as a control system. Based on the facts given by users, certain search strategy and appropriate inference rules are adopted to get the final conclusion by reasoning the knowledge base. It examines the status of the knowledge base, handles the content of the knowledge base and determines the order in which inferences are made. It may use various inference methods.

- The user interface it is the medium of interaction between users and expert system. It mainly includes screen displays, a consultation/advice dialogue and an explanation component. In addition, expert systems provide interfaces for communication with external programs including databases and spreadsheets.

The key functionality of an expert system is the knowledge processing. The knowledge can only be represented in the form of binary data, as the form on computer, to be stored, operated and used for actual problem. Representation of knowledge is to turn human intelligent behavior into a kind of description that computer can understand. There are various types of knowledge representation utilized in expert systems. The classic example uses rules which are the most widespread form of knowledge representation. The employee knowledge and the evaluation results of the test series will be turned into rules for the expert system. This will be realized by using fuzzy logic

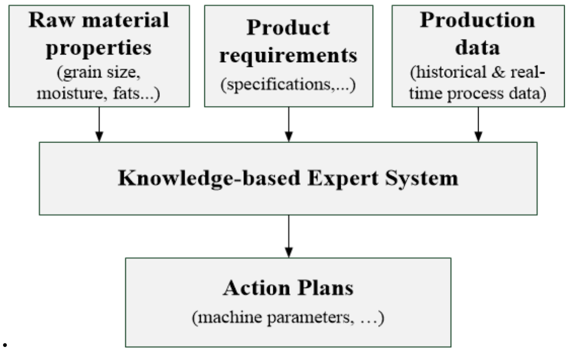


*Figure 5: Overall concept*

Additional fuzzy statements such as "IF … THEN something more" or "slightly reduce" will be defined. According to [7] the input for the system consists of information about material properties, product requirements and production data, as shown in Figure 5. Based on upon knowledge the knowledge-based system will identify the optimal machine parameters need to be used to reduce energy consumption without influencing the expected product quality.

To achieve this main objective a general methodology to help solving the selection problem has been developed. The major steps of the developed methodology are: definition and analysis of the process requirements in terms of quality and quantity, identification of energy savings opportunities, identification and integration of potential (required) measurement systems to obtain valuable product properties, realization of multiple experiments in real production environment and generation of multiple solutions and perform a preliminary economical study of the process configurations. This methodology has been applied with a compound feed production company in northern Germany.

For the implementation of the system, several technical objectives should be accomplished. Figure 6 illustrates the overall system architecture of the expert system-based approach.

Concerning the implementation of the intended expert system-based approach, there are mainly two groups of development tools:

- Computer programming languages, either conventional (e.g. C++, Pascal, etc.) or AI languages (e.g. PROLOG, LISP, etc.). Using these languages, the system designer has a great deal of freedom in choice of knowledge representation techniques and control strategies. However, use of these languages requires a high degree of expertise and skill.

- Expert system shells. They attempt to combine the flexibility of artificial intelligence languages with the cost-effectiveness and provide more general development facilities. There are a number of commercial shells available in the market with varying features (Nexpert Object, XpertRule, KnowledgeScape, etc.). Most of them are relatively low priced and provide a rule-based knowledge representation mechanism.

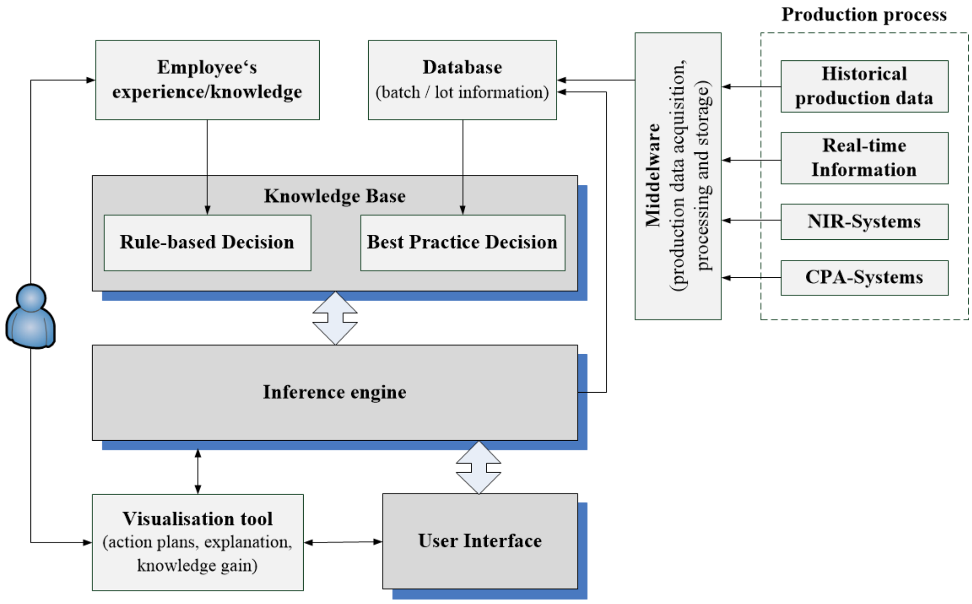


*Figure 6: System architecture of the expert-based concept*

It is common knowledge that the knowledge acquisition stage is the major bottleneck in the development of expert system-based solutions, regardless of the domain. In few words, the success of such a system depends on how much knowledge it has and how qualitative that knowledge is. The knowledge base is responsible for gaining Best Practice Decisions and Rule Based Decisions. For generating Best Practice Decisions a Middelware, as an interface between production IT systems and the expert system has been developed. It consists of a software tool for collecting process data (historical and real-time batch/lot information, sensor values). With sensor values the authors mean information about material properties. For these reason Computerized Particle Analyzer (CPA) and Near InfraRed systems (NIR) have been installed. The CPA system is used to collect valuable information towards material properties such as grain size. Within NIR other properties such as moisture, protein, fats, ash and starch will be collected. The acquired information (historical and real-time batch/lot information, sensor values) will be processed and stored into a database. The choice of using databases appears to be appropriate due to the fact that most expert system shells provide convenient interface possibilities to database systems (MS SQL, MySQL …). The stored information will be processed (aggregation, comparison …) in order to gain statistical results based on achieved production processes. The result of the processing step will provide employee and expert systems with information that will be translated into decisions, called Best Practice Decisions. Rule Based Decisions are the rules that the employees will generate/define based upon product requirements, their experience/knowledge and observations. For our knowledge base, we will consider only production rules. These rules occur in sequences and are expressions of the form:

IF <conditions> THEN <actions>

where if the conditions are true then the actions are executed [7].

By using Rule Based Decisions together with Best Practice Decision, details about other production processes, the system will be able to generate particularized advices on how the employees should set systems parameters dependent on the new requirements. This on how to change the parameters of the machine will result in an energy consumption reduction, while keeping the same product quality.

In addition to the user interface of the expert system and in order to facilitate the generation of new knowledge and to validate the output of the production adviser (expert system) an additionally interface, a visualisation tool, is needed.

After analyzing existing solutions several technologies have been chosen in order to achieve the objectives defined above. Table 1 shows the technologies used for the development of expert system.

| Function | System component | Selected technologies |
|---|---|---|
| Reasoning | Expert system shell | KSX expert system |
| Data acquisition, processing | Middelware | Java programming language |
| Data storage | Database | MySQL |
| Explanation, statistics | Visualisation tool | WordPress, D3js |

*Table 1: Parts and technical implementation of the expert system*

Actually the system is in a development phase and will gradually be evaluated and adapted to the requirements of the users

## 4. Results

The software tool for data acquisition and processing has been implemented, tested and evaluated. The correctness of gathered information is validated. For the storage of this information several structures have been defined and created in the database in order to facilitate the inference engine the extracting of specific values during the execution of defined rules. The above mentioned expert system shell, KSX, is currently in implementation phase. Based on the experiments performed by a compound feed producer and on the historical process information, many rules have been defined. These will be translated to the language of the expert system and constitutes the Best Practice Decision part of the knowledge base. Figure 7 depicts some good results obtained by controlling some process parameters.

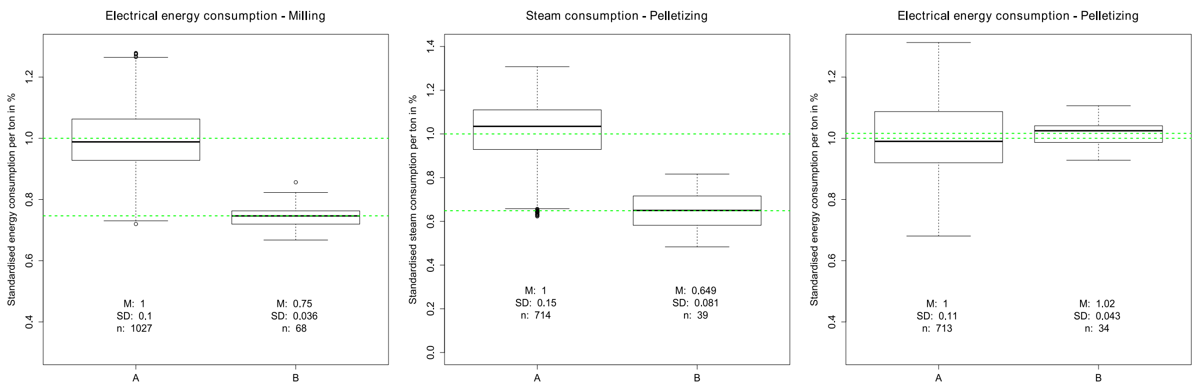


*Figure 7: Energy saving through process control and expert system*

The lot size production led to idle processes, which could be minimized the energy consumption by intelligent planning and the use of the expert system. Furthermore, the implemented approach could reduce the energy consumption through optimized control of parameters like the mesh sizes, the engine speed in the grinding process, the length of the channels in the pelletizing process and the steam temperature.

Through the use of the presented approach, first expectations have been fulfilled. Figure 7 illustrates the saved electrical energy of the milling process, the electrical and thermal energy of the pelletizing process. Furthermore it shows the difference of energy consumption between the old production system (A) and the expert system-based approach using generated process planning (B).

## 5. Conclusion

It is obvious from the results of the experiments described above; that the developed expert system-based solution will be valuable for producers in the feed sector. The system helps to determine uncertainties on material and energy flows. It will offer to employees a solution to the difficult problem of parameterizing a production system without the need of specialized knowledge. The developed Middelware tool will reduce the burden to link IT production systems with new solutions. In addition to the user interface of the expert system a visualization tool accompanying the expert system will provide supplementary explanations, for the selections made giving to the employees more insight to the process and helping them to identify possible problems and gain further knowledge for the expert system. Through the optimization of the product portfolio, all actors brought their expertise into an intensive experience exchange and developed a deeper understanding of the energetic correlations. The employees were very motivated to make a major contribution to the improvements and had the ability to track the energy use in the production process in more detail. Furthermore the effects of changes in the process flow were established in an objective and transparent manner. The results can be transferred to other industries. The use of the solution in comparable industry sectors may be an interesting test case. There are many processes that require a system to control heating and cooling of sensitive materials. Likewise there is a conflict of objectives between quality and the minimization of energy consumption. The applicability of this kind of systems to other industrial sectors is substantially dependent upon the compatibility to existing production processes and the acceptance of this kind of systems by end users.

## Acknowledgement

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# A framework for assessing the energy efficiency of non-mechanised agricultural systems in developing countries

Francis Molua Mwambo[1], Christine Fürst[2]

## Abstract

There is a continuously growing global demand for agricultural products, including food, fodder and fuels that urges for reasons of ensuring a sustainable development innovative methods to assess the impact of agricultural management. Existing methods of energy efficiency analysis for agricultural systems take into account human labour and draft animal power as inputs and consider also land-use characteristics as factors affecting the production in systems in most developing African countries. However, most of these methods fail to address properly different scales in decision making, i.e. connecting the management planning level with regional development considerations. With this paper, we introduce an alternative method to assess the energy efficiency in agronomic land-use. Our work intends to conceive a comprehensive and scale sensitive assessment framework that supports consulting land-use, decision making, and policy planning.

## 1. Introduction

Agricultural intensification involving the cultivation of high-yielding crop varieties combined with the application of sufficient fertilizers, pesticides and irrigation have been proposed as a relevant solution to address the problem of food insecurity menacing the majority of the population in many developing countries. But such strategy will likely be constrained by the rapidly increasing energy demand. According to [6] the global agricultural productivity is expected to be increased by as much as 50-70% by 2030 in order to meet the increasing human demands for food and other biomass-based products. The increases expected from developing countries' are at the upper margin considering the fact that their current productivity is lower and at the same time most of the population growth is occurring in developing countries compared to the developed countries. Figure 1 shows an agricultural performance review of Africa and 2 other developing regions over the last 50 years. The trend reveals that Africa is grossly lagging behind in productivity compared to the other developing regions [10]. Africa's productivity is hampered mostly by constraints of energy and land-use among other factors. Tackling the problem from a sustainable development standpoint has provoked the need for an alternative method that can be used to better analyse the energy efficiency considering African land-use schemes including inputs from human and draft animal labour. An accurate analysis will reveal decisive information through which the energy efficiency in agriculture can be improved, including the necessary support for the formulation of such energy efficiency oriented policy.

Furthermore, we are faced with a continuously growing global demand for energy that is intended to be fed more and more by renewables and here especially by biofuels [11]. Consequently, for agriculture being a consumer and producer of energy at the same time [9], energy efficiency analysis supports optimising the sustainable use of energy [11, 13, 18, 1, 2].

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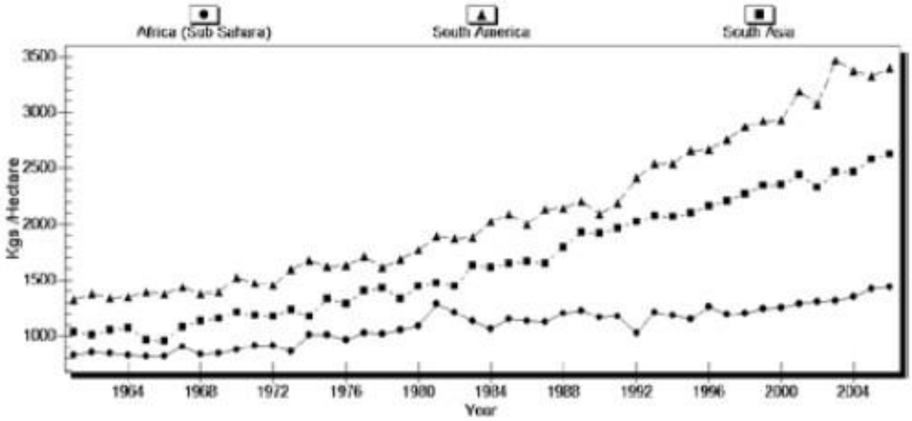


*Figure 1: Cereal Yields per Hectare: Africa versus Latin America versus South Asia (Copied from Kariuki, (2011) who states the original source)*

Energy efficiency analysis describes the role of direct and indirect energy inputs in the production system. Until now, relatively few studies on energy efficiency analysis have been conducted on agricultural systems in developing countries [26]. So far, there is no standardized and sufficiently reliable method for analysing energy efficiency in non-mechanised agricultural systems as is the case in most African developing countries where human labour and draft animal power are still predominant input energy sources as shown in Table 1.

| Region | | Percentage of area cultivated by different power sources | | |
|---|---|---|---|---|
| | | Human Labour | Draught Animal | Tractor |
| All developing countries | 1997/99 | 35 | 30 | 35 |
| | 2030 | 25 | 20 | 55 |
| Sub-Saharan Africa | 1997/99 | 65 | 25 | 10 |
| | 2030 | 45 | 30 | 25 |
| North East/North Africa | 1997/99 | 20 | 20 | 60 |
| | 2030 | 10 | 15 | 75 |
| Latin America and the Caribbean | 1997/99 | 25 | 25 | 50 |
| | 2030 | 15 | 15 | 70 |
| South Asia | 1997/99 | 30 | 35 | 35 |
| | 2030 | 15 | 15 | 70 |
| East Asia | 1997/99 | 40 | 40 | 20 |
| | 2030 | 25 | 25 | 50 |

*Table 1: Proportion of area cultivated by different power sources (Source: [6 p.153])*

Already in 1995, the FAO [5] states (see also Figure 2): "Human and animal labour requirements fall outside the traditional boundaries of energy sector planning, and their dynamics are far more complex than those of fuel and electricity supply. However, since human labour remains the predominant source of energy for agricultural production in much of Africa, and transitions to animal traction and fuel using machinery are important for the social and economic effects, human and animal labour requirements and trade-offs remains an important area for research." Consequently, adapted approaches that respect the specifics of subsistence agriculture need to be developed.

As a preliminary approach, this paper presents the conceptualisation of a comprehensive framework for assessing energy efficiency in subsistence agricultural production systems. In the subsequent section 2 we examine shortcomings of current methods of energy efficiency in analysing non-mechanised agricultural systems in developing countries. This is followed by section 3 on how to conceive the methodological framework. Finally, in section 4 we summarise how we envisage the further development and application of the framework.

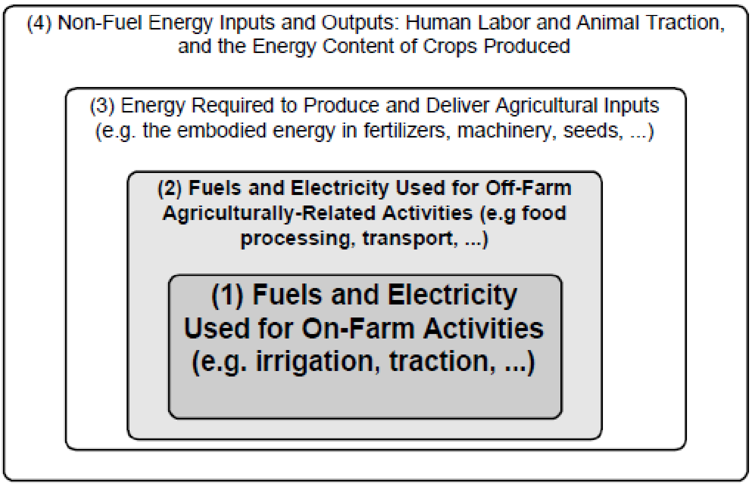


*Figure 2: Levels of agricultural energy analysis by FAO (Source: [5])*

## 2. Requests for improving energy efficiency analysis

There has always been a need for alternative approaches through which energy analysis could lead to sustainable development in developing countries' agriculture. In 1993, the United Nations [25 Chapter 14] emphasises on the relationship between energy and agriculture. It underscores the need to enhance productivity and thus, sustainable development in developing countries. In 1995, the FAO [5] reiterates that agricultural productivity is closely associated to direct and indirect energy inputs; and policies are required to consolidate this relationship to the benefit of farmers. However, agricultural development policies in most African countries are designed and implemented with little or no regard to this association. Consequently, opportunities which can enhance production in both quantitative and qualitative terms are often lost. Energy development plans in most developing African countries rarely take into consideration the present and future energy needs of agriculture.

Energy efficiency is a widely used term with different meanings in public policy making. Efficiency is the ability to produce an output from the minimum resource level required [22] while the ratio of energy output to energy input defines the energy efficiency [19]. According to [17] a distinction between energy conservation and energy efficiency is that the former is a change in behaviour while the latter involves an adoption of a particular technology that enhances energy saving. The advent of the concept of energy analysis was initiated in order to account for the fact that when heat or work is put into or taken out of a system and that system ends up in a different state. Consequently, some property of the system has to account for the difference. Thus, a given system under a given set of conditions has certain energy content as explained in [24]. Following the distinction made in [17 p.4787] a combination of both energy conservation and energy efficiency may be necessary in some developing countries. For instance, it may require farmers in developing countries to primarily change their behaviour from traditional land-use practices before adopting alternative land-uses that might have been recommended in a policy aimed at improving energy efficiency in agriculture.

The shortcomings of existing methods of energy efficiency analysis stem from the fact that the energy inputs from human, and draft animal labour in developing countries are often ignored [23 p.129] even though these inputs may be enormous [21 p.129] . [27, 28] consider energy inputs from various sources including humans and draft animals in agricultural systems in developing countries. However, most analyses were targeted at farm scale [28, 27]. Scenarios that involve also different management strategy below farm scale have so far rarely been considered in energy efficiency analysis [28]. The links between agricultural energy inputs, yields, economic returns, land requirements and land-use change need further research [11, 29]. The information contained in existing methods could much more be useful if land-use and land management are integrated in a standardized energy analysis methodology. An overall advantage of integrating land-use and land management would be that energy efficient management and land-use strategies can be recommended as benchmark when formulating agricultural policies. Also, most of the currently applied methods ignore the regional interplay of energy fluxes which is so decisive for sustainable rural development in developing countries. Finally, existing methods of farm energy efficiency use different approaches and subsequently produce different results [15 p.356]. Furthermore, there are difficulties in comparing different agricultural systems using existing methods because of the non-uniformity in the units in which energy efficiency is measured [23 p.123].

## 3. Methodological framework

To further develop the concept of energy efficiency analysis, we suggest combining the eMergy approach by Odum [16] and a technique in Data Envelopment Analysis (DEA) pioneered by Farrell [7] and later improved by Charnes *et al*., [3]. EMergy is a concept to better allocate and account for energy influxes (both inputs and outputs) in a production system. Its broader perspective of environmental inputs, direct connection to economics, and internal optimising principle [8] are a plus in analysis especially as energy, economics, and the environment are considered mutually dependent [26, 14]. Using transformity coefficients the influxes are converted to their energy equivalents measured in Solar eMergy Joule (SeJ) and subsequently analysed using DEA to process information in a way that enhances decisions making and energy efficiency oriented policies in agriculture. DEA is a non-parametric linear programming methodology through which it becomes possible to compare the productivity of different agricultural land use practices by considering a system of inputs and outputs. The best practice is benchmarked and the relative energy efficiency that can be improved in the other land uses that are not benchmarked can be calculated. Another advantage is that different land use schemes are considered in the DEA analysis. The application of DEA is also useful to obtain result that is informative as much as possible even when there are constraints in the data [2].

For this study, data on agricultural land use, crop yield, human and draft animal labour in agriculture are sought from the BiomassWeb Project partner institutions including the affiliated agricultural services in Ghana. Since developing countries' subsistence agriculture is rainfed, meteorological data on the rainfall and other renewable energy inputs from nature can be informative. Table 2 shows exemplarily the energy influxes in a non-mechanised agricultural system while Table 3 shows the agronomic land use characteristics commonly practiced in non-mechanised agricultural systems in Ghana as a representative developing country in West African. Figure 3 shows our suggested overall framework for an enhanced energy efficiency analysis that could cope with the specific problems of animal and human labour in African agricultural systems.

| **Renewable energy inputs from nature** | **Non-renewable energy inputs from nature** | **Purchased energy Inputs** | **Service energy inputs** | **Biomass energy outputs** |
|---|---|---|---|---|
| Solar energy for photosynthesis<br>Wind (kinetic energy) for pollination<br>Rain for rain-fed irrigation<br>Earth for geothermal/ geochemical input | Topsoil loss associated with agricultural land use & farming practices<br><br>Seeds/ seedlings for sowing | Fertilizers<br><br>Pesticides<br><br>Other chemicals | Human labour<br><br>Draft animal labour | e.g. crop yield |

*Table 2: A list of exemplary energy inputs and outputs in a non-mechanised agricultural system*

| Farming system | Farming practice | Effect of soil |
|---|---|---|
| Rotational bush burning | Slash & burn. Fallow period with or without fertilizer | Destruction of vegetative cover, Expose soil to erosion, Leaching of soil nutrients. |
| Permanent tree crop system | Slash & burn but presence of tree canopy | Minimal soil loss by erosion due to tree canopy. |
| Compound farming system | Slash & burn with or without fertilizer/ manure. Livestock grazing | Soil loss due to erosion, leaching of nutrients, Soil compaction due to livestock. |
| Mixed farming system | Slash & burn with or without fertilizer/ manure | Soil erosion & nutrient depletion. |
| Special horticultural farming system | Slash & burn with fertilizer/ manure & chemical application | Soil erosion, eutrophication & acidification due to fertilizer & chemical application. |

*Table 3: Characteristics of agronomic land use schemes in Ghana (Source: [4 p.4])*

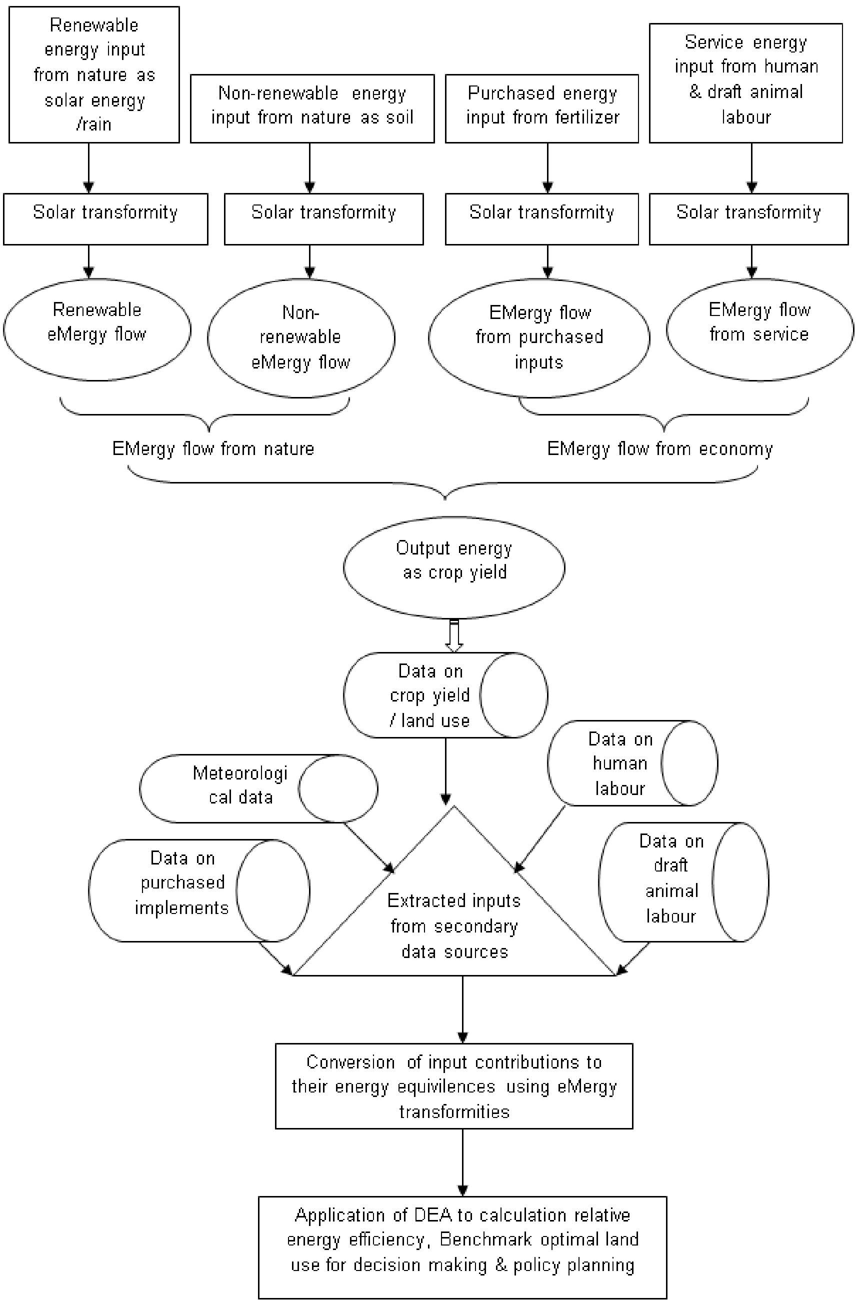


*Figure 3: Conceptual framework*

The eMergy component of the framework accounts for the various energy inputs to the production process in a given system. The energy use of the unit processes in the production system sum up to produce the output (yield). The inputs and outputs are converted to their energy values using transformity coefficients in eMergy. These energy values including their corresponding land-use schemes are fed into the DEA model component of the framework. The land-use schemes are the decision making units (DMUs). DEA uses a total factor productivity ratio to calculate the efficiency by attributing virtual weights to the input and output energy values. The performance of entities is then calculated using a linear optimisation process which maximises the ratio of each entity by finding the best set of weight for the entity. The optimisation is constrained by the fed data such that each entity is compared against the best observed performance. In this way, the best land-use can be benchmarked for decision making and policy planning that optimises energy use in agriculture.

In 1995, the FAO [5] had already highlighted the complexity involved in assessing energy efficiency in non-mechanised agricultural systems that employed human and draft animal power as input sources. In view of this complexity; our system boundary pays greater attention to direct inputs, and the produced outputs delivered at the farm gate. Transportation and agro-processing of output have not been considered in this framework. These limits have been adopted because of data constraints. Unlike in mechanised system where the embodied energy of machines is standard and energy is consumed only when a machine is at work the energy consumption of living systems (humans and draft animals) is continuous during their life span. Also, humans and animals need to be fed even when they are not momentarily expending energy at work. For this reason we further consider pasture land for animal grazing to be within the confinement of the system boundary in order to minimise the dependence of draft animals on the output energy (excluding crop residue). The other indirect inputs include energy used in the production of rudimentary farm implements and agro-chemicals. Figure 4 shows a sketch of an exemplary system boundary of a non-mechanised agricultural system.

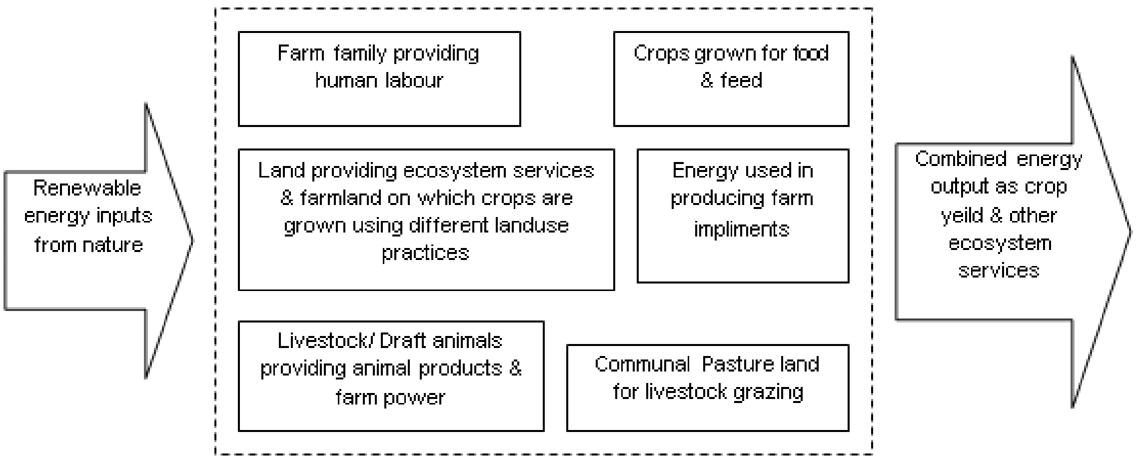


*Figure 4: Sketch of system boundary*

## 4. Discussion and conclusion

Following the oil crisis in the 1970s, the relationship between agriculture and energy (in this case fossil fuel) became vividly clearer and scholars have become increasingly aware of the dependence of agriculture on energy [20]. Since then, the analysis of energy use in agriculture has gained much momentum as many scholars have shown interest in the subject [26]. The main objective of a good energy analysis is to determine how much energy is actually needed to produce a given product or get a service done. But a more fundamental challenge is deciding upon a logical and consistent system boundary because different boundaries may lead to different results and conclusions [28].

The single ratio of output energy to input energy which defines energy efficiency obscures the visualisation of all the possible options through which the efficiency of a production system whose output depends on multiple inputs can be improved [2]. The method and framework in this paper presents therefore a unique approach that combines eMergy and DEA to account for farm energy efficiency in non-mechanised systems, and support for policy making from a sustainable development perspective. The eMergy component of the method and framework ensures that all fluxes are captured and sum to the total energy use [26]. It further considers input energy contributions from natural resources (sun, rain, wind) to man-made agricultural systems for the benefit of the farmer and therefore considers ecosystem services in agriculture. The DEA component of the framework increases the number of assessable alternative approaches that could be used to improve on efficiency by incorporating data from both renewable and non-renewable energy inputs including land-use. More interestingly is the scale sensitive approach of the framework to conduct assessment at regional scale. An assessment at regional scale will be useful in relating energy fluxes and balance to ecosystem services from both associated agricultural and naturally occurring ecosystems. The reference unit of SeJ further provides a means to compare different production systems in quantitative terms besides a qualitative approach.

Our future research tasks include fine-tuning the framework, and adapt it for assessing agricultural energy efficiency at regional scale, as well as to improve on the previewed weaknesses highlighted below. Some challenges include the paucity of reliable data on agricultural land use, crop yields, human and draft animal labour. Data are scantily documented in most developing African countries. DEA is a data oriented analysis approach. It does not require any prior assumptions on the underlying functional relationships in converting inputs into outputs. However, the advantage of not requiring such prior assumption can pose a weakness whenever over specialisation is the case. [12] caution that it can result to practically ignoring some inputs and outputs. Another current weakness may be related to the limits of the system boundary defined above. However, following [28] assessment at multiple levels minimises the problem of defending a particular system boundary.

## Acknowledgement

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# $CO_2$ Emission from Vegetable Oil plants Using IPCC Guideline 2006: Iran's Experience

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## Abstract

Vegetable oil plants are one of the most important energy consumer industries and Iranian vegetable oil plants don't have a suitable energy saving. In order to estimate the amount of greenhouse gasses emission of vegetable oil plants of Iran, calculations have been done by Tier l method based on IPCC guideline (2006) and a designed software usage. This method is based on emission factors.

Total emission of $CO_2$ from vegetable oil refinery plants and vegetable oil extraction plants for 5 years (2005-2009) is respectively estimated to be about 2195.3 Gg and 488.1 Gg. It is necessary to mention that $CO_2$ emission trend in the studied period is not the same, which shows that energy saving management is not the same in different years. Therefore it is essential to provide the energy management program for vegetable oil plants in Iran.

## 1. Introduction

Although natural emission of greenhouse gases (GHGs) is essential to maintain life on earth, many human activities emit additional GHGs to the atmosphere. It has been shown that there is a direct link between increasing concentration of GHGs in the atmosphere and the global climate deterioration [13, 14].

In 1992, countries and governments around the world met in Rio de Janeiro to address the climate change challenge by taking action to reduce GHGs. As a result, the United Nations Conference on Environment and Development (UNCED) prepared an international environmental treaty known as United Nations Framework Convention on Climate Change (UNFCCC or FCCC). Again, in 1997, more than 160 countries met in Kyoto, Japan, to find a practical procedure to reduce GHG emissions. They agreed to reduce GHG emissions according to the Kyoto Protocol that set out targets and options available to achieve those targets [35].

Energy is the backbone of the world economy. Fossil fuels, particularly petroleum fuels have been and still are major sources of fuel for powering, among others, transportation vehicles, agricultural machinery, and power generation. The combustion of fossil produces carbon dioxide, which is a major greenhouse gas. Concentration of carbon dioxide in the atmosphere has almost doubled from the preindustrial value of about 280ppmto 379ppmin 2005 [14].

Less drastic estimates predict temperature increase rates of 0.088 _C per decade for this century. Other investigators forecast for the near future that rising air temperature could induce more frequent occurrence of extreme drought, flooding or heat waves than in the past. Review of the progress on this issue in the negotiations might suggest a negative answer. More than a decade of discussion in international negotiations and earlier scientific consideration of this issue, has not led to specific consensus on what is ''dangerous anthropogenic interference with the climate system''[2].

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Later, in the negotiations leading up to Kyoto, proposals from governments to establish long-term stabilisation targets were not adopted despite extensive debate on the issue of the 'adequacy of commitments'' of the UNFCCC.4 While the initial conclusion of this debate led to the Berlin Mandate to negotiate stronger mitigation commitments for Annex I Parties, which ultimately resulted in the Kyoto Protocol [6], It has not resulted in agreement on long-term targets. Since 1997, international climate negotiations have been dominated by short-term issues such as the design of rules of the Kyoto Protocol[6].

This could be seen as grasping for a next step based on the perception that mitigation costs are likely to be too high to achieve more ambitious objectives, regardless of whether such a step is strategically necessary to protect the climate [2]. Further increases due to anthropogenic activities have been predicted. Carbon dioxide concentrations are expected to be 100% higher in 2100 than the one observed at the pre-industrial era [14].

All countries that are Parties to the Kyoto Protocol [36] are required to regularly submit GHG emissions data to the UNFCCC Secretariat. The UNFCCC has a 'Kyoto Protocol Reference Manual on Accounting of Emissions and Assigned Amounts' [37], which details how GHG inventories should be calculated. Industrialized (Annex I) Parties are requested to submit their detailed GHG inventories, including CO2 data, annually. Developing (non-Annex I) Parties should submit GHG data periodically as part of their national communications. The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP) as a source of relevant information on climate change to governs and interested parties [31].

Climate on Earth has changed many times during the existence of our planet, ranging from the ice ages to periods of warmth. During the last several decades increases in average air temperatures have been reported and associated effects on climate have been debated worldwide in a variety of forums. Due to its importance around the globe, agriculture was one of the first sectors to be studied in terms of potential impacts of climate change [1].

Anthropogenic emissions of greenhouse gases (GHG) led, over the past two centuries, to a considerable increase in the concentration of these gases in the atmosphere. GHG act as a blanket that retains solar heat in the atmosphere. Therefore, elevated concentrations of GHG cause increased atmospheric heat retention. This creates higher global temperatures or what is more commonly known as global warming [8].

Global climate change has been one of the challenging environmental concerns facing policy makers in the past decade. The characterization of the wide range of greenhouse gas emissions sources and sinks as well as their behavior in the atmosphere remains an on-going activity in many countries. Ideally, emissions data can be obtained from in-field investigations, but in reality such data are not always available or reliable. However, several studies related to GHG emissions and Kyoto Protocol and the Intergovernmental Panel on Climate Change (IPCC) guidelines were reviewed in order to establish sound references [9, 17, 18, 27, 33].

Questions about the timing, level and form of the next round of mitigation commitments are moving to center stage of the international negotiating agenda on climate change. A key will be to intensify and broaden participation in emission reduction so as to bring absolute global emissions trends down and allow stabilization of concentrations of GHG to occur in a timely manner. The Kyoto Protocol calls for starting new negotiations on next steps by 2005 [34].

Beyond avoided climate impacts; a number of other specific policy benefits may be triggers for mitigation. This includes eco-system stability and resilience [26] and the ability for natural resource systems to continue to provide the necessary resource base for future economic development [4, 23].

Emissions of CO2 from fossil fuel combustion is based on energy consumption data and emission factors based on the carbon content of the various fuel types, corrected for the fraction of carbon that remains unoxidised in ash. The carbon content per detailed fuel type was based on the IPCC default values and for the oxidisation fraction also the three IPCC defaults for solids, liquids and gaseous fuels were used [11]. Another set of benefits maybe related to sustainability goals of nations, regions or local communities [3- 5, O'Connor, 2002; ). For example, synergies with greenhouse gas mitigation can improve local environments and reduce health risks from urban air pollution, or, with adaptation, and communities to adapt practices to variability in climate, which also prepares these communities to deal with future climate changes [7].

Thus in addition to concern about the magnitude and distribution of the direct impacts of climate change, and about the costs of mitigation, a variety of other policy ''benefits'' may begin to drive national and international action to strengthen climate policies [28].

Compared to mitigation cost assessment, much less research has been devoted to comprehensive assessment of the long-term benefits of mitigation [12, 22, 38].

Policy decisions are made difficult by cascading uncertainty and delays in the cause–effect chain due to inertia in the systems involved. Uncertainty cascades throughout this chain effect, as the uncertainty range at the top of the chain grows in significance after moving through the intermediate drivers and indicators of change. The broadest bands of uncertainty found at the bottom of the chain [16, 20].

Characterising uncertainty in each of the steps of the cause–effect chain is therefore essential to understanding and interpreting the results of assessment of emissions and their impacts for policy assessment [20, 29, 32]. Despite the uncertainty, climate changes are already underway and these are having a discernible effect in some sensitive sectors [26, 30].

On the basis of Article 4 and 12 of the United Nations Framework Convention on Climate Change (UNFCCC) and Article 7 of the Kyoto Protocol, all Parties to the Convention are required to submit national inventories of greenhouse gas emissions and removals to the Secretariat of the Convention. So, one of the obligations of the countries that have ratified United Nation Framework for Climate Change Convention is to report their greenhouse gas inventory to the Secretariat of UNFCCC through their National Communications (UNFCCC website).

For inventory of GHG, IPCC (International Panel on Climate Change) has developed methods and guidance that have been broadly applied by countries ratifying the UNFCCC [39].

IPCC Guideline 2006 is a software tool which helps countries for calculating GHGs inventories.

Energy Sector is one of the most important and the greatest sector that need to be taken into account in developing the inventory. This sector plays an important role in GHG emissions [25].

In this sector, the industry is one of the main energy consuming sectors in Iran and accounted for 23.8 % of total energy consumption in 2010 [19].

The current guideline, which has been used in calculation CO2 emission of vegetable oil plants of Iran, is IPCC Guideline 2006.

## 1.1. Introduction to Vegetable Oil Plants in Iran

There are 49 vegetable oil plants in Iran, but only 39 plants are operating now. The plants are divided to oil extraction plants, oil refinery plants and some plants which do both activity (oil extraction and refinery). Nominal capacity of production in oil refinery plants is 3463 kT/yr and production capacity is about 550 kT/yr for crude oil and 2 mT/yr meal in oil extraction plants.

Vegetable oil plants are one of the most important energy consumer industries and their energy saving situation is not in Iran.

Energy consumption in vegetable oil plants according to statistics in year 2010 is shown in table 1 [10].

| Natural gas ($m^3$) | Fuel Oil (lit) | Gas Oil (lit) |
|---|---|---|
| 182772351 | 32045138 | 19730480 |

*Table1. Annual energy consumption in vegetable oil plants in Iran (2009)*

## 1.2. Introduction to vegetable oil production process

The Process of Vegetable Oil Production is divided to two sectors: oil extraction and crude Oil refinery, which are explained below [10]:

### 1.2.1. Oil extraction Process

This Process consists of the following steps:
- receiving and reserving oil seeds
- Seeds preparation
- Pressing the oil seeds
- Chemical extraction by solvents

### 1.2.2. Oil refinery process

This process consists of the following steps:
- Alkali refining
- Bleaching
- Winterization
- Hydrogenation
- Nickel Removal
- Deodorization

## 1.3. Emission estimation techniques

Several techniques are available for calculating emissions from vegetable oil processing facilities. The technique chosen is dependent on available data, available resources, and the degree of accuracy sought by the facility in undertaking the estimate [21].

### 1.3.1. Direct Measurement

Use of stack and/or workplace health and safety sampling data is likely to be a relatively accurate method of estimating air emissions from vegetable oil processing facilities. However, collection and analysis of samples from facilities can be very expensive and especially complicated. Sampling data from a specific process may not be representative of the entire manufacturing operation and may provide only one example of the facility's emissions. However, it may be misleading to assert that a snapshot (stack sampling) can better predict long-term emission characteristics. It is the responsibility of the facility operator to properly calibrate and maintain monitoring equipment and the corresponding emissions data [21].

### 1.3.2. Mass Balance

Calculating emissions from a vegetable oil processing facility using mass balance appears on the surface to be a straightforward approach to emission estimations. Inaccuracies associated with individual material tracking or other activities inherent in each material handling stage can often result in large deviations of total facility emissions [21].

### 1.3.3. Engineering Calculations

Theoretical and complex equations or models can be used for estimating emissions from vegetable oil processes. Use of emission equations to estimate emissions from vegetable oil processing facilities is a more complex and time-consuming process than the use of emission factors. Emission equations require more detailed inputs than the use of emission factors, but they do provide an emission estimate that is based on facility-specific conditions [21].

### 1.3.4. Emission Factors

Emissions factors present the mass of GHG emissions (carbon dioxide, methane, or nitrous oxide) per unit of activity data, where the activity data are typically a process rate or equipment count [15].

## 2. Methodology

In order to estimate the amount of greenhouse gasses emission of vegetable oil plants of Iran, estimates and calculations have been done by Tier l method based on IPCC guideline (2006) and a designed software usage. This method is based on emission factors.

Based on the amount of different fuel type's consumption in vegetable oil industry and regarding to the emission factor of different greenhouse gasses of fuels, the amount of greenhouse gasses emission is calculated.

For calculating the CO2 emissions, considering the amount of fuel consumption in the sector and carbon emission factor, first the carbon content of the fuel is calculated, and then the specific net and actual carbon emission and finally the actual CO2 emission are calculated.

It is necessary to mention that in order to calculate CO2 emission from different fuels, national emission factors have been used.

Total emission of CO2 from vegetable oil refinery plants and vegetable oil extraction plants for 5 years (2005-2009) is respectively estimated to be about 2195.3 Gg and 488.1 Gg.

## 3. Results

According to the calculation by IPCC software, CO2 emission from oil extraction plants in a 5 year period (2005-2009), the highest emission belongs to year 2006, which is shown in table 2.

| | **2005** | **2006** | **2007** | **2008** | **2009** |
|---|---|---|---|---|---|
| **Natural gas** | 45.62 | 49.66 | 47.76 | 53.85 | 40.16 |
| **fuel oil** | 34.04 | 47.08 | 36.09 | 33.16 | 33.17 |
| **disel oil** | 14.13 | 13.58 | 13.89 | 13.32 | 12.62 |

*Table2.* $CO_2$ *emission from oil extraction plants (2005-2009)*

CO2 emission from oil refinery plants is presented in table 3, which the highest emission belongs to year 2006.

| | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|
| **Natural gas** | 319.5 | 375.67 | 342.28 | 300.5 | 311.02 |
| **fuel oil** | 87.96 | 73.52 | 75.51 | 66.76 | 68.26 |
| **disel oil** | 57.87 | 40.97 | 36.05 | 23.64 | 15.79 |

*Table3. $CO_2$ emission from oil extraction plants (2005-2009)*

Figures 1 and 2 also shows the trend of $CO_2$ emission respectively in oil extraction plants and oil refinery plants by different fuel types.

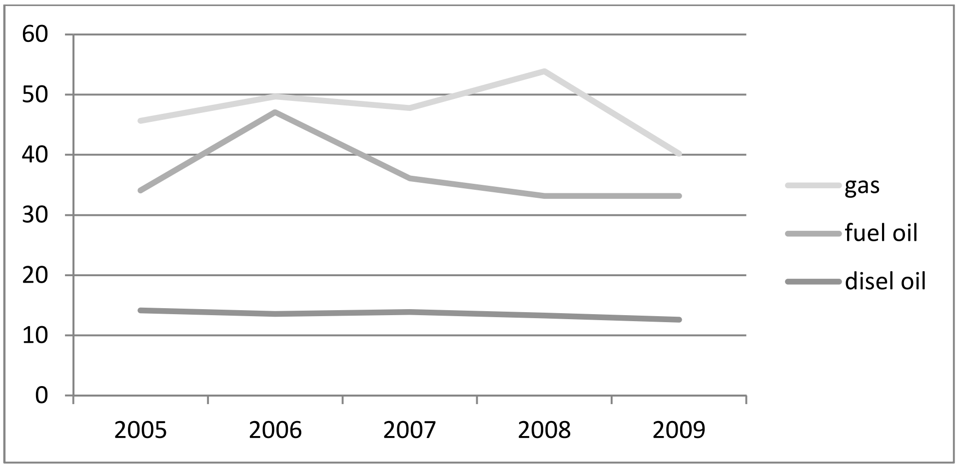


*Figure 1. Trend of* $CO_2$ *emission in vegetable oil extraction*

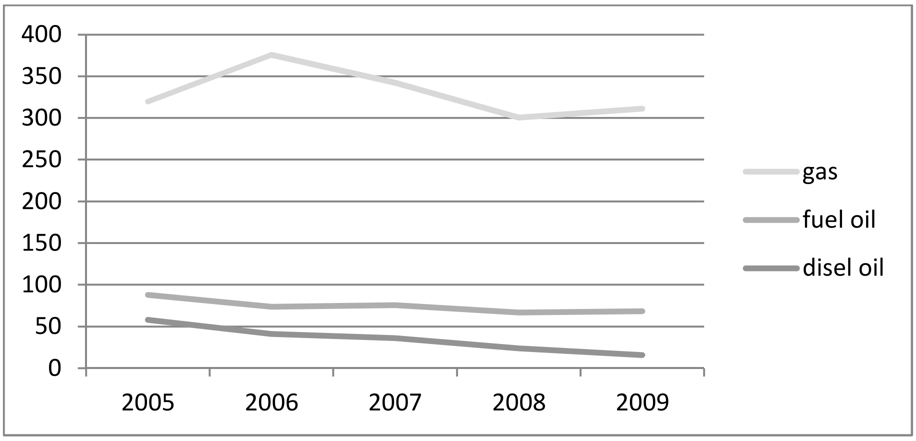


*Figure 2. Trend of* $CO_2$ *emission in vegetable oil refinery plant*

## 4. Conclusion and discussion

In order to survey the CO2 emission trend of vegetable oil plants in 5 – year period (2005-2009), the production amount and total CO2 emission (from different fuel types) from oil extraction plants and oil refinery plants have been shown respectively in figures 3 and 4.

As it is shown in the figure 3, CO2 emission and production trends are almost the same, but in 2007 CO2 emission is reduced while production is increased. CO2 emission has been increased while production has been decreased.

About oil refinery plants, production and CO2 emission trends are the same, but in 2005, while production has been increased, emission has been decreased. Production has been decreased in 2006, while CO2 emission has been increased.

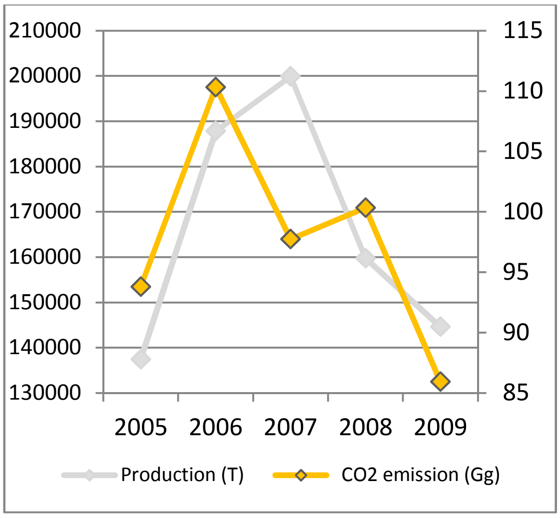


*Figure 3. $CO_2$ emission and oil production in vegetable oil extraction plants (2005-2009)*

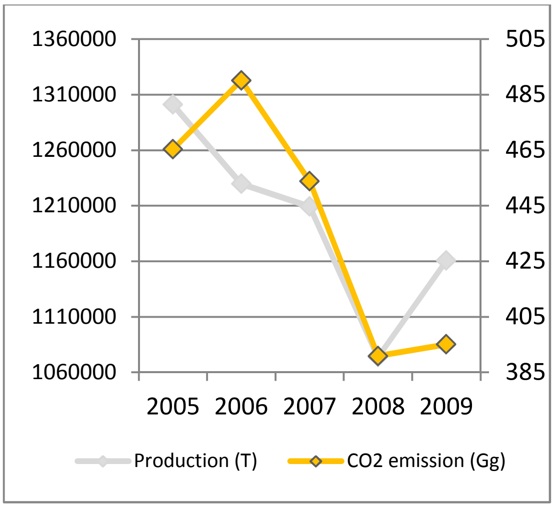


*Figure 4. $CO_2$ emission and oil production in vegetable oil refinery plants (2005-2009)*

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# Findings of an Action Research on implementing an Integrated Energy Management in a German SME

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## Abstract

The responsible and sustainable use of energy in private, public and business environments is one of the major societal challenges of our time. An essential part of this challenge is to increase the energy efficiency of (high energy) companies and implementing a sustainable energy management. In this paper we demonstrate that this is a complex socio-technical problem that asks for a holistic view and the need of integrated energy management systems without neglecting the difference between the needs and roles of the various stakeholders in a company. These findings are based on an ongoing action research where we conduct interviews with 15 groups of interest in the company that is operational in the area of fastening technology and has more than 2300 employees in 30 subsidiaries.


## 1. Introduction

The responsible and sustainable use of energy in private, public and business environments is one of the major societal challenges of our time. One of the key factors of a successful implementation of the energy turnaround is the energy efficiency of (high energy) companies. In Germany, for instance, government acknowledges this need e.g. with the introduction of the “Erneuerbare-Energien-Gesetz” (EEG) law.

In later versions of the EEG incentives were added for manufacturing companies that implement an energy management system conform to DIN EN ISO 50001 [1] or conduct an energy audit based on the ISO 16247 [2]. The key concept of the ISO 50001 is to establish a continuous improvement process (CIP) increasing the organizational energy efficiency. This process is split into four iterative phases: Plan, Do, Check and Act [3]. On completion of each iteration, a new revision of energy management processes should be implemented. This CIP method is analogue to common methods of business process management (BPM). Since the main goal of the CIP (introduced according to ISO 50001) is to increase the sustainability of a company there is a great affinity to Green BPM [4] concerning the optimization of the energy consumption.

In organization, energy efficient tasks play a major role for energy conservation. For example Schröter et al. [5] estimate that about 15% of all consumption could be saved by efficient task, according to Meyer [6] it is up to “25% . While energy efficiency tackles both, ecologic and economic dimensions, the latter is rather important. Especially small and medium enterprises need to increase their efficiency, for the simple reasons that energy costs are one of the main cost drivers in production processes and especially smaller companies may struggle due to increasing costs (ibid.).

In the following sections we will survey the state of the art of a socio-technical scope on energy management, afterwards we describe our research approach and present our findings. We conclude by discussing our findings and give an outlook on our next research activities.


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## 2. State of the Art

Most organizations lack proper information on energy consumption, demand and pricing, which is necessary to improve sustainability. This has proven to be substantial to instantiate suitable measures on various organizational levels. For example, Schwartz et al. [7] and Jakobi et al. [8] showed that individual feedback on the employees' energy consumption is a valid instrument to lower energy consumption in office environments. On a more strategic level a study conducted by the IHK Siegen-Wittgenstein, the regional chamber of Industry and Commerce, for instance, pointed out that enterprises with an active energy procurement policy, buying directly on the energy exchange market, can save up to 34% of their energy costs [9]. These examples show that IT-supported organizational information management about energy consumption, procurement and production is vital to succeed. But in order to achieve that kind of economization, the company needs accurate energy consumption forecasts based on historical consumption, which is not necessarily given in organizations.

In principle energy management could rely on the manual collection of consumption data (and conform to ISO 50001). Yet an effective and holistic eco-controlling could only be carried out by IT support [10] as information technology enables the company to schedule and control energy consumption during the manufacturing and production. Hence, one key component for a modern energy management is the implementation of a computational energy management system, since it allows the involved stakeholders to gather the needed information on, e.g. the current load, energy peaks and the energy efficiency of a certain product. Sangmeister et al. stated companies now save about 10% of their energy in the first year through the introduction of such energy management systems [11]. IT-systems itself, however, are dead capital, if they are not effectively used in practice. Hence we must understand the integration of an energy management as an integrated organization and technology development process [12] with the "green business" as a guiding principle [13]. To achieve a this goal, Süpke and Heil [14] have identified three core elements: Involvement of all relevant stakeholders, expansion of the business strategy by including a sustainability dimension, and the implementation of new processes derived directly from the new strategy.

A holistic approach resting on the three-pillar model of social, ecological and economical sustainability [15] is one of the modern corporate objectives. Nevertheless, there are still too few companies with clear strategies and management concepts, from which sustainability management can be derived [16]. In addition, energy management cannot be equated with energy efficiency [17]. The management of energy has to be aligned with the corporate strategy (ibid.). Concerning this, the adoption of "green" business processes is an essential part in the successful implementation of energy management and sustainable corporate strategies. The alignment of the sustainability strategy with the corporate strategy as well as the alignment of the intended sustainable processes and the real processes must be regularly monitored. Well-known instruments to assess the adoption of business processes are maturity models, which should also be used during and after the implementation of energy management [18] in order to secure the success of the corporate strategy.

This brief survey on energy management shows that energy management is a complex task that must be perceived as a socio-technical challenge.

## 3. Field of Application and Method

This work covers the empirical, analyze phase of an ongoing action research [19] where we participate with a SME in South Westphalia.

The company is operational in the area of fastening technology, has more than 2300 employees in 30 subsidiaries, and thus can be characterized as decentralized. In contrast the company has a centralized energy management department, which is part of a shared service center and is responsible for managing all subsidiaries in this matter.

Our research activities addressed the holding company and three subsidiaries, while a second more focused empirical study addresses only the holding and two subsidiaries.

### 3.1. The First Study

Our status quo analysis was carried out in September 2013, when we conducted ten semi-structured interviews over the course of two days with various stakeholders in the company (Management, Maintenance, Controlling, IT Department, Energy Management, Energy Procurement, and Production Management). The questions focused on the general organizational energy management activities and the existing infrastructure, the individual need of information and their individual assessment of the importance of the internal energy management. On average, the interviews lasted 45 minutes and were transcribed and analyzed with qualitative methods.

### 3.2. The Second Study

While the first study was conducted in order to assess the status quo of the energy management and unveil the untapped potential for an action-centered visualization approach, the second study is more focused on action taken and is still ongoing. The study takes place in a joint research project, which was established about 3 months after completion the first study. In this research project, the following goals are to be achieved:

- Design and implementation of a holistic and modular energy management system
- Design and implementation of a strategic and an operative indicator system for an energy controlling as part of the energy management system
- Integration of the energy data into the business processes of the company, especially the integration into the ERP-System in order to allow e.g. the calculation of the direct costs of the products and a production scheduling under consideration of the, energy consumption of particular process steps

As part of the second study (which will be concluded in September of this year) we identified 15 groups of interest which are part of the requirements engineering, the research and the design process. Additionally, to the first interviewees, the groups of interest consist of a production manager of a new subsidiary, two project managers (the two projects are the implementation of a factory data collection module and a maintenance module of the ERP-System), the factory manager of one subsidiary, three managers of the most energy consuming organizational units (electroplating, hardening, production) and the local controller. The groups of interests are likely to be expanded while the project goes on.

## 4. Findings

### 4.1. First Study

In the following section we will outline the results of the study, ordered by the groups of interest.

- Maintenance
  The maintenance department is responsible for the servicing and maintenance of production facilities. This includes both tools and materials, as well as energy and building technology, including gas and compressed air facilities.
  The manager of the maintenance department is also responsible for the cost centers associated with energy, water, gas, and compressed air consumption. The necessary information is gath-

ered manually at the end of each month and is transferred to the central environmental management department.
From the perspective of the maintenance department the importance of integrated energy data management is rather high, since it could possibly enable them to avoid load peaks during the production cycles. Furthermore, they could implement a base load optimization process, focusing especially on the auxiliary process time, e.g. between shifts or during the night.

- Controlling
  The controlling department at the cooperation is divided into central, international and business division controlling. It consists of 14 members. Our interviewee is part of the business division controlling, which deals primarily with the value chain and manufacturing costs controlling.
  In regard to energy data management their main task is to enable the different production departments the allocation of direct expenses of their product. Due to the state of the energy data management (manual data collection, monthly polling of the consumption data, no IT support) precise cost allocation is impossible and they need to rely on the distribution of overhead costs (such as energy costs). Another request of the controlling department is the possibility to identify the major energy drivers (e.g. electroplating, hardening) and support in the process of calculating machine hour rates.

- IT-Department
  The IT-Department consists of 20 employees and is a central service unit for the holding and all the subsidiaries. The requirements identified in the discussions on energy data management in the field of IT are to be classified with low priority for the business and have a strong operational focus. However, they are aware of their importance in the implementation of an integrated energy management system, since an information system is one key element of environmental and energy management.

- Energy Procurement
  The department is part of the general procurement department and is responsible for the purchase of electricity and gas and is supported by an external consulting company. Their procurement structure is organized into ten tranches a year, which are ordered at different points of time, in order to minimize the price risk. The main requirements for this department are the support of aggregated views on the consumption of electricity and gas (weekly, monthly, and yearly). Furthermore, they need a breakdown of the energy costs into the dimensions working price, “KWK”[6]-apportionment, “EEG”[7]-apportionment, offshore apportionment and energy tax.

- Business Division Building Fasteners
  For the business division building fasteners the consumption data of the energy carriers, water, waste, compressed air, electricity and gas are important. Due to the unique production process water consumption especially is relevant to the manager. The consumption data is read once a month from the corresponding meters. In addition to the manager, all the foremen and employees need to be informed about the consumption, since the change of consumption is discussed in the regular meetings among the foremen. A critical requirement for this business division is the task-oriented visualization of energy data, since overall consumption is not that useful for

[6] The “Kraft-Wärme-Kopplungsgesetz“ subsidizes the contruction of cogeneration plants and technologies

[7] The “Erneuerbare-Energien-Gesetz” is a German law that regulates the priorization of the feed-in of electricity from renewable sources into the power grid and guarantees their producers fixed feed-in prices.

the foremen and employees. Furthermore they need support in their foremen meetings, in order to monitor and benchmark process changes both in the subsidiary and as well as between subsidiaries.

- Business Division Electroplating
  As part of the initial study, one manager of an electroplating department was also interviewed. From his perspective, when it comes to energy data, the main concern is water consumption. Compressed air is the second most important resource, whereas electricity and gas are not as important. From his point of view, the biggest improvement would be a batch-oriented analysis of energy consumption. Moreover he needs continuous monitoring of the compressed air, since bottlenecks can decrease efficiency drastically.

- Business Division Screw
  The division manager's opinion is that energy data management is not really important for him. The only interesting scenarios he could think of were a comparison of energy consumption in the procurement process of new machinery and in support of the audit process.

- Business Division Environmentalism – Industrial Safety – Facility Management (ESM)
  The ESM division is the central division when it comes to energy and environmental (data) management. In addition, they are responsible for the implementation of the ISO 50001 in German Subsidiaries. Their main concern with the current state of energy data management is the manual collection of the consumption data. Not only does it delay the monthly reporting, but it is also the main source of errors in the current environmental controlling. Their main demands on energy management are the automation of the data collection, an alert system which informs the energy manager of relevant incidents, the support for strategic environmental controlling and the integration of an information exchange between energy contractors and the company.

The status quo analysis revealed four major weak spots of the existing energy management:

1. Although the company implemented certified energy management (ISO 50001) in 2012 and an environmental reporting system based on the Global Reporting Initiative[8], the data collection is still done manually and only down to subsidiary level. Hence real time collection, analysis and visualization are not possible, which means the managers and employees cannot use the information for their day-to-day activities
2. The performance measurement and controlling system is too general and only fits the requirements of the environmental manager
3. The implemented energy management is fragmented and does not follow a holistic approach. As a result there is insufficient provision of information and inconsistencies occur
4. Although energy management is a major concern for both the ESM division and the management, most production divisions regard it as being less significant. Even so, most of the interviewees could think of at least some scenarios where they could benefit from integrated energy management. Nevertheless there is a gap between the management and the employees that are part of the operational business.

[8] https://www.globalreporting.org

On the basis of the first study, we developed (coordinated with the company) an integrated energy management concept that consisted of the major areas: hardware, software and processes.

The discussion of this concept and how to implement it started in February 2014 and is still ongoing. The key of the concept includes a measuring sensor system which allows the energy consumption of the e.g. machinery to be monitored. This is partially realized in practice (e.g. one subsidiary was equipped with sensor technology). The data will be stored in a central real-time database system to allow precise evaluation of the energy consumed in the production process. At the moment, an operating and machine data logging software has been selected and will be installed, thus connecting the measure points by the end of July. In addition, two value-added services have been selected and will be implemented. The former is a web application for both strategic and operative eco-controlling and the latter is a web-application which allows the forecasting of energy consumption based on historical data.

The energy management solution is the core element of the project which we started with the company. Nonetheless the implementation of both new and altered business processes are also a major part of the project, and will be addressed in the second study.

### 4.2. Second and ongoing Study

Whereas the first study aimed at the analysis of the state of the energy data management in the company, the second study is more action focused in order to implement an energy management system and engage in the change of the corresponding business processes.

In this study we focused on two production business divisions and the holding. Yet we started with a requirements analysis of one subsidiary first, which is the pilot enterprise for both, the company and ourselves. And was not covered in the initial study.

- Energy Procurement
  As part of the research project, we will develop a module that enables the company to forecast their energy consumption based on the collected energy data. The energy procurer needs an algorithm, which helps him with his procurement process (when to buy) and supports his reporting.

- Maintenance:
  Although we interviewed one maintenance department in our first study, we also interviewed the local maintenance at the chosen subsidiary. Additionally to the requests of the other maintenance department, they need an integration of the implemented energy management system into the maintenance module of their ERP-software. Furthermore they requested a feature, which detects electrical interferences.

- Production:
  From the point of view of the local production assistant the energy management system needs to be integrated with the operating data module of their ERP-software. This would allow them to evaluate, whether there is an upcoming assignment for a machine and if it could be e.g. disconnected from the compressed air grid. In addition, he thinks that through the connection between the consumption and operating data one can finally analyse the direct costs of the products. Moreover, it should be integrated into the efficiency overview, which now only consists of the number of items per hour.

Additionally to the conducted interviews, we informed all participants about our research project and our next steps. In the aftermath most of the stakeholders engaged in a discussion and pointed out, that they need support for their project team, which tries to increase energy efficiency of processes and the subsidiary in general. They envisioned a tool, which allows them to benchmark processes and supports the evaluation of their measures. Generally they are really interested in the comparison with other subsidiaries and hope that the implemented energy management system will help them with energy audits and reports.

## 5. Conclusion

As seen in the state of the art and based on our first study, the implementation of an energy management present a socio-technical challenge where different stakeholders and their roles have to take into account. Further a holistic energy management system needs to be integrated in both the existing infrastructure and the business processes of the company. Moreover a strategic and operational environmental controlling must be implemented in order to qualify for the tax benefits and to unfold the full potential of an energy management system. A process integration is imperative for a modern approach on environmental (data) management. Furthermore, the different attribution of importance of the energy (data) management by the subsidiaries and the holding must be addressed, since at the current state of the project, the needed infrastructure for the measurement of the consumption data is about to be rolled out, but the subsidiary lacks proper use cases and business processes to incorporate the data into their processes. Right now we are about to finish the requirements analysis with the subsidiary, and are working on both operational and strategic concepts for an environmental controlling. Besides we are working on a concept for the integration of our energy management system into the existing infrastructure (ERP-system).

As part of the ongoing research activities in the research, we will analyze the implementation of our energy management solution in three different companies and will work on the concept of the holistic energy management.

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# *Switch off the light in the living room, please!* – Making eco-feedback meaningful through room context information

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## Abstract

Residential and commercial buildings are responsible for about 40% of the EU's total energy consumption. However, conscious, sustainable use of this limited resource is hampered by a lack of visibility and materiality of consumption. One of the major challenges is enabling consumers to make informed decisions about energy consumption, thereby supporting the shift to sustainable actions. With the use of Energy-Management-Systems it is possible to save up to 15%. In recent years, design approaches have greatly diversified, but with the emergence of ubiquitous- and context-aware computing, energy feedback solutions can be enriched with additional context information. In this study, we present the concept "room as a context" for eco-feedback systems. We investigate opportunities of making current state-of-the-art energy visualizations more meaningful and demonstrate which new forms of visualizations can be created with this additional information. Furthermore, we developed a prototype for android-based tablets, which includes some of the presented features to study our design concepts in the wild.

## 1. Introduction

Residential and commercial buildings are responsible for about 40% of the EU's total energy consumption [1]. With disaggregated real-time energy consumption feedback, dwellers can be enabled to make better informed energy related decisions and therefore save energy. In general, empirical studies have shown that savings up to 15% [2] can be achieved.

These promising results have led to a vivid research discourse and development investigations in smart metering technologies. Based on these results, the fine-grained collection of consumption data is not a vision anymore, but reality. However, with the increasing volume of data, its visualizations become more complex. A major challenge in sustainable interaction and eco-feedback design (SID) [3] is to enable consumers to make informed decisions about energy consumption and thereby supporting the shift towards or implementation of sustainable actions. In particular, current research focuses on how to make feedback more informative and action-oriented. A promising approach presents the concept of context awareness. The aim of this approach is to reduce information complexity and to provide a rich context for interpretation to make data more meaningful for the user. By reducing the complexity of information and providing a rich context, context awareness enables the user to interpret consumption data.

Contributing to this, we present the concept of *room* as context information. Rooms play an important role in structuring domestic routines and thus domestic energy consumption. We developed various design studies that illustrate how room information can be used to enrich feedback mechanisms and contextualize user interfaces of mobile home energy management systems (mHEMS).

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## 2. Related Work

In recent years, several related concepts have emerged in the literature concerning eco-feedback systems for domestic environments that make information about energy consumption accessible to users. In this section we give a short overview about the evolution of eco feedback systems and about the relevance of context-information for designing eco-feedback systems.

### 2.1. Eco Feedback Design

Common concerns addressed by most eco feedback systems include the presentation of data, temporal aggregation/disaggregation, historical and normative comparison and the subject of motivation, support of devices and context [4]. Thereby a rapid development of energy feedback systems takes place. Early eco-feedback systems were simple video screens providing information about the total energy consumption of the household (smart meter systems), such as ‘eco-eye’ [5] or the ‘power-aware cord’ [6]. More sophisticated systems provide feedback on appliance level (smart plug systems) like ‘DEHEMS’ [7]. Nowadays, a variety of solutions are realized as web-portals [8] or smartphone applications [9], combining multiple features and visualizations.

Currently, it is noted in the literature that a simple indication of consumption data is not enough [8], [10], [11]. Additional context information is required to increase the interpretability of consumption data and to help users establishing a connection between the abstract concept of energy and their domestic life. Therefore, approaches of ubiquitous computing and context awareness get of sustainable interaction design research.

### 2.2. Context Awareness and Context-Aware Eco Feedback

In Sustainable Interaction Design, context awareness is defined as the consideration of the living environment of the user. Schilit and Theimer [12] were among the first to use the term, defining context-aware computing as „the ability of a mobile user’s applications to discover and react to changes in the environment they are situated in“ [12]. Hull et al. and Pascoe define context-aware computing (situated computing) more general, as devices detecting and sensing the user’s local environment, showing and using gathered information for system methods itself 01/08/2014 13:57:00 [13], [14]. Dey et al. divide context-aware systems into three categories [15]. The first category is “presenting information and services”. This means that the system provides the user with sensor information. For example, by showing the users’ current position through the placement of a marker on a map. The second type covers automatically executing services, such as car navigation systems that calculate a new route when an exit has been missed. Finally, according to Dey et al., a third group of context-aware software attaches context information for later retrieval and use. These categories are similar to the definition of context-aware computing by Brown [16], who defines three categories as follow:

- Presenting information to the user
- Running a program
- Configuring the screen of the user

In terms of energy feedback, there are already a number of approaches to enrich consumption data with additional context information. For instance, Costanza et al. [17] present an interactive feedback system, where users could tag their context directly within consumption feedback. On the one side this allows a visual linkage of specific activities and energy consumption and on the other side new forms of visualizations are possible (e.g. event-centric/energy-centric forms of visualizations). Neustaedter et al. [10] use data from personal calendars to contextualize consumption data of users. Although many events and especially most of routine activities were not registered, it could be recognized that calendar entries can be used for the declaration of energy consumption (e.g. a house party explains high consumption, while eating in a restaurant would imply low consumption). Also, people's location at home helps to contextualize and individualize feedback. Jahn et al. [18] e.g. use the position of the user to present eco-information for the devices at hand. Guo et al. [19] use an active user treatment approach with an RFID based check-in/check-out, to get the position of a user and personalize consumption data with it.

## 3. Room as a context

In several preliminary studies we examined, among other things, what information users needed to make sense of their energy consumption. We found out that their presence in a specific room is an important information for the user to reconstruct activities and thereby linking consumption patterns with activities [4], [11], [20]. In the following chapter, we describe the importance of rooms for everyday-activities and for identifying wasted energy.

### 3.1. Room as a domestic order for everyday activates

People live in homes and undertake activities and interact in this physical environment. Here, rooms have a special meaning when it comes to everyday-activities. Rooms often are decorated differently and serve a particular purpose. A room-structure specifies which activities are appropriate in it and what technology is available to carry them out [21]. For example, in the most cases cooking in the bedroom is unusual. Also for architects, rooms are of central importance. The planning of electrical sockets is related to the intended use of the room and switches for lighting and heating are used to control devices on room-level. Additionally, switches for lights are usually attached next to the door, that when entering or leaving the room, one can switch on/off the required appliances.

In the 1990s, the concept of rooms gained high attention in the context of designing information and communication technology. In their investigation Harrison and Dourish [22] linked insights from architects and urban designers with their own studies to differentiate between space and place. Space is therefore a three-dimensional environment with objects and events that have relative positions and directions and places are spaces that are valued ("We are located in space, but we act in place" [22]).

### 3.2. Understanding of energy consumption and energy wastage

The interplay between technology, places and activities can be used to classify energy consumption and thereby make wasting visible. Schwartz et al. [11] have demonstrated that dwellers distinguish energy consumption between consumption of background services (typically always-on devices like the refrigerator and freezer) and activity related consumption (like using TV for watching, light for reading, etc.). Generally, activity based consumption is closely related to the person's presence (respectively activities which in turn are related to places [21], [22]). Therefore, the actual place of habitants in their home is a strong indicator for energy being wasted (e.g. light in a room where no one is present is a wasting of energy). We use this heuristic by identifying the presence of users in the corresponding rooms to expand existing visualizations of eco-feedback systems and to create new forms of visualization to support the user in his sustainable practices. In the following sections we conceptually describe such a system.

### 3.3. Using room context to make eco feedback more meaningful

We identified four, non-exhaustive, visualization categories where room-context information could help to make feedback more meaningful for the user:

- Analytic charts identifying spenders in the home
- Time series consumption graphs enriched by dwellers' presence information
- Person and domestic activity centred consumption visualization
- Domestic scoreboard systems


***Figure 1** Using room-context information to enrich eco-feedback visualization (left) and to adapt home control interfaces (right)*

The room context information could therefore be used to identify spenders, which are defined as potential energy wasters. Analytic charts on device level allow making such spenders visible. For example, the device-level chart in figure 1, left, shows that 21% are potentially spending by splitting the overall consumption into consumption with presence and without. Such graphs help users to control their habit of switching devices off when not needed.

Further presence information could be used to enrich time series consumption graphs in various ways. For instance, historic feedback graphs commonly show a curve of the device's consumption in a daily, weekly or monthly interval. Such graphs on a room level could be enriched by peoples' presence time in that room, e.g. assign a colour to each dweller and colouring the graph's background accordingly for the time each person was in the room (see also in figure 1, left the bar diagram below). Such graphs may make it easier for dwellers to identify consumption patterns and match them with their own behaviour.

The third improvement reverses the previous visualizations, by showing the consumption of the person's immediate environment over the time. This person-centred visualization in combination with the previous one allows gaining new insights and surprising facts about one's own domestic energy practices. Last but not least, the room-context information could be used to define new indicators for domestic scoreboard systems like average room temperature when people are present and non-present. Further, this information could be used to personalize recommendations, tips, or statistics.

### 3.4. Room context aware home control interfaces

In a further step we explored, how room context information could be used to adapt home control panels. We have identified two categories, in which room-context helps to reduce the panel complexity and nudge people to switch off spenders:

- Adapt the control panel to the devices of the actual room
- Make aware about spenders outside the room

One of the current problems of control panels is the large number of switching options that can lead to a cluttered design. Architectures solve, for example, the problem of complex control panels by making use of rooms as a domestic order system: *A room only includes the controls for the room*. This is a smart choice as people most often are interested in controlling activity-related devices, which typically are in the person's current surrounding. Room context information helps to adopt this strategy by showing only controls of the actual room on the user interface. This radically simplifies the complexity of home control panels.

An exception to the rule above, are devices outside the room that have been forgotten to be switched off, e.g. because of laziness, so they still consumes energy. To nudge people to switch off these devices, the control panel should make aware about these spending devices. Figure 1, right, presents our solution for this demand, where we split the control panel into two sections: The top section shows the controls in the actual room. The bottom section shows the detected spenders outside the room. By focusing on the controls that are important in the current context, the panel is more structured and the number of switching options is greatly reduced.

## 4. Placing and spacing: A new view on domestic indoor location

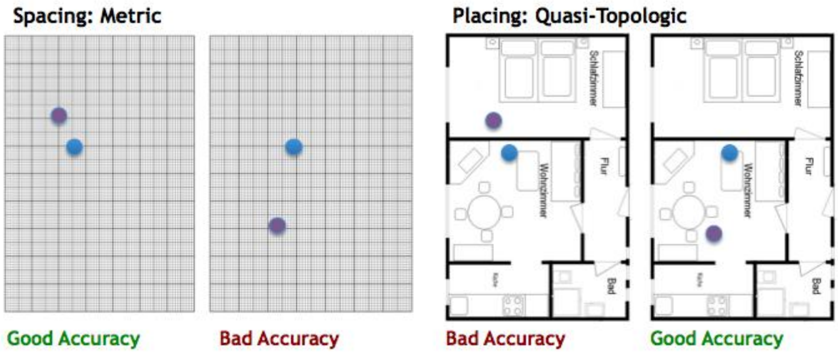


***Figure 2*** *Difference between "space-oriented" and "place-oriented" localization*

The distinction between place- and space-oriented approaches leads to different requirements for locating in domestic environments. The major difference between common indoor localization solutions and room localization is that *space-oriented* approaches are relying on metric error measures, commonly defined by the distance between the actual and the estimated position. In opposite, *place-oriented* approaches rely on a quasi-topologic error measure defined by the ratio whether the actual room is estimated correctly or not. Figure 2 gives an example that good space accuracy does not necessarily imply good place accuracy. Yet, until we have specially optimized place-oriented localization techniques, existing space-oriented techniques could be used as a heuristic.

Concerning the various localization techniques, we principally can distinguish between four classes: The first group are beacon-based approaches that use proximity detection with short-range radio communication, for example RFID or NFC. Based on a globally unique identifier, e.g. a smartphone can look up the position of the beacon (e.g. [1]). But these approaches depend on additional hardware to locate the position of the user. The second group are geometry-based approaches estimating the position e.g. by triangulation and trilateration, determining positions from measurements of angle of arrival or distance between sender and receiver. The intersection of lines or radii respectively provides the current location (cf. [2]). One disadvantage is that conventional WiFi-routers are hardly suitable, because they either need special antennas allowing angle-measurement, or, for trilateration, a much more precise measure of distance than can be provided by electromagnetic waves. The third class of indoor-positioning approaches use accelerometers and gyroscopes of a device to log the movement: speed and direction, starting from a given position to calculate a new position. Such dead reckoning techniques suffer from a fast increasing inaccuracy as small errors add up every step [3]. The fourth group is based on fingerprinting the signal strength of e.g. WiFi routers at different places. One disadvantage is that such a system must be trained beforehand [4]. Yet, it has the great advantage that existing router infrastructures in domestic settings could be reused for the positioning.

## 5. *MyLocalEnergy* - a prototype of a room-context aware HEMS

We have developed a fully functional room-context aware home energy management system prototype called *MyLocalEnergy*. The system was realized as a server-client architecture with a low-power home server where the energy- and position-data is stored in a local database. The client was implemented as a native app for Android devices that communicates with the home server via web-services. Although the client could be used on smartphones, it was optimized for Android Tablets.

The positioning is mainly computed on the Android client, which tells the home server in which room the person actually is. We therefore use a fingerprinting approach based on available WiFi network signals as WiFi routers are available in most domestic environments and no additional hardware is needed. Furthermore, a combination of multiple Received Signals Strengths (mRSS) provides relatively unique fingerprints. Reducing the error rate can be handled by setting up additional WiFi AP [4]. We also minimized the mentioned training problem by providing a user interface, where users iteratively can add, edit and delete multiple measurement points and assigns them to a room. The users themselves can improve system accuracy by adding additional measurement points at places that are important from their perspective. We further implemented some filters that validate the results.

Through smart plugs and a smart meter we measured the overall electricity consumption of the household as well as the individual consumption of appliances (cf. [4] for more details on this "traditional" part of our HEMS system). A tomcat webservice is running on our server, which provides energy consumption services, e.g. *getActualConsumption(deviceID)*, position services e.g. *getCurrentRoom(personID)*, as well as additional fusion services understood as a logical linkage of positioning and energy data e.g. *getConsumptionInCurrentRoom(personID).*

On the user interface we provide, among others, a room-context aware time series consumption graph, which either displays current live consumption or historical values together with information about the users' presence. Based on feedback from our living lab participants, we added additional statistical information about the potential wastage. This information includes, for example, how much the potential wastage would cost per hour.

Furthermore, we implemented control/assistance features, too. Like in figure 1 on the right, the Android client provides a context-adaptive display showing the home devices in two groups: The primary group includes all devices in the immediate environment of the user (room); the second includes all other devices. This slightly differs from the concept outlined above as some of our users wanted to switch on devices in other rooms as well that is why we display more than the appliances in the room in this view. Yet, to ensure that users still get aware about spenders, they are marked with an extra symbol in the list. In addition, an Android application notification is sent to the user if a spender is detected. We further have included a programmable timer function. This feature, e.g. allows switching off a VCR after recording the television program in order to save stand-by consumption.

## 6. Evaluation

We split our evaluation in a technical and a conceptual part concerning overall user experiences. For the technical evaluation of the position service we use a test routine asking the user at random selected points in time, whether the actual recognized room is correct or not. We have run this routine in two different households with three WiFi networks available and collect overall 29 measuring points in two days. We achieve a correctness of about 85%, which means that with an optimal establishment of the position service a good accuracy could be achieved. The accuracy of the position determination, however, depends on the existing WiFi infrastructure and the structural conditions of the household. The WiFi networks should have sufficient signal strength and the routers should be placed in different corners and floors to get best results. The use of repeaters/extenders can distort the results, since in this case the distance to the router cannot be recognized. For the prototypical implementation, the position recognition is sufficiently accurate to examine the usefulness of the system in terms of supporting the user within a sustainable use of energy. We have not carried out a major technical evaluation, since the position determination is not the focus of this work.

We evaluated the user experience by conducting interviews and workshops with seven private living lab households [23] concerning the perceived usefulness and shortcomings using room-context to make the consumption feedback more meaningful and how such concepts should be realized. Overall, our participants appreciate the design concept and said that additional context information would help them to get a more profound understanding of their domestic consumption. Additionally, the participants agree, that their room-based position is a useful information, especially in the historical consideration of consumption data to inference on ineffective behaviour. A further aspect that people regarded as practical was the better clarity by the distribution of the devices in two categories in the control panel. Due to the fact that we measure up to 18 single devices four households, the usual control-panel become cluttered. The people also noted that with an accurate detection of the position, some device could automatically be switched on or off, e.g. lamps. However, there were several points of criticism and detail improvements like that participants sometimes felt disturbed when there always receive notifications when they just leave a room with active devices for a short time to make a coffee or something.

## 7. Discussion and Outlook

The first energy monitors simply feedback more or less the raw measured energy data. Today real-time, disaggregated consumption measurement is reality. The major challenges in domestic settings concerning lowering the energy consumption are:

- How can we prevent an information overload given the vast amount of raw data
- How can we make consumption feedback more meaningful

We contribute to this challenge by outlining the concept of room as a context and how it could be implemented. Concerning other approaches on context-aware consumption feedback in literature [10, 17, 18], we do not think that room as a context will replace them, but supplement them. For instance, room-context complements the device context and visa versa. E.g when a user comes near a device, our room context-aware user interface could be adapted to a device context-aware one as outlined in [18].

In summary, this paper has outlined the potential of room-context aware HEMS. However, for the practical use several challenges have to overcome: Firstly the practical value of the positioning must be studied under realistic conditions with a larger sample and in long term. Secondly, while people always take the smartphone and the tablet with them when they leave the home, they often put the device on a desk, a sideboard, etc. when they are at home. Concerning this, future smart-watch based positioning services have a great potential. Thirdly, we got aware that our solution is implicitly optimized for single households. Hence, in future we have to investigate how multi-person households appropriate such design concepts and if, in which way the concepts must be extended.

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# Like! You saved #energy today.

# Fostering Energy Efficiency in Buildings – The implementation of social media patterns as symbols in Building Management Systems‘ Graphical User Interfaces using Peirce's semeiosis as a communication concept

Andreea Tribel[1], Jan Geffken[2], Oliver Opel[3]

## Abstract

This paper starts with a short definition of the research field sustainable ambient computing (SAC), which unites ambient intelligence, and ubiquitous computing. SAC takes into account not only the ecological aspects of life cycle assessment and energy efficiency, but also includes HCI as main pillar. Part of SAC is building management systems, which, in their current form, struggle with lacking user integration and rebound effects. The prospect is to build, implement and test a graphical user interface in a new energy efficient building at Leuphana University, which provides a convenient surrounding and an user-friendly system at the same time. According to the pragmaticist approach of C. S. Peirce's sign theory, we propose abduction as a method of inference and semeiosis as a triadic communication process. Regarding the spread of social media usage, we suggest using elementary communication patterns taken from this field for building management systems, because known communication patterns encourage the usage of uncommon ambient computing systems. Hence, acceptance, a major challenge when trying to successfully integrate users, is facilitated. Here fore we looked on typical communication patterns of the most used social media platforms. A successful usage of these patterns in this specific context will raise the perception und knowledge of energy consumption, and can be expected also to change habits on the long run.

**Sustainable ambient computing (SAC)** reflects the main ICT trend in the societal and industrial development today. Computers have become part of ordinary things like walls, doors or even car seats. They build a surrounding with contactless switches (e.g. light in buildings) or actually invisible things to happen like variable heating and air conditioning in buildings or windows open and closed by smart systems and no longer by humans.

Viewed from a systems point of view, the aim of smart buildings, for example, is balancing convenience and energy efficiency. This should by no means result in using more computers hence more energy. Therefore in SAC the life cycle assessment of the systems to be taken into account is an utterly important part of the sustainability aspect concerning hardware.

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As well as for the hardware part, the software part has to be sustainable by means of anticipating and guiding users and user groups: A successful communication respectively HCI (human-computer-interaction) within BMS (building management systems) or smart buildings fosters not only energy efficiency, but may also change habitual and cultural patterns in the long run.
SAC, therefore, suggests a holistic view on any ICT supported system.

However, whilst computers became a nearly invisible surrounding for us, the usage of smart phones, smart buildings and other smart systems did not fulfil the promise for sustainable nor energy efficient infrastructures yet [1].

Planned as "closed" systems, BMS are often used to rigidly control the indoor climate. They produce a large data stock that is supposed to be used by the manager of the system to control energy efficiency and provide a comfortable ambient, however a purpose that is hardly ever reached. The lacking flexibility and interaction with users and user groups in the room often results in discomfort for the user and users bypassing the rigid BMS regime, resulting in inefficiencies on the system side. In general, "[t]he environmental effectiveness of eco-technologies strongly depends on the way users interact with them" [2].

There are several challenges – the position of the building, the weather, the subjective feel of the user. She might feel cooler in the very early hours of the day, but would love some cooler air after lunch. Also the gradual difference between the outside and inside temperature – a somehow subjective "feels like" for the person in the room. While the user can easily handle brightness in a room because of its visibility, room climate is more challenging from a user's point of view. We conclude therefore that there has to be some communication between the system and the person in the room.

Part of the interaction between user groups and the BMS is the preparation of sampled data for a user-friendly visualization that leads to clear instructions for the BMS. To create user-specific feedback, it is necessary to collect data about the handling of actors like thermostat settings and environmental parameters like humidity and outdoor temperatures.

Because of the otherwise increasing hardware requirements, energy and data, the sampling rate, the resolution and the accuracy of information should be balanced out for the needs of the user and user groups. For a sustainable system the mass of sensors and data has to be minimized to the basic necessary data that enables an interaction between the user and the BMS, e.g. the use of heating energy for the day before compared to a similarly used room. There are three main levels between the user and the system: sensor-actor-level, database and Graphical User Interface. While the development of the GUI is based on the semeiosis as communication method, the development of the level of database and sensors/actors is based on a technical efficiency perspective. Thus the holistic view is given by this interdisciplinary research approach, resuming the idea of sustainable ambient computing.

Regarding the Human-Computer-Interaction, dyadic communication models following the action-reaction syntax are fine for closed systems only. We suggest therefore Peirce's triadic sign model and its semeiosis as methodical concept. Semeiosis uses the sign or the object, respectively representamen and interpretant relation, in analogy to action-interpretation-reaction [3] for any process that brings out another sign. This triadic model is, according to the late Peirce, not an infinite process. Peirce avoids the infinite progression giving „the ultimate logic interpretant the status of a habit or, when the occasion made it necessary, the effect of a change of habit produced by any intelligent mind – not necessarily human" [4] An introduction to Peirce's "way of thinking", his method and the derivative of a process driven communication model will show how social media platforms as genuine communication tools form symbols that can be used to achieve the supposed objectives.

Known as the founder of pragmatism (around 1878), Peirce moved away from his own theory of pragmatism nearly thirty years later in 1905, and renamed it pragmaticism: “Pragmaticism, then, is a theory of logical analysis, or true definition; and its merits are greatest in its application to the highest metaphysical conceptions.” [5] Pragmaticism in the Peircean meaning moves away from the ontological question that asks what is existent in a first category, using the term critical common-sense [6]. For Peirce, inference in the scientific inquiry cannot be made without a basic knowledge of the world called (critical) common-sense. Common-sense is indispensable for the scientist assuming a set of inferences that cannot be doubted: “[…] The test of doubt and belief is conduct. No sane man doubts that fire would burn his fingers; for if he did he would put his hand in the flame, in order to satisfy his doubt. There are some beliefs, almost all of which relate to the ordinary conduct of life, such as that ordinary fire burns the flesh, [which] while pretty vague, are beyond the reach of any man’s doubt.” [6] The term “critical” implies furthermore something crucial for (scientific) inquiry, namely that still any proposition can be object of doubt or can be criticized. This is Peirce postulate on science, called fallibilism. The scientist should doubt any, also later proposed inferences, views or beliefs, until they are proven.

Peirce’s theory of signs, called “semeiotic” in his own term, is not meant to be a metaphysical explanation of the world, a philosophy in the traditional meaning [7] nor a solely linguistic method. Although the names and concepts are completely abstract, they are meant to be used on any category of life: “[…] all this universe is perfused with signs, if it is not composed exclusively of signs” [8]. Thus semeiotic is a method used e.g. in medicine, chemistry or jurisprudence. Peirce wanted to overcome the dyadic induction - deduction process of natural science with its strict method and terminology, as the only possible scientific method of inference. He introduced a third form of inference, called abduction. This is regarded as the only logical possibility to develop new ideas by forming an explanatory hypothesis [8]. The abductive rule will be deductively proven and inductively falsified [9] and is considered by Peirce as the only creative method of inference.

Using sign theory means therefore concentrating on processes in a sign-sphere which is called semiosphere [10]; the logic of the sign process forms patterns that allow an usage on any other sign formations, in any other sphere. We will take this approach here for the graphical user interface of a building management system, whose design metaphor follows the logic of social media platforms.

A brief introduction of the sign and a presentation of the three sign classes explain our different take on communication, expanding the dyadic model of input-output, used in communication technology, e.g. Shannon & Weaver’s model [11], into the triadic form with an interpretative process. It is from utter importance to distinguish these sign classes, as they show why sign theory is an actual communication theory.

The notation of sign, as Peirce states, is that of a threefold medium with an integrated quality. A sign consists of the representamen, “something which stands to somebody for something in some respect or capacity” [9], of its object, which can be a real-life thing or an idea, and its interpretant, the sign which it creates in the third state. An interpretant does not have to be a person or a mind, but a state where the process of interpretation and sign re-creation occurs. Peirce notion of a “quasi-mind” [5] allows the interpretation and usage of this triadic concept from a calculating machine to a group of humans.

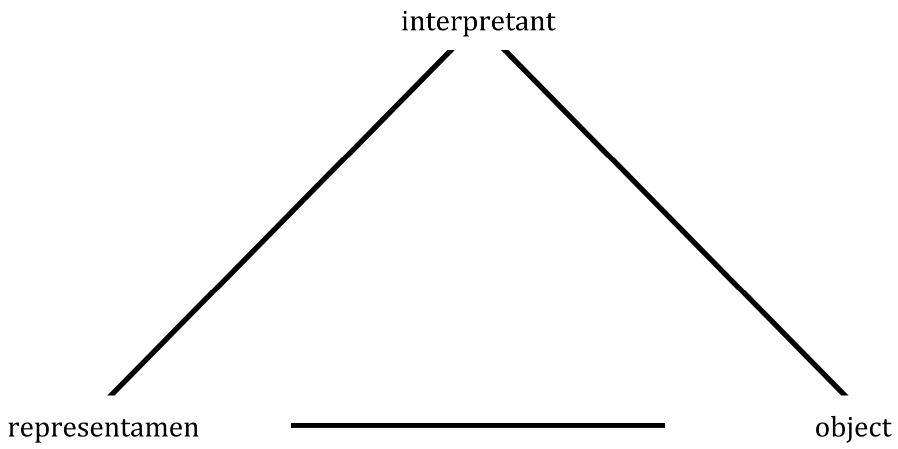


*Figure 1: Sign*

The existence of a sign is mediated through another sign, e.g. a word through an utterance, and it creates another sign: The same one respectively a lookalike (an iconic sign), an indicative one (an indexical sign) or a sign qua convention, a symbol.

One can be interested in a sign in three different ways, namely on the thing itself, on something the sign is indicating or on an association with the sign, a representation (of something) which calls up an association or an “idea” [12]. The first sign class, icon, is a sign that looks like the represented object, like a diagram in geometry or a portrait [13]. It is a sign that one can directly perceive. The second sign class contains signs that indicate something: an index would be smoke that indicates fire. Symptoms like raised temperature and shivering are indexes for a severe illness. For the third class, the symbolic sign, the relation between its object and representamen is due to a convention. A symbol enables us to “create abstractions” [14, 15];, it exists because it is interpreted in a certain way. The symbol for heart does not look like a heart itself nor does it denote a certain heart, but any heart. Any sign is already a symbol, because we use the concept of language to denote it. Mathematics is a science that is based on symbols.

A symbol contains all sign classes in it, what can be shown on a pictogram of an emergency sign.

*Figure 2: Emergency sign*

As an icon, it denotes a simplified picture of a human being that runs in the direction of the pointing arrow. The pictogram itself indicates a certain situation, an escape. The emergency sign itself can be only interpreted as a symbol, for which the person that looks at it only knows the interpretation. Without having seen a sign like this before, or without knowing that green as a colour has a positive connotation in our culture, a correct interpretation would not be possible [16].

Supposing communication is a triadic concept mediated through signs in a semiosphere, communication proceeds as following: The iconic sign is also the object, the indicating sign is a representamen and the symbolic sign is the interpretant. Thus communication implies continuous processes that are developed through symbolic signs. Defining communication as an action using and by itself building symbols means we can already take functioning symbols and their patterns and apply them to different semiospheres.

This paper will not examine social media as a communication medium in the sociologic way. The discussion about reasons of usage or impact on people, society or technology shall here be left disregarded, although this is an important part of the discussion. With blogs starting to get common around 1999 [16], the usage of social media platforms like Facebook and Twitter has pervaded everyday life since the spreading of smartphones with mobile Internet access [17]. The most important social media platforms are blogs, Facebook and Twitter. A blog is run by one or more authors who generate content that can be commented by the reader. Blogs became popular for many reasons, like the blog software Wordpress and webhosts like Google's Blogger, which are non-expert systems that do not need programming skills. They also became popular because they enabled people to speedily publish and receive a feedback from their readers [16]. Facebook is a platform that allows the user to connect with friends respectively other users, share activities and e.g. pictures. Facebook's "like" button grew up to the symbol of social media. It gives an instant positive feedback to the posted content. Twitter unites the key functions of blogs and Facebook-like content generation (in 140 signs), feedback in the function "reply to", connection and sharing with other users via the timeline and the positive feedback, the "favourite" button.

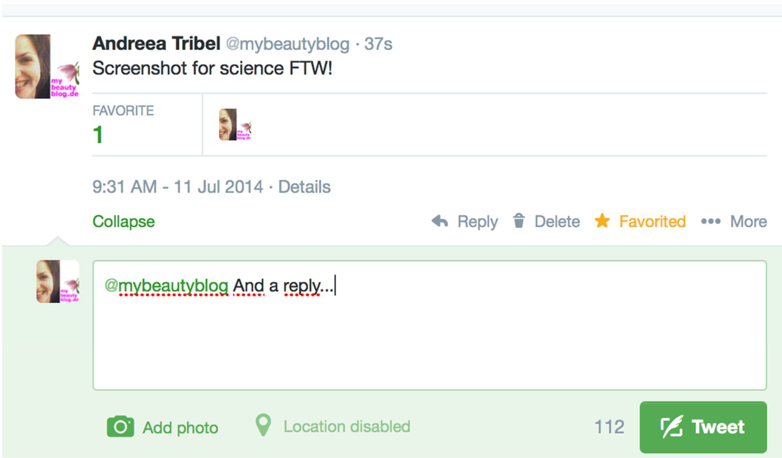


*Figure 3: Screenshot of an initial tweet, a reply and a favourite tweet*

An overlapping logic or structure, respectively, determines the special semiosphere of social media: the possibility of feedback, interaction with several people and immediate, positive acknowledgement of the utterance (Like and Favourite buttons). Further the usage of the platforms creates symbols, thus signs qua convention, for communication mediated exclusively through computing devices - just like Facebook's thumb and the claim "Like!". These symbols are encoded twice because of their usage in online as well as communication processes solely. It can therefore be supposed that these symbols will be used correctly in a manner that is common for the user, as in any computer mediated communication process, e.g. in a building management GUI (Graphical User Interface).

Introducing the term of sustainable ambient computing SAC, ambient intelligence plus ubiquitous computing, means to bridge the gap from computing as an engineering approach with ubiquitous systems that solve real-world problems [18] to a conception of information and communication systems that are ecological from the perspective of life cycle assessment, user-friendly and have a supportive effect on decision making as well on cultural habitual change. In this research field building management systems can be considered as environmental technology at the intercept between industry and everyday life. Tools and systems in this field are made for different user groups, i.e. experts, engineers and non-experts or everyday users of the building. The latter group shall be enabled to partly take control of the system themselves, so the human-computer interaction becomes a stronger focus in BMS research and development.

A main goal of generating a successful interaction between the BMS and the user is saving a maximum of energy by avoiding rebound effects. Rebound effects are lowered energy savings (due to technical efficiency) by increased usage, often because of less costs or a "greener" feeling [19]. A high degree of automation in the BMS can lead to inefficiencies due to rebound effects in two ways. First, the "efficiency improvements ([...] energy) made possible through technological improvements are counteracted by increasing demand […]" [20]. Second, if users can`t influence the energy demand, e.g. the heating, in a way that fits their requirements, they will find other ways to achieve a better surrounding. This lack of participation could cause a difference up to 70% between the planned and the real energy usage of a building [21]. A difference like this can, for example, be a result of simultaneous opened windows and activated heater. Thus the impact of uncontrolled usage underlines the importance of manipulation possibilities and a resulting satisfying communication between the users and the BMS from both perspectives.

Regarding SAC as a semiosphere allows usage of the triadic conception of signs and their classes on different levels. There are sign processes concerning hardware and machine language, which are related to the engineering part. Another sign process is the communication between the system and the user group, allowing decision making and eventually changing behaviour. Deconstructing the semeiosis (sign processes), these can be regarded the following way: The hardware as a concrete object and technical medium, the software and sampled data as an instrument thus representamen, and the usage or interaction with a user or user-group as interpretant. In the special contextual situation of BMS we gain a sustainable usage in matters of energy consumption qua the hardware and engineering part. Further a successful usage of the interface between system and user is essential, which should result in creating new "symbols". That is the status of the interpretant, which is not only a habit, but also the effect of a habitual change. This means a successful interaction with the user would minimize the system's infrastructure, generating a sensibility for energy efficiency, and resulting in more energy efficient behaviour. Supposing BMS data is already processed and filtered thus simplified for the user, the GUI will be convenient to handle if we are using a certain set of symbols that are derived from the usage of social media platforms. Therefore we essentially suggest using common signs already known for communication purposes in a communication context, as we explained before.

The conceptual metaphor for the GUI [22] includes double coded symbols we know from social media usage. We can find them similarly in all proposed three main platforms. First comes the possibility to generate content. This is proposed without any quality nor interpretation. Because the building management system generates the first content, we must regard this in the sense of common-sense as a set of inference or data that already exists. The user should have the possibility to generate "own" content, so not only participating to but initiating (sic!) the communication process with the system. She could choose the components of the information like temperature and humidity to correlate to the felt temperature. Second, different forms of feedback have to be possible. Comments and spreading information could be regarded as indexical signs in the process. The single user might be regarded as peer to a group where, however, information is shared or commented. The possible feedback to the system should further include the possibility to manipulate it to a certain extent, even up to the submission of a first data set initiating the communication process. The communication process continues while setting the object, such as the data, into a context. Here we postulate the interpretant in a way that the symbol that comes out qua convention is able to put its object (the subjective “feel like” in the building) in a solely positive context. This happens in social media activity with the “like” button or the “favourite” star. What differentiates the mentioned symbols from a symbol even more widely known, e.g. a traffic light? For the latter, the convention respectively the interpretant arises not from the user itself, but it is imposed by an invisible authority. The user knows that traffic lights command and forbid certain actions on crossroads based on a societal convention, and also an everyday situation that can be connected to negative notions like prohibits or being late. The positive connotation that involves social media activity becomes apparent in the virtue of the “like” button or thumb symbol, because these terms are used in colloquial language.

We used the method of semeiosis to analyse the social media as a sphere of signs, a semiosphere, and determined three utter important communication patterns. We propose using these symbols, understood as habit changing possibilities, in a case of building management systems. The logic of the elaborated, practical communication process should be able to develop a successful communication between users and the BMS.

The prospect of this analysis follows Peirce’ understanding of science. After having deduced what the requirements for the graphical user interface of the BMS are, a first GUI will be designed as part of an interdisciplinary project. It will be implemented and tested in a new energy efficient building at Leuphana University by an interdisciplinary project team.

We will keep the interdisciplinary perspective and theoretical foundation based on Peirce’s theory and, at the same time, take into account the technical requirements (i.e. the resolution of the sensor system, the monitoring concept and the design of the BMS) and knowledge to create a set of requirements for the design of the GUI. Finally all parts together build the holistic SAC system, however a centralised database will still be needed, as well as data mining, filtering and comparing algorithms to generate content for the user – the informatics part of the concept.

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# Classification of Techniques for Energy Efficient Load Distribution Algorithms in Clouds – A Systematic Literature Review

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## Abstract

Cloud Computing has recently become an important driver for IT service provisioning. In addition to its associated benefits for both customers and IT service providers, cloud computing also comes along with new challenges. One of the major challenges for providers is to reduce the energy consumption, since today already more than fifty percent of operational costs in data centers account for energy. A possible way to reduce these costs is to distribute load in terms of virtual machines within the data center. Developing algorithms for this purpose has been a topic of recent research. In order to capture the state of the art of energy efficient load distribution in clouds, this paper presents a structured literature review on load distribution algorithms that aim to reduce the energy consumption in data centers for cloud computing. The algorithms are reviewed in terms of their type, their evaluation method and their potential side effects in terms of drawbacks.


## 1. Introduction

In recent years, IT has become an important factor for increasing energy demand. Especially with the rise of cloud computing, large data centers have been built. These consume huge amounts of energy which cause high operational costs. Current studies have shown that the energy consumption of data centers increased by 56% from 2005 to 2010 [1]. Given that more than fifty percent of the overall costs in data centers account for energy, it is eligible for data center operators even to slightly decrease the energy consumption since this can have a significant impact on their profitability [2]. While data centers have several energy consuming components, such as for example cooling and ventilation, a major source of energy waste is the inefficient usage of computing resources [3]. An important method that can reduce the overall energy consumption is using load distribution within a data center by migrating virtual machines [2]. Since in clouds the resources used by customers are scaled according to their current demand, distributing load is very important. Thereby, load distribution is one of the major challenges that cloud data centers need to face [4]. In recent years, numerous algorithms for distributing load in clouds have been developed, many of these with the aim to reduce energy consumption. These algorithms apply different techniques in order to save energy: as an example, some algorithms use techniques such as a rule-based migration of virtual machines [5] while other algorithms rely on genetic programming [6]. Hence, there are multiple approaches to reduce energy consumption in data centers. An analysis of such algorithms can help to classify different types and techniques of algorithms and to identify potential side effects, for example in terms of negative effects on the availability of a service. In addition, the methods that are applied to evaluate the algorithms can be identified in order to point out gaps in current research.

### 1.1. Research Question

In order to be able to classify algorithms that can be applied to reduce energy consumption in data centers, the first research question that is to be answered in this paper is:

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**RQ1**: Which types of load distribution algorithms are used in order to reduce the energy consumption in data centers for cloud computing?

The advancements of these algorithms need to be demonstrated. Although there is no standardized method for this, there are different approaches for evaluating load distribution algorithms, such as mathematical models, simulation approaches or testbeds [7]. These methods may not be applicable in real cloud environments: for example, assumptions made in simulation approaches may be too simplistic and thus limited in their applicability [7]. In order to comprehend the most common evaluation method for energy efficient load distribution algorithms and in order to identify possible weaknesses of these methods, the second research question of this contribution is:

**RQ2**: How are the improvements of energy consumption evaluated?

Load distribution can have drawbacks. For example, the migration of a virtual machine between two different physical servers can affect the performance and hence result in higher response times. This in turn can lead to violations of service level agreements (SLA) and thus result in contractual penalties. Investigating potential side effects is thus an important factor when designing or analyzing algorithms. Therefore, the third research question aims to identify such side effects:

**RQ3**: Have side effects been investigated and, if yes, which side effects have been described?

In order to answer those research questions, a structured literature review is conducted.

## 2. Related Work

There is only little literature on the systematic analysis of energy efficient load distribution algorithms in clouds. In [8], a survey on and analysis of resource scheduling algorithms is presented. However, energy efficiency is only marginally considered in this paper since it is not its focus. In publications that deal with the development of new algorithms, comparisons are made with other algorithms in general. However, these usually do not include a systematic analysis of other algorithms, such as in [9]. Some papers do provide more detailed information about other algorithms, but focus on very specific types of algorithms, such as the Ant Colony Optimization algorithm presented in [10].

## 3. Literature Review

According to [11], a literature review consists of the four steps *material collection*, *descriptive analysis*, *category selection* and *material evaluation*. The material collection defines the material that is to be collected. The descriptive analysis provides an evaluation of formal aspects of the material. The category selection defines structural dimensions that are used to analyze the collected material. The material evaluation comprises the evaluation of the material and an interpretation of the results. Before the review is carried out, the delimitations of this study are presented.

### 3.1. Delimitations

This literature review is a representative study that aims to identify relevant research outcomes with respect to the research questions defined in section 1. Therefore, a set of criteria was defined to be able to select relevant publications. In order to be recognized as relevant, a publication needs to meet all inclusion criteria (I) while not meeting any of the exclusion criteria (E). Table 1 lists all criteria that were used to determine the relevancy of a publication.

| Inclusion Criteria | | Exclusion Criteria | |
|---|---|---|---|
| *I1* | The publication is written in English. | *E1* | The algorithm requires a specific hardware configuration. |
| *I2* | The paper is published in a proceeding | *E2* | The algorithm is designed for a specific |

| | | | |
|---|---|---|---|
| | or journal. | | problem, for example MapReduce. |
| *I3* | The publication describes an algorithm that aims to reduce energy consumption. | *E3* | The algorithm does not have an emphasis on energy efficiency. |
| *I4* | The algorithms' setting is a cloud computing environment. | *E4* | The publication does not clearly describe the functionality of the algorithm. |
| *I5* | The publication is in the form of a completed research paper. | *E5* | The publication does not clearly describe the evaluation of the algorithm. |
| | | *E6* | The algorithm requires all information a priori in order to distribute load. |

*Table 1: Inclusion/Exclusion Criteria*

### 3.2. Material Collection

In order to identify relevant research outcomes, a structured keyword search was conducted. The applied search term, the time frame investigated in the context of the search, and the queried databases are listed in Table 2Table 1.

| Parameter | Value |
|---|---|
| Search term | energy efficiency *OR* energy efficient *OR* energy conservation *OR* energy aware *OR* green it *OR* green computing *OR* green ict *OR* energy saving *OR* sustainable *OR* sustainability *OR* energy consumption *OR* power consumption *OR* power management *OR* energy costs<br>*AND*<br>(load balancing *OR* load distribution) *OR* ((vm *OR* virtual machine) AND (migration *OR* allocation *OR* provisioning *OR* scheduling *OR* placement)) *OR* live migration *OR* capacity management *OR* resource management<br>*AND*<br>cloud computing *OR* infrastructure as a service *OR* software as a service *OR* platform as a service *OR* iaas *OR* sass *OR* paas *OR* cloud *OR* data center *OR* data centre |
| Time frame | 2008 – 2014 |
| Databases | ACM Digital Library, AIS Electronic Library, Computing Research Repository, Directory Of Open Access Journals, Ebsco Host, ScienceDirect, Emerald, IEEE Xplore Digital Library, JSTOR, Oxford Computer Journal Database, Palgrave Macmillan, SpringerLink, Taylor & Francis Online, Wiley Online Library, WISO |

*Table 2: Parameters of the literature review*

The period of search covers the years from 2008 to 2014. The beginning of the period was set to 2008 since this is the year in which *Amazon* introduced its cloud platform *EC2* and thus made cloud computing a popular topic. The major databases (according to [12]) have been selected for the search. The applied search term as shown in Table 2 is split into three parts. Each part describes a term that is relevant for this research including various synonyms. The first part consists of terms regarding energy consumption and energy savings. The second part includes synonyms for load distribution in terms of migrating or placing virtual machines. The last part limits the search to cloud environments. Within the individual parts, the terms are connected with a Boolean *OR*. The three parts however are connected with a Boolean *AND*. Terms within the search query that consist of two or more words (such as "energy efficiency") are treated as phrases. The querying with the search term was restricted to abstracts. If a database did not support this type of search, a full text search was applied. In order to decide whether a publication is relevant, its abstract was read. In the case that only a full-text search was possible (which was the case for SpringerLink), a title filtering was conducted before reading the abstracts. If the relevance of an article could not be determined clearly, the entire article was read. The search query returned 1910 results. After the initial title filtering, the remaining abstracts were tested according to the criteria that are listed in Table 1. After this step, 125 publications remained. Subsequently, these articles were completely read and checked according to the criteria. As a result, 80 relevant publications remained.

### 3.3. Descriptive Analysis

The set of relevant publications comprises 80 papers. The distribution of these papers over the search period is presented in Figure 1. While there are only few publications located in the beginning of the search period, there is a strong increase in the number of publications in the subsequent years. This increased research attention indicates the constantly rising importance of energy efficient load distribution in data centers. In addition, the high number of publications suggests that this topic is attractive to the scientific community and still has open questions.

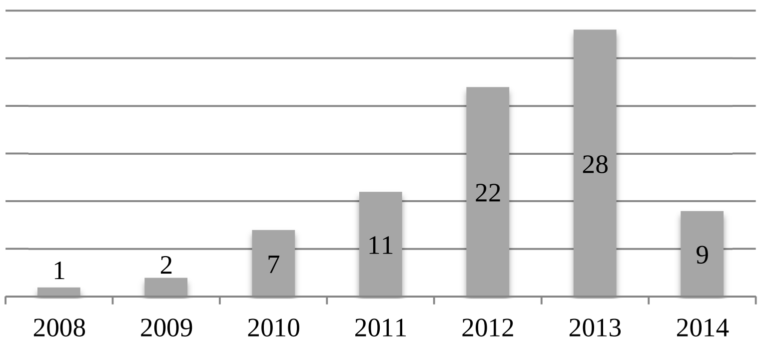


*Figure 1: Number of publications per year over the reviewed time period*

The majority of the papers was published in proceedings (54 publications), the smaller part in journals (26 publications). The 80 publications spread over 63 different outlets. Therefore, leading publication outlets are hard to identify. In fact, this relatively equally distribution shows the wide acceptance of this topic in research.

### 3.4. Category Selection and Material Evaluation

Since this paper aims to examine algorithms for energy efficient load distribution in clouds as well as the applied evaluation method and side effects of the algorithms, the categories for the material evaluation are derived inductively while reviewing the material [11]. These categories are made up by the type of algorithm, the evaluation method and the investigated side effects. A total of 28 different types of algorithms was identified and then grouped into 11 categories as shown in Figure 2. The grouping was conducted based on the field of the algorithms. For example, the topics Reinforcement Learning [13] and Fuzzy Q Learning [14] appeared in the collected material and both belong to the field of machine learning. Therefore, the group *Machine Learning* was build.

*Static* algorithms include simple threshold-based [15] and rule-based approaches [5]. All integer programming approaches such as Boolean Integer Programming [16] or Mixed Integer Programming [17] are grouped in **-Integer Programming*. *Machine Learning* refers to algorithms that use Reinforcement Learning, Fuzzy Q Learning, or Learning Automata. **-Fit* comprises of algorithms that use Best Fit [18] or First Fit [19] approaches or modifications of these. In *Bio-inspired Computing*, algorithms are aggregated that try to imitate their biological counterparts, for example genetic algorithms [20] or algorithms that apply ant colony optimization [21]. The category *Misc* represents independent types of algorithms that only appeared once in the collected material. An example from this category is an algorithm that uses Lyapunov optimization [22] or an algorithm that uses Space Partitioning in order to distribute load [9]. The frequency of algorithms exceeds the number of publications because some papers, for example, introduce more than one algorithm [23] or combine different types of algorithms [24].

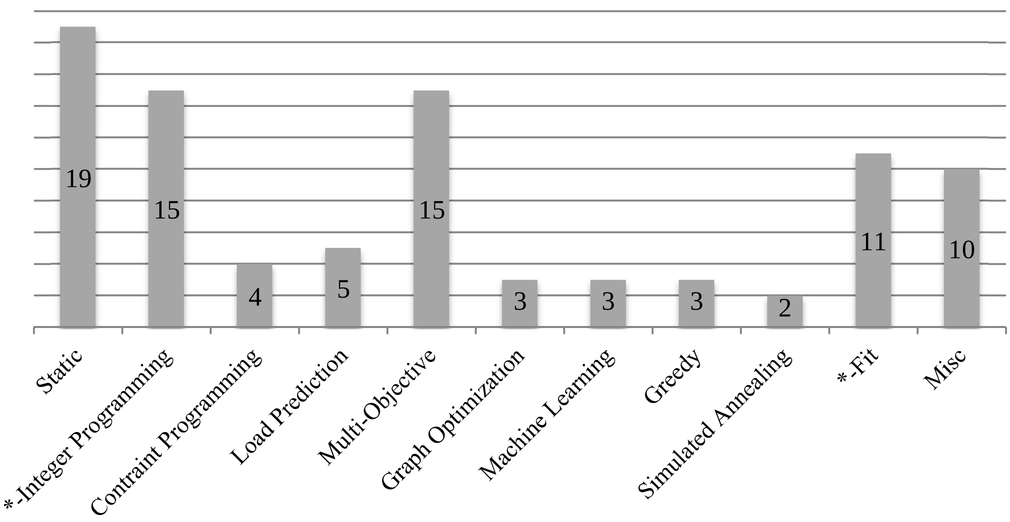


*Figure 2: Frequency of Algorithms in publications grouped by the type of algorithm*

The majority of the publications seek to provide better solutions for the bin-packing-problem, meaning to provide a solution that is more energy efficient for placing virtual machines in a data center. While algorithms which were published at the beginning of the investigated time frame rely on simple techniques such as rule-based approaches [5] in order to do this, the algorithms are getting more complex over time, such as in [25] or [22]. Besides static algorithms, Linear Programming approaches and Multi-Objective optimizations are the most common implementations. In recent years, Bio-inspired computing has been gaining more attention. Most of the investigated algorithms work reactively. This means that they only react to specific situations, such as an overloaded server, in order to start a load distribution procedure [26]. It would be better, however, if the algorithms prevented such situations proactively, for example by using prediction methods in order to distribute the load according to a prediction, such as presented in [27]. This could help to use overbooking while simultaneously not decreasing the service level. However, only few algorithms use prediction approaches (confer figure 2).

With regard to the second research question, namely how the improvement of the energy consumption is measured, the analysis showed that the majority of the algorithms is evaluated by simulation (67 publications). A much smaller proportion used test environments for evaluation (14 publications). Only four publications conducted a purely mathematical evaluation of their proposed algorithm(s). The sum of evaluated publications exceeds the total number of publications since some algorithms were evaluated using multiple evaluation methods, such as in [28]. A major difference in the evaluation can be found in terms of the quality of the simulation. The majority of the authors do not use real data in order to strengthen the simulation results. Additionally, most algorithms are tested only with respect to one specific workload. Since the workloads can be unpredictable [29], it does not make sense to test against one specific workload only. Testing against a single workload shows the potential effect of an algorithm in a specific case, but does not allow to make conclusions about the general quality of the algorithm. Precisely, only 26% of the papers, such as [29] or [25], explicitly consider different types of workflows and thus demonstrate the suitability of their algorithm. Furthermore, only about half of these 26% use real workload data in order to evaluate their developed algorithm.

With regard to the third research question, the literature review has revealed that by far not all papers do consider side effects. In total, 33 publications at least mention side effects and claim that their investigation is highly relevant − in general, they refer to terms such as “SLA-violations” in order to describe side effects. In fact, only 28 papers seriously investigate side effects. The most investigated aspect in terms of (negative) effects of algorithms is performance (investigated in 14 papers). But also response time (in 6 papers), availability (in 6 papers) and throughput (in 2 papers) are investigated. However, the investigations of these aspects are hardly comparable with each other because they mostly apply different, often self-defined metrics in order to determine the effects. In some cases, it is even questionable if the applied metrics are related to the side effect at all. For example, Khosravi et al. define SLA-violations as the number of rejected virtual machine requests [30]. This is not a suitable metric for SLAs or even for the availability of a service, which is apparently meant by this definition. Thus, this important aspect seems to be still ambiguous.

## 4. Discussion

The conducted literature review revealed a few weak points in in the research on load distribution in clouds. First of all, many papers do only consider low-load situations. For cloud environments, this is a problematic assumption since in clouds, the servers are usually higher utilized or the workloads are even unpredictable [29]. Furthermore, considering only a specific type of workload for an algorithm is problematic since workloads can vary significantly in clouds [31]. Therefore, these limitations are problematic regarding energy efficient load distribution in clouds. Secondly, it can be stated that the simulation-based evaluations of the individual papers are hardly comparable. A total of 69 papers used simulation in order to evaluate their contributions. Out of these, 37 used a proprietary development. Since it is often not clear how these proprietary tools are constructed or even how they estimate energy consumption, their results are difficult to compare. Seven papers did not use a proprietary tool, but instead each used a tool that in each case just occurred once in the collected material. Therefore, their results are also difficult to compare among each other. In total, 25 papers used *CloudSim* [32] for the evaluation. While these results are comparable with each other, the problem hereby is that *CloudSim* has not been developed for ascertaining the energy consumption in clouds. There are indeed components included for this purpose, but the implementation is very rudimentary: servers are the only energy-consuming components of a data center and in the servers, only the CPU consumes energy. Taking a look at the energy-consuming components of a data center (such as presented by Jing et al. in [33]), this approximation is too simplistic [34]. The validity of the results evaluated with *CloudSim* in terms of the overall energy consumption of a data center is thus at least questionable. Another problematic aspect is that in many evaluations, a homogenous infrastructure for the whole data center is assumed. In practice, it is unlikely that the entire infrastructure of the data center is completely homogeneous. This may be a realistic assumption for single clusters within a data center, but not for an entire data center. Therefore, this assumption cannot be made in practice. Summing up, it can be stated that these aspects that were not sufficiently considered should be taken into account in future research.

## 5. Conclusion

In order to capture the current state of the art of energy efficient load distribution algorithms in cloud data centers, a structured literature review was conducted. The number of results indicates that this is a highly relevant topic in current research. Thereby, the interest in energy efficient load distribution has significantly increased in recent years and it is likely that this trend will continue. The advantage of the investigated algorithms is their independence of technical aspects of data centers. The algorithms can work with different hardware configurations while not needing any information about the cooling status and can yet still reach their goals. In fact, the results of the identified research outcomes indicate that the overall energy consumption can be reduced in most cases. Unlike other methods that can be used to save energy, such as Dynamic Voltage and Frequency Scaling or partial shutdowns, load distribution algorithms implicate an aspect of generality. Since data centers are very diverse, this generality makes the idea appealing. However, the literature review has also shown that several aspects have not been sufficiently considered in research yet. Although the review showed that the algorithms have become more complex over time and augur higher energy savings, the analysis also revealed that the evaluation needs to be improved in terms of simulation since there are still too many aspects left out. For example, the simulation tool for evaluation that is most commonly applied, *CloudSim*, only models the CPU as a energy consuming component in a data center. Evaluation tools that do not rely on *CloudSim* are often confronted with the problem that their results are not replicable. Therefore, both the comparability of the different results and the transferability of the results in practice are doubtful. These aspects must be addressed in future research.

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# Monitoring Dashboard for Cloud Sustainable Greenhouses

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## Abstract

The growing evidence of major environmental changes promotes sensitivity to the causes that give rise to them. The companies, namely the ones focused on agriculture production in Greenhouses, are concerned with their production efficiency and business success and the persons are concerned with their possible contribution on those (abnormal) environmental events and, indirectly, with their effects on their own health.

Greenhouse production involves several and distinct resources or services, from time and persons to multiple type of equipment. If most of the production knowledge lies on human experience, the capacity to decide quickly against real situations comes from the availability of real and useful information, timely.

Accepting Chang [1] perspective that Cloud Computing "*provides scalable and inexpensive on-demand computing infrastructures with good QoS… as well as new business opportunities for service-oriented models*", it outlooks that Greenhouse Production under a cloud architecture supporting information systems control, has the potential to be sustainable.

Therefore, the aim of this paper is to:

a) demonstrate that existent technological initiatives are not sufficient for efficient control of sustainable Greenhouses;
b) propose an ICT platform based on open source technology composed by: i) a servo unit, using embedded technology, that allow the integration of several sources of data (raw data, sensors, cameras, drones, etc.) existents in the Greenhouses; ii) a dashboard to monitor and control remotely required Greenhouse production variables and equipment; iii) an API mainly supported by Restful services, for future integration of new devices or systems and iv) a Decision Support System to help the Greenhouse management, remotely.
c) propose a cloud architecture to support the integrated information system, to store and help processing the huge amount of data, efficiently, towards the sustainability of the Greenhouse;
d) evidence that the use of communication channels is essential for effective management and represent the necessary *add-on* to ICT;


## 1. Introduction

Nowadays, it has become known the importance of undertaking actions that reduce the environmental impact within all sort of processes, both industrial, business, or in our daily lives.


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An already wide range of literature reviews exist about the various aspects and facets of this concern, for instance, the green supply chain management [2], green building [3], green manufacturing [4], green product life-cycle and services [5]. And naturally both green IT and green IS are today central issues [6], [7].

In this context, generic greenhouses sustainability are the subject of several research projects of monitoring and control, as represented by [8] [9] examples. Sustainability here means the capacity to controll the internal environment, essentially.

The Greenhouse production needs to start changing its business paradigm. It is clear that this activity involves several distinct resources (and services), from time and persons, multiple infrastructures and type of equipment, and, besides the expected production results, there are continuously relevant data that is generated and needs to be processed. In the emerging Cloud Manufacturing [10] context, accepted as a tentative to shift from production-oriented to service-oriented manufacturing, IT services are seen as instances of (traditional) resources, since any (manufacturing) activity needs to look to the global market.

But if most of the production knowledge lies on human experience, the capacity to decide quickly against real situations comes from the availability of real and useful information timely (extracted from the data generated).

Some of this information can come from the User Experience and capacity to analyse the current production results, but some other might not. The capacity to mitigate (or integrate) all this enormous, but diffuse, information that all resources produce continuously, is a hard and delicate task. The use of auxiliary equipment (and solutions) efficiently integrated is an add-on that producers need to have, in order to ensure their business sustainability [11].

Accepting the almost omipresence of Information and Communication Technologies (ICT) in our quotidian, the rising of Cloud Computing (CC) lead us to believe that, technologically, it is possible to have virtually unlimited resource capacity for computing and storage [12] and the ubiquity support for traditionally centralized applications can be a fact [13]. Typically, such ubiquity can only be supported if multiple resources inter-operate efficiently and can dynamicaly be reconfigured. Nevertheless, this capacity is one of the main challenges of cloud computing [14]. Indeed, new technologies provide new experiences (and persons love that), and consequently new ideas arrive. However, new resources (not only technological) are required too.

This spiral of events represents evolutionary steps to the raising of a technocentric society, as an analogy to the egocentric stage in Piaget's model [15]. But technologies will not be sufficient if human behaviour does not change too. The *"intelligence was not the product of any simple recipe or algorithm for thinking, but rather resulted from the combined activity of great societies of more specialized cognitive processes"* [16].

The cloud paradigm enables the efficient retrieval of information from multiple data to achieve an efficient monitoring and control. New devices (mobile, mainly) and emergent communicational technologies demand richer information systems. Generally the use of dashboards represents an appropriate tool on decision making, but expanding it with efficiently integrated communicational services that allow human-to-human co-decision, represents a relevant added value.

Because the greenhouse production is (increasingly) commercialized in more global markets, the existence of efficient mechanisms to deal with unknown customers and service providers, is a critical requirement. Thus, its sustainability should not be seen only based on its internal capacity to produce but in the capacity to manage well all the participants in the system.

In traditional ICT transactional architectures, the human behaves as a mere user from outside the system, making impossible to have an effective human interaction. Thus, the real user (human) requirements cannot be well supported indeed, because they are not easily tangible and technically specifiable. The user will need to continue to adapt to the system and follow the system wizards. He cannot have his own reasoning and interact humanly with the system [17].

Under the cloud *SaaS* (Software as a Service) model, the application's Presentation Layers are now structured in a set of widgets (cloud-based full-fledged applications or cloudlets [18]) or specialized Apps, to support a service that can easily be "composed" (integrated) in a dashboard "*expected to improve decision making by amplifying cognition and capitalizing on human perceptual capabilities*" [19]. Despite of this, the components are not effectively integrated, but merely functionally organized, indeed. Furthermore, besides the restricted inter-interoperability, the lack of effective and really integrated communicational instruments, essential to enable the user participation (embedding his experience) on decision processes, represents another important weakness.

The state of the art confirms the existence of many attempts to project and develop cloud based solutions. The *Greenhouse Drone* from iNano Institut; the *Akisai Food and Agriculture Cloud*, from Fujitsu; the *IOS HomeKit* that explores a complex network of sensors offered as greenhouse automation services, from Apple; the *Agriculture Greenhouse Automation* with remote sensors under XBee modules, from University of São Paulo, etc., are relevant examples of such initiatives. Also relevant is the fact that all those proposals focus on technological solutions and in the Greenhouse Environment Control, essentially. To the best of our knowledge, at the time of this writing, none of the projects is already implemented.

## 2. Towards Sustainable Greenhouses

Like multiple economic activities, traditional manufacturing has been hardly "shaken" to efficiently integrate ICT in their processes. Nevertheless, efforts to modernize legacy applications or systems and to capitalize traditional knowledge, still continue to slow down an efficient ICT adoption and consequent business model changes, an essential requirement to re-align with new market requirements. In this process the human has been a passive actor and the knowledge does not represent the real human capital. Indeed, following working processes and responding to system's events can be efficient enough (can be measured), but does not allow the co-creation of knowledge and thus unable to be effective.

### 2.1. More than an innovative business model

Nowadays social-economic trends such as consumption growing, globalization, innovation and sustainability policies, determine new orientations. The agriculture production in greenhouses has been looking for low cost processes and scalable production capacity [20]. Apart from the required (internal) environment controlled resources (humidity, watering, sanitation, etc.), some other resources involved in this type of production (human resources, equipments, etc.), even existent in a global market, must be discovered, selected and managed, and the capacity to get the "best" ones will be determinant, but it is not enough to achieve the expected efficiency and sustainability [21]. A possible scenario can be the choice between hiring an expensive full time Agriculturist Hydroponics instead of having their services whenever necessary (surely less expensive. The easier the engineer can efficiently (remotely if needed) support his responsibility, for one or many greenhouses, the more effective and cheaper will be its services.

Agility and quickness are critical in nowadays competitiveness requirements. The globalization, innovation and ICT are transforming many sectors to anywhere, anytime platforms. Traditional stakeholders (technicians, suppliers, customers, others) can be "transformed" into services and following Putnik, these are the essential requirements to react to global market changes and the main problem arises from the people themselves, whose mind-sets need be changed. So the challenge is not only the ICT adoption but more the way one does it [22].

### 2.2. New shift on Agriculture in Greenhouses paradigm

As happen with several other existing business areas, a greenhouse business has essentially providers, customers and collaborators involved. But the real perspective arises from the assumption that the set of "stakeholders" involved in a production in greenhouse is increasingly greater each day, independently of the specific, or not, kind of cultivation explored. This assumption comes from the concept of service. There are several services involved, indeed, and services: a) are not necessarily supported by humans; b) could not be supported by machines; c) could not be part of the greenhouse company and d) could be internal or external.

The greenhouses traditionally need to have: a) its internal environment completely controlled and managed; b) the supply chain managed; c) the knowledge of customer's requirements and d) the business trends perception. Furthermore, the emerging business models implies yet: a) global perception of concurrent "threats"; b) global perception of interesting and available "services"; c) perception of the quality of the "services" and d) the ability and capacity to dynamically reconfigure the provision of "services".

But emerging (changing) agriculture in the greenhouse paradigm will need to be definitively sustainable and thus requires the possibility:

i. *to follow and assimilate all resource efficiency recommendations* (green energy, green IT, etc.)

ii. *to manage efficiently all the (contracted) services*, having monitoring dashboards that allows: i) to analyse the quality of services provided; ii) to know the status of any internal environmental indicator controlled by external services; iii) to interact immediately and personally with the "owner" of a particular service; iv) to broker for alternative services; and v) to interact or integrate with (other) independent (related) institutions (security, firemen, etc.)

iii. *to easily assimilate external (and concurrent) collaboration*, where interested collaborators (suppliers, engineers, technicians, etc.) need: a) "to convince" the company to accept their services; b) have appropriate skills for the required specialized tasks; c) have availability and capacity to remotely support the required tasks; d) have the capacity to managed several tasks for several interested customers (greenhouses); and e) have appropriate (technological) tools to support their job.

The sustainability is not based only on the resource's efficiency but also on the capacity to efficiently manage the networks of collaborators. Following the behaviour of social networks, the collaborators must be able to join the company (offer their services) easily and the company must know that they exist, which are the best collaborators and how to interact with them.

### 2.3. Cloud, Ubiquity and Pragmatics: emerging challenges

Nowadays dynamic and global business models brought the need to quick react to market changes, and the high availability and capacity to effectively support the changed requirements, becomes the main sustainability criterion. To handle that, companies need to have appropriate information systems that allow permanent real and effective perspectives of the market of resources, with efficient tools to broker and select them. The possibility to have the needed resource, in the needed time and where it is needed, represents the advantage of, and requirements from, Cloud and Ubiquitous Information Systems [21].

Furthermore, the huge amount of (real-time) data coming from (environmental) internal resources and services, together with the information coming from the network of external collaborators (mainly services), requires considerable storage and processing capacity. Thus, the need to have enough (in quantity and quality) resources and an efficient network of suppliers, in a dynamic and continuous reconfigurable environment, brings cloud based infrastructures as an important add-on to support these new information and processing systems.

To align the system to human, the system architecture needs to support human-to-human real and synchronous collaboration that allows the co-exploration (co-creation) of the system with other agents (humans). Thus, the architecture needs to be communicational based, having direct human participation and collaboration in any particular phase of the production process. Assuming this, *Pragmatics* [21] and Collaboration engines together with effective brokering mechanisms need to be implemented. The evidence of this comes from today's social networks success and their use for our own interest in a completely autonomous way. The larger the communicational capability of the architecture is, the greater is the effectiveness of the system.

## 3. Cloud and Effective Dashboards for Sustainable Greenhouses

Cloud Computing is much more than unlimited IT capacity. It is an opportunity to achieve, indeed, new business models. The success of human capital promotion with social media, and the new communicational (smart) devices capacities, brings web (wired or not) to high levels of intelligence support, supporting value creation and (self) efficient business models to use it [23].

### 3.1. Cloud Communicational Architecture

To overcome the evident and known technological interoperability handicaps, a semiotic framework [22] is required, based on an architecture that sustains two main characteristics: a) *ubiquity*, that cloud should grant to the registered resources (and services), since it focus on the agility and quickness competitiveness requirements, and b) *communicational*, where innovative and efficiently integrated communication tools will support the semiotic features (pragmatics).

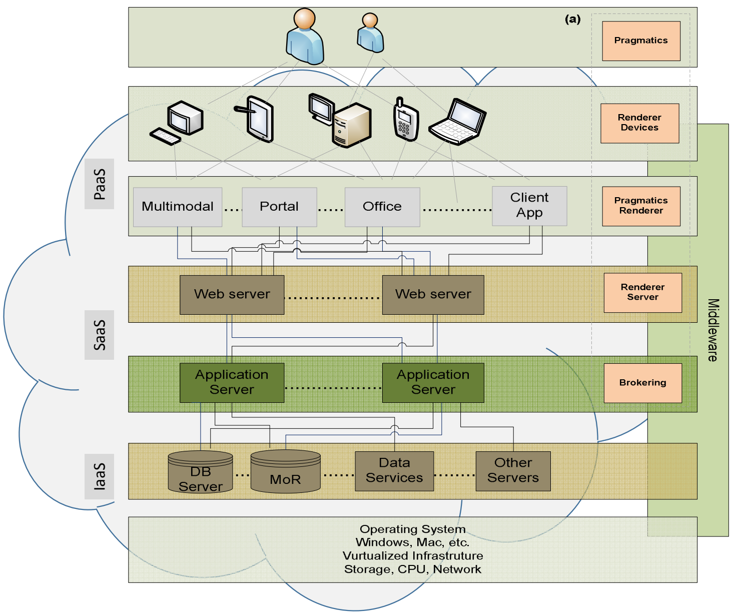


*Figure 1 - Communicational Architecture where devices are Pragmatics renderers*

So, such framework will be supported by a Cloud based Communicational Architecture (Figure 1) built on open-source technology, that has integrated: a) RIA pattern based *dashboards* [24], with integrated monitoring services and sufficient interaction to allow human (user) agility and competence, b) multimodal capacity, for multiple client device classes support, c) communicational services to allow pragmatics (considered as its innovative part), where human-to-human real interaction is completely supported, and d) scalable storage and processing capacity to assure the real-time required data processing and flow.

The semiotic component (Figure 1 (a)) of this architecture will be supported by a Pragmatics Rendered [17] that works as a communication enabler, and consists of a set of integrated collaboration technology that makes the bridge between the user/devices and the "system". A federated or community cloud (Market of Resources) will be created using a particular cloud RESTful API that will support (cloud) services composition and governance (pragmatics services behave as *SaaS* in the cloud). The communication services will be supported by existing P2P technology and rich and innovative cloud communicational services must be explored (*SignalR*, *WebRTC*, *LoKast*, etc.). A specific and advanced brokering mechanism will support the selection of resources (or services) and the dynamic reconfiguration (the Market of Resources will behave as a *PaaS*), using big data processing technologies.

### 3.2. Greenhouse Effective Monitoring Dashboard

The global ICT platform proposed (Figure 2) will be composed by: **i)** a servo unit, an infrastructure middleware type with embedded technology, that allows the (continuous) integration of several sources of data (raw data) coming from existing equipment (sensors, cameras, drones, etc.) in the greenhouse (Figure 2 a)); **ii)** an opened SaaS RESTful API that will support the integration of new equipment or collaborators (devices or services) (Figure 2 b)); **iii)** a rich and effective dashboard to remotely monitor and control the required greenhouse production variables (internal and external) and inherent equipment (Figure 2 c)) and collaborators network, allowing co-decision processes, and **iv)** an integrated Decision Support System to help on global greenhouse management.

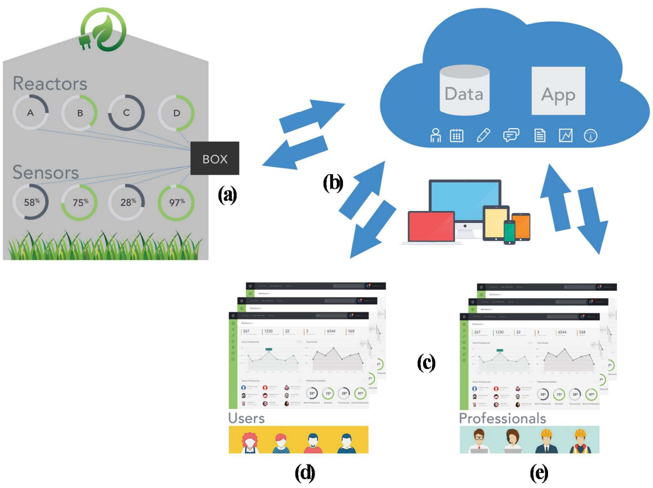


*Figure 2 - Architecture of the Global Platform*

Functionally, the dashboard (Figure 3) must have integrated several outputs resulting from several sources of data and must be prepared to be used by distinct user profiles. Considering the sources of data, there will be data coming from the greenhouse (internal) "equipment" (humidity, temperature, etc.), as well as data coming from external collaborators, such as the QoS provided by a particular engineer, his availability, their reports, their decisions, recommendations, scheduled tasks, etc.

Considering the user profiles, the application should be used by full members (Figure 2 d)) of the greenhouse as well as by external collaborators (Figure 2 e)). Naturally each profile has a particular set of features but the most relevant comes from the existence of an integrated set of communicational channels (Figure 3 a)) that allow direct and immediate (synchronous) collaboration, an essential requirement for effective co-decisions.

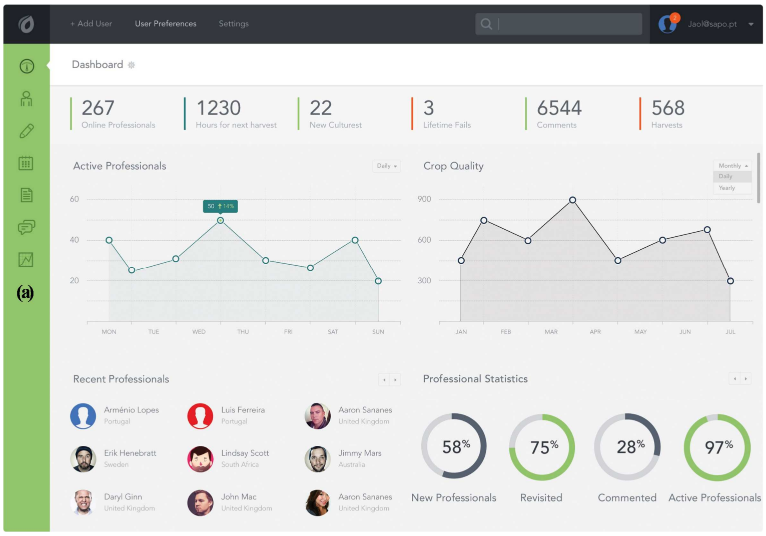


*Figure 3 - Effective Dashboard*

The existence of an Integration API allows the possibility for anyone to register into the "network" of resources (cloud services) and thus be available to the resource brokering mechanism. The greenhouse manager can, carefully, select the "best" provider for the service that is needed.

A Decision Support System will help full members and collaborators to manage all complex situations. Wizards should take care and orient on solving alert situations or reconfiguration needs, for instance.

In the following developments, this platform will be prepared to be adapted to different contexts or scenarios. Such platform fits, among many others, in critical scenarios for humans, with delicate or dangerous situations, such as examining mines, wells, underground viaducts, hostile environments, etc. Its capacity to integrate new equipments (robots and drones are possibilities, indeed); its capacity to process huge amount of data; the existence of effective communication tools and the existence of an open SaaS API, makes it able to be continuously explored.

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# Supporting Sustainable Development in Rural Areas by Encouraging Local Cooperation and Neighborhood Effects using ICT

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## Abstract

The following paper presents an approach how information and communication technology (ICT) can be used to support local cooperation and neighborhood effects. The presented approach maps typical real-world processes in the area of local cooperation between stakeholders from schools, universities and companies to an Internet platform with the motivation to support the communication between the aforementioned audiences and thereby reduces demographic problems in the model area in a sustainable, long-time perspective. The paper describes the process from the conceptual application of the idea as well as the prototypical realization of the technical prototype *vitaminBIR*. This encompasses, from the conceptual perspective, the definition of the main goals of the platform supported by a survey collecting needs and preferences of all addressed audiences and the conceptual phase of the platform itself. Furthermore, from the implementation perspective, the prototypical implementation supported by different software libraries, a concept for data self-management, and an iterative usability study to also check against the prior evaluated needs and preferences of the audiences, is addressed.

## 1. Demographic Problems in Rural Areas in Europe

The emigration of young people to the bigger cities and the brain drain related with this fact [1], [2] as well as the general aging of the society [3], are big demographic problems especially in rural areas in Germany, and in other European countries, nowadays [4]. Companies observe a shift from a “buyer’s market” to a “seller’s market” regarding employees for open position [5]. Local authorities need to handle the population loss on several levels, e.g. spatial development [6], cultural development [4], or tourism and leisure activities [7]. For these reasons, it is apparent that strategies for the sustainable development, especially for rural areas, need to be found. An important aspect hereby is to show up young people the potentials of their hometown and region [8] and related with this, the possibilities for qualifications and jobs. As job search and recruiting is usually intrinsically motivated by people and companies, we want to present a community-based approach to encourage all persons involved to cooperate in that matter with an intended advantage for both parties.

## 2. Supporting Local Cooperation and Neighborhood Effects using ICT

The approach presented in this paper mainly focuses on the idea to support local cooperation and neighborhood effects by information and communication technology (ICT), in particular by providing an interactive Internet platform. In detail, our goal is to map typical real-world processes of local cooperation and neighborhood effects, i.e. interactions between people from different involved audiences, e.g. schools, companies etc., to an ICT system. Therefore, we focus on (1) an easy understandable transfer of the real-world processes to the navigation structure of the system to achieve a good ease of use, (2) a screen and information design that is attractive for all involved audiences, (3) a high level of information quality that ideally exceeds the expectations of the user,

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and (4) a mainly self-managing system to reduce runtime service costs. All information provided in the system is, by concept, restricted to information that follows the guideline to work against the aforementioned demographic problems, e.g. job offers only from companies inside the specific local area, educational events provided by the local university, etc.

### 2.1. Conceptual Application

As part of the pilot project *LandZukunft* we apply the described approach on the cooperation processes of audiences in the District of Birkenfeld in Germany. The pilot project *LandZukunft*, which is funded by the German *Federal Ministry of Food and Agriculture*, focuses on the sustainable support of rural areas during their endeavor to develop regional value chains and protect local jobs. While applying the presented approach, we focus on the processes of cooperation of schools, universities and companies on the organizational side, as well as the neighborhood effects between pupils, students and human resources departments of local companies on the social side. By supporting these audiences and the restriction of the information on the platform to a specific local area, we specifically follow the concept to reduce emigration of young people as well as the mentioned brain drain. When we are successful in this, we expect to have positive impact on the sustainable development of the appropriate local area. With the application described in the following, we furthermore plan to create a solution that can be transferred to other rural regions with similar problems, after a successful prove of our approach in the District of Birkenfeld. Since *LandZukunft* is a pilot project, this transfer of knowledge and technology is also one of the main concepts of the funding.

It is proofed that peer networking has (1) a high impact on the job search or recruiting and its factor of success for students as well as for companies and that (2) these neighborhood effects can be supported by ICT [9]–[11]. Therefore we decided to design an Internet platform, which supports these peer networking aspects with the goal to help pupils and students to find good apprenticeships and jobs in companies near their hometown as well as companies to find appropriate job candidates. To round out the general idea, the platform also encourages offering and searching for side jobs between pupils and students among themselves, e.g. private tutoring. On a higher organizational level, the platform motivates company leaders and human resources authorities as well as headmasters of schools to find and agree to long-term partnerships. Long-term partnerships in this context can be partnerships between schools and companies with periodic practical events, workshops as preparation for apprenticeships, or appointments for networking between pupils and companies. Also practical events or job fairs organized by a university in collaboration with companies etc. belong to this category. Summarized, we offer a platform to encourage different audiences to long-term cooperation between each other. We expect that these changes lead to positive demographic effects and with this a reduction of brain drain to bigger cities as well as to positive effects regarding the other connected aspects already mentioned, e.g., spatial development, cultural development etc.

In order to identify the processes that should be supported by the platform as well as the information required by the audiences for the same, we conducted a paper and web based survey before we started into the conception phase. The survey (survey data: $n=304$, 138 pupils ($\mu=16.64$ years), 150 students ($\mu=26.23$ years), 16 company representatives) was, in the beginning, prepared as one generic questionnaire for all audiences and afterwards elaborated as three different versions for the specific audiences. That way, we were able to create questionnaires optimized for each audience on the one hand regarding language, e.g., youth or business language, and question selection, e.g., by adding additional questions for specific audiences. On the other hand it enabled us, to relate the answers on specific question between the audiences, e.g., regarding expectations of responsibilities or preferences of specific audiences on the same topic. The survey results enabled us to gain an objective perspective on the steps that are seen as most relevant to be supported by such a platform, to be able to give them a higher importance in the platform concept, e.g., the expectations of all audiences from which side a communication regarding an open job position should start[2]. With these results we can especially support the preferred steps on the platform. Beyond this, we determined the information that is required and expected by the users of the platform to support the aforementioned steps, e.g., which information companies expect from applicants when applying for an open position[3]. Additionally, we identified some technical preferences by the survey, e.g., if the users want to use existing or separately created user accounts to access the personalized or private sections of the platform[4].

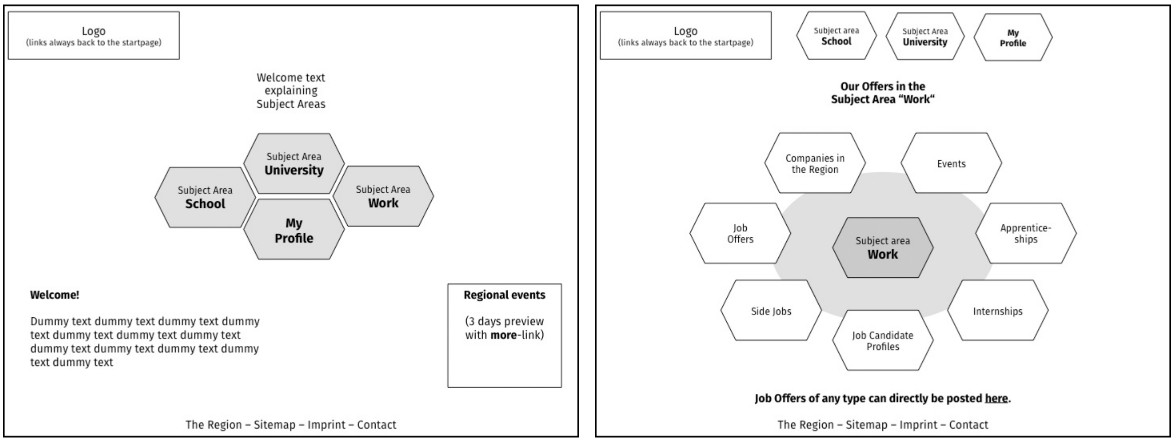


*Figure 1: Concept draft of the Homepage and the Subject Area "Work" of the Internet platform. (Translated from German.)*

Based on these survey results, we elaborated the first concept for the Internet platform, which can be seen as first screen design concept above (see Figure 1). The concept follows a combination of a target group and intention based navigation approach. That way, the information a user is searching for on the platform, can be found in not more than two mouse clicks. If possible, the user can also find the information without giving any personal information in advance, i.e., it is not necessary to request user information to provide the information. Summarized, users from all audiences can come to a page containing the relevant information with only two clicks and will, if is is appropriate for the particular information, be able to filter the given information to find the best-fitting results afterwards. An additional top menu supports direct navigation over all pages for returning, experienced users who want to skip the two-step process. The screen design concept drafts showing the exemplary results page of a two-step process of a student searching for a side job offer as well as the top menu can be seen in the following (see Figure 2). By focusing on the aforementioned two-step process while developing the concept, we hope to reduce the bounce rate[5] to a minimum.

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[2] The majority of the participants over all audiences expect the applicant to contact the company, not vice versa. Survey result excerpt: Students: 54,4%: applicant contacts company, 36,2%: no preference; pupils: 6,2% applicant contacts company, 68,2%: no preference; companies: 68,8%: applicant contacts company, 25,0%: no preference

[3] Most relevant information from company perspective as evaluated by the survey: Name, residence, age, motivational letter, employment type, branch, earliest starting date, language knowledge, photo

[4] Survey results: All audiences prefer the creation of own accounts instead of reusing existing Facebook, Twitter, Google, Microsoft or XING accounts.

[5] The bounce rate is the number of users leaving a platform directly after the first page view.

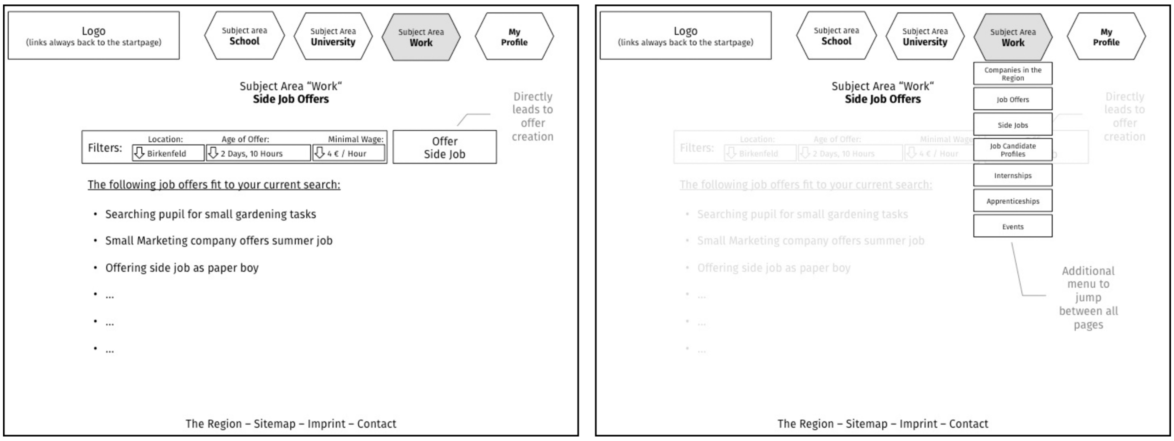


*Figure 2: Concept draft of a results page with filter and the additional top menu on the platform. (Translated from German.)*

## 2.2. Prototypical Implementation

Our prototype, *vitaminBIR* (www.vitamin-bir.de), is developed as interactive Internet platform based on the content management system *TYPO3* for easy content management and own extensions to provide specific interactive components on the platform, which directly support the use cases addressed. On the one hand, when designing *vitaminBIR* a major aspect of our technical concept was also a self-managing design, to reduce management effort for the developed platform to a minimum. On the other hand, we always focused on simplicity and low entry barriers for all involved audiences to motivate the users to use the cooperation features provided by the platform. This process is also supported by an iterative usability and adaption cycle before the release of the Internet platform. Both aspects will be elaborated a bit more in the following paragraphs.

**Data Self-Management**

When delivering a service like the aforementioned Internet platform, one of the major problems is the data management, in specific the effort to keep the collected information correct and up to date. To provide such a huge amount of different types of information about schools, companies, jobs, apprenticeships, job candidate profiles etc. in a high information quality, it is necessary to automatize most of the data management steps to keep the effort on a minimum. An approved approach to solve this problem when delivering a service is, to involve the user into these processes and to reduce the administrational effort for the service provider hereby as much as possible [12]. Thus, the effort of data management is almost completely shifted from the platform provider to the user. When designing and implementing *vitaminBIR* we followed this approach in many ways:

1) The management of all personal and institutional account data is completely outsourced to the user, while the system validates the input when the user tries to store the same to only allow consistent data states to be saved. The validation of the data is done by a combination of the internal validation capabilities provided by the *TYPO3 Extbase* technology and program logic implemented in PHP. The required data model and controller classes are realized as standardized *TYPO3 vitaminBIR Model* extension. An example for the internal *TYPO3 Extbase* validation of an email address can be seen in the following source code snippet:

```
/*
 * @var string
 * @validate NotEmpty, EmailAddress
 */
protected $email = '';
```

2) All data-based lists on the platform, e.g. job position listings, school listings, company listings, events etc., are also managed by the responsible person directly on the platform. Using the *TYPO3 Fluid* template technology these listings are automatically created from the data objects. The conditional functionalities of *TYPO3 Fluid* hereby help to be able to deal with optional fields and empty field values in a professional way. The templates are also part of the aforementioned *TYPO3 vitaminBIR Model* extension. An example for a *TYPO3 Fluid* condition to show the application deadline of a job offer on the platform can be seen in the following source code snippet:

```
<f:if condition="{jobOffer.applicationDeadline}">
    <f:then>
        <f:format.date format="d.m.Y">
            {jobOffer.applicationDeadline }
        </f:format.date>
    </f:then>
    <f:else>
        not provided
    </f:else>
</f:if>
```

3) The service provider can define self-management rules in the backend of the platform to motivate the users to keep their information up to date and to automatize the process of checking and updating information using email, i.e. a user can be asked by email, when a data object has not been changed for a while, if the information is still correct. The user can confirm that the information is correct or adjust it on the platform by using direct links also provided in the email. An exemplary rule-based self-management flow can be seen below (see Figure 3). The service provider has only to act, if the user does not react at all. To provide such functionality another own *TYPO3 vitaminBIR Maintenance* backend extension has been developed.

By combining these approaches we hope to minimize the effort of data management on the platform by still having a high level of information quality. Especially for the last mentioned approach of self-management (3) a wide-ranging document is currently in development, which will be the basis for the setup of the rules in the backend of the platform before the official release.

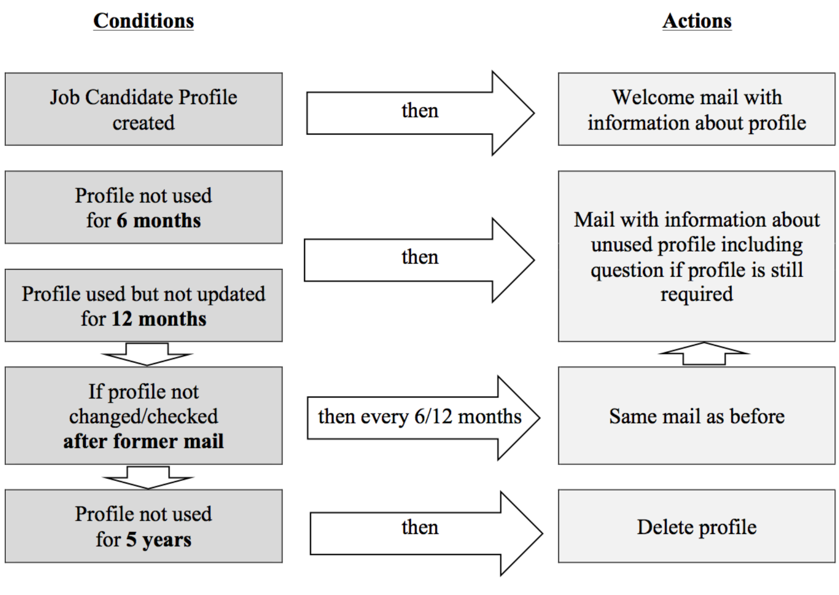


*Figure 3: Exemplary rule-based self-management flow for job candidate profiles.*

**Usability and Adaption Cycle**

Another problem when developing a service for such a broad variety of users and processes is the potential loss of the formerly aimed simplicity as well as the potential fail of providing not the processes that were expected by users. Therefore we conducted an iterative usability study with adaption cycles to keep on track regarding the former problems. The study was split into three usability tests with about five participants from each user group, i.e., three appointments for tests with five pupils, five students, and five employees from human resources departments of companies in the District of Birkenfeld. The first test took place using an early Alpha Version, the second test some weeks later using a revised Beta Version and the last test will take place in the near future using the revised Release Candidate Version. Between these tests the time was used to adjust the platform based on the feedback from the former tests. The tests were conducted as qualitative usability tests with *Concurrent Probing*[13], which means that the participants follow some tasks they have to do on the prototype platform while the supervisor analyses the behaviour and interrupts in case of unexpected behaviour of the user. The tasks given to the participants were typical tasks for the appropriate audience, i.e., creating a job candidate profile for a holiday job for pupils or finding a nearby company for an internship for students. About half of the participants in the second and third iteration are participants who already participated in the former test/tests to be able to not only get feedback on the current version, but also on the realized changes. Due to the fact that the usability tests were not the main focus of the project, they were conducted in the described, simple form, but as systematic continuation of the web and paper based survey in the beginning of the conceptual process. Like the survey at the beginning of the conceptual process, the usability tests supported the development process to keep the whole project on track regarding the needs and expectations of the future audiences of the platform.

Beside all the former mentioned approaches to ensure a good information quality and to provide a platform, which specifically fits the needs of the appropriate audiences, we are also collecting and analysing classical usage data on the platform using the open-source software *Piwik*[6]. By doing so, we will try to evaluate the most used features on the platform and navigation problems of the users to be able to further improve the platform also after the release date.

## 3. Summary and Outlook

As presented above, the elaborated steps to support sustainable development in rural areas by encouraging local cooperation and neighborhood effects can be transferred into an ICT system. The advantages of ICT systems for this matter are evident: ICT systems, in our case the Internet platform, are available for a large number of people, without time restrictions and hold only a very low entry barrier. Compared to short-time collaboration projects, such a system can also consist for several years with a relatively low managing effort, to sustainably support development of a specific region, not only during the runtime of the current funding or developing project.

Summarized, with *vitaminBIR* we try to provide an ICT system that helps the District of Birkenfeld, as well as other regions in the future by transferring the concept and the software, to reduce the previously mentioned demographic problems, by efficiently supporting real-life processes which reduce the influencing factors of emigration of young people from rural areas. During the whole conception and realization process of *vitaminBIR* it was always important to continuously check the developed platform against the needs and expectations of the audiences, to ensure that the platform can really have a sustainable and positive supporting effect for the model region.

[6] http://piwik.org/

Beside the development of the Internet platform, our team is already in the process of promoting the platform. We thereby directly address our main user groups, i.e. pupils, students, and human resources departments of companies. The first Release Version of *vitaminBIR* will be published in August/September 2014.

## Acknowledgements

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# Design and Implementation of an Environmental Decision Support System: tools, attributes and challenges

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## Abstract

This paper presents the approach and findings related to the implementation of an Environmental Decision Support System (EDSS), designed to assist the Moroccan national decision makers, in particular, in their evaluation of the state of the environment, and in their approach to sustainable development and environmental policymaking. We describe the background of the environmental situation in Morocco and the need that drives the development of an EDSS. The EDSS offers a number of salient features and attributes that help with framing the decision making process, ranging from the management and monitoring of indicators, modelling of environmental problems using a knowledge-based approach, uncertainty handling using fuzzy logic, dissemination of information with the society, as well as stakeholder involvement. The description of these features is linked to the main system components and tools. We also discuss some of the major challenges we faced during the different project phases in spite of the recognized importance of the EDSS for environmental management and evaluation at the highest levels. We discuss the perhaps most problematic set of challenges, namely elicitation of the requirements, scarcity of data and knowledge, and failure to define clear criteria to frame the selection of relevant indicators.

## 1. Background

Morocco is a mountainous country, vulnerable to both marine and Saharan influences. The increase in population has conducted to an increase of the gross domestic product (GDP), which stressed by deficient resource management, has led to the degradation of the environment. The annual cost of environmental damage has been estimated at nearly 4.8% of Morocco’s GDP (World Bank, 2002). Morocco is a country that lacks natural resources, especially arable land and water. During the last years, intensive agricultural production, uncontrolled irrigation schemes, industrialization, and urbanization have made the country subject to enormous problems. The country has suffered from severe air and water pollution, soil erosion, and environmental health degradation. The country is also subject to impacts of global climate change. Forest ecosystems and biodiversity are threatened by deforestation. Emissions of greenhouse gases increase, and access to safe drinking water in rural areas is still below expectations. As for liquid sanitation, it remains a problem. Water resources quality can be altered by uncontrolled sewage or siltation of reservoirs; and coastal waters suffer sometimes from oil pollution; and despite the construction of social housing, some citizens still live in unhealthy places [1].

The main approach adopted by Morocco to achieve the targets of sustainable development (SD) is environmental. One of the initiatives that support the Moroccan strategy for sustainable development is the establishment in 2010 of a National Charter for the Environment and Sustainable Development CNEDD [2] which constitutes a positive and constructive action. Its aim is to: 1) consider the preservation of the environment and sustainable development as a national priority, 2) to disseminate awareness among citizens, all managers, whether public enterprises or

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private, government, local authorities and elected officials of the need to preserve the environment and to take it into account in the economic and social projects. It is a collective involvement. The National Charter for Environment and Sustainable Development is considered the first initiative of its kind in Africa and the first in the Arab World. The charter is guiding environmental policymaking and laws on natural resources and sustainability. The charter led to the integration of sustainable development principles into sectorial strategies, the implementation of the Strategy for Improvement of the Environment (MANE) and the National Initiative for Human Development (INDH), as well as the formulation of concrete and operational proposals like the National Strategy for Environmental Protection (SNPE) and the National Strategy for Sustainable Development (SNDD).

Another initiative is the Moroccan National Environmental Observatory (ONEM) that aims at improving knowledge related to the Moroccan environmental system and performing a deep analysis of interactions environment-development. In this perspective, ONEM’s approach is based on a number of fundamental principles: 1) to collect, analyze and disseminate information; 2) to produce statistics and indicators on sustainable development; 3) to develop a network of decision makers in terms of environmental monitoring; 4) to contribute to the definition of public policies in terms of sustainable development; 5) and to publish reports on the environmental situation.

As can be felt from the different abovementioned Sustainable Development initiatives, and given the scale of the environmental problems in Morocco, the need for an integrated Environmental Decision Support System (EDSS) [3-6] for monitoring the environment is critical to effective evaluation, management, and follow-up. Such system should also support decision making for regional environmental protection in order to reconcile economic demands and social needs with the capacity of the environment to sustain human and other life. Incorporating economic, social and environmental data is necessary to achieve the targets of ‘Sustainable Development’. This approach should help clarifying the socio-economic causes of environmental degradation and their impacts. Furthermore, the adoption of one of the best practices in environmental modeling, namely the technical model Driving Force - Pressure - State - Impact - Response (DPSIR) [7] should assist in gaining insight into environmental problems.

In order to bring science to decision makers and help in structuring the activities of the decision making process, the EDSS should integrate a set of tools such as, a database on ecological and socio-economic indicators along with their historical data, Geographic Information Systems, Multiple Attribute Decision Making methods (MADM), simulations and tools for knowledge acquisition and modeling.

All these needs have been developed in an EDSS designed to assist the Moroccan national decision makers in particular in their evaluation of the state of the environment and in their approach to sustainable development and environmental policymaking. The detailed architecture and the different design decisions and technology choices of the EDSS have been discussed in [8]. The EDSS building block architecture gives a number of evident attributes like the ability to scale up, flexibility and simplicity of process reusability and duplication when there is a need to. The modular design allows the EDSS to follow the need to build complex environmental services to be offered at different scales and open to a wide audience ranging from NGOs, experts, decision makers and citizens. The system allows composing different functionalities to higher level entities thus allowing creation of different deployment scenarios possibly distributed at different administrative regional and national levels.

## 2. The major EDSS attributes

The EDSS offers a number of salient features and attributes that help with framing the decision making process. It allows:

1) the definition, management and monitoring of indicators and historical data,
2) the modelling of environmental problems using the DPSIR framework that brings ecological indicators as well as socio-economic drivers and pressures into the same picture,
3) it also incorporates possible responses to environmental issues and gives support to evaluation of relevant policy alternatives,
4) it uses a knowledge-based approach and leverages heuristic expert knowledge in order to analyze the DPSIR causal links,
5) it supports uncertainty handling using fuzzy logic,
6) it promotes communication with the society using a GIS Web Mapping service and a mobile application, and
7) it supports stakeholder involvement through scenario development and evaluation.

### 2.1. An integrated and generic approach

The framework employed to guide the selection of indicators was initiated within the DPSIR model. The goal of using DPSIR in the EDSS is to guarantee that scoping goes beyond sectorial interests and limited problem perceptions, focusing on finding the balance between socio-economic needs and the protection of ecosystems, which is an essential perquisite for achieving the targets of sustainable development. During this phase, sufficient understanding about the functioning of the studied ecosystem of any environmental issue should be gained, including the identification of relevant indicators and cause-effect links between them.

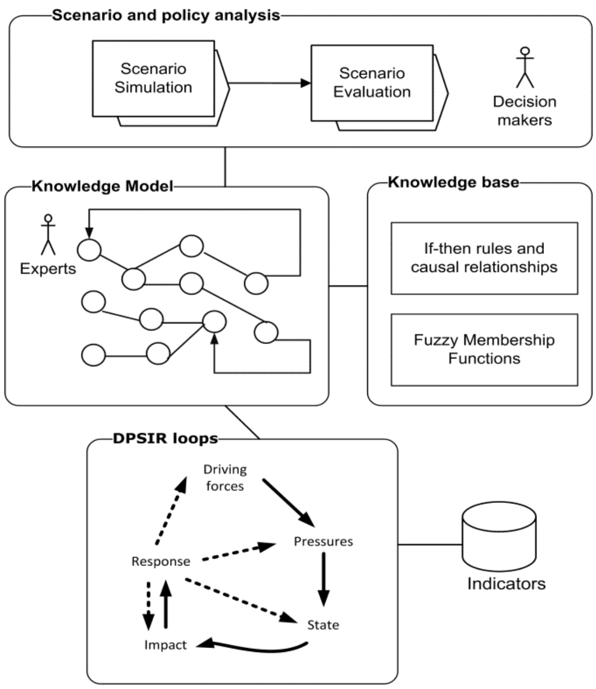


*Figure 1: The different components of the knowledge-based model*

The strength of the generic and integrated decision support approach was proven by two case studies, traditionally belonging to two different areas of expertise. Namely, the EDSS was used to analyze river water quality which allowed the identification of key pressures on water quality in the Bouregreg-Chaouia basin. Hereafter we provide details of a second example that includes a case study to evaluate key policy options that can mitigate air pollution impacts on the public health in big cities.

Assessing air pollution impacts on health or evaluating the different policy options to mitigate the impact of air pollution on health is a complex process that brings together socio-economic aspects as well as ecological indicators in an attempt to understand and control the pressures that drive the ecosystem changes. A knowledge-based model, based on Fuzzy Cognitive Maps (FCMs) [9] and Rule-based Inference systems, was chosen to be utilized to perform an integrated evaluation of the air pollution issue because of the nature of the application. The model is made of nodes that represent the different air pollution pressures like emissions of sulfur dioxide; impacts like health risks induced by respiratory and cardiovascular complications; and responses or remedies like the introduction of clean fuels, industrial pollution control or creating low emission zones. The model supports also representation of complex cause-effect relationships between the different indicators in the form of fuzzy inference systems that dynamically determine the influence induced by one indicator on another. An inference algorithm was outlined to process acquired data against the knowledge base and answer questions, evaluate a range of possible scenarios or predict output under consideration of human perceptions, uncertainty and complex cause and effect factors. The different components of the model are summarized in Figure 1.

The developed DPSIR loop related to air pollution with the different causality links between indicators is illustrated in Figure 2. Qualitative descriptions of some of the considered indicators are shown in Table 1. A sample set of if-then rules describing the causality links between the different concepts are shown in Table 2. The DPSIR-based cognitive map and the rules were elaborated in consultation with environmental experts.

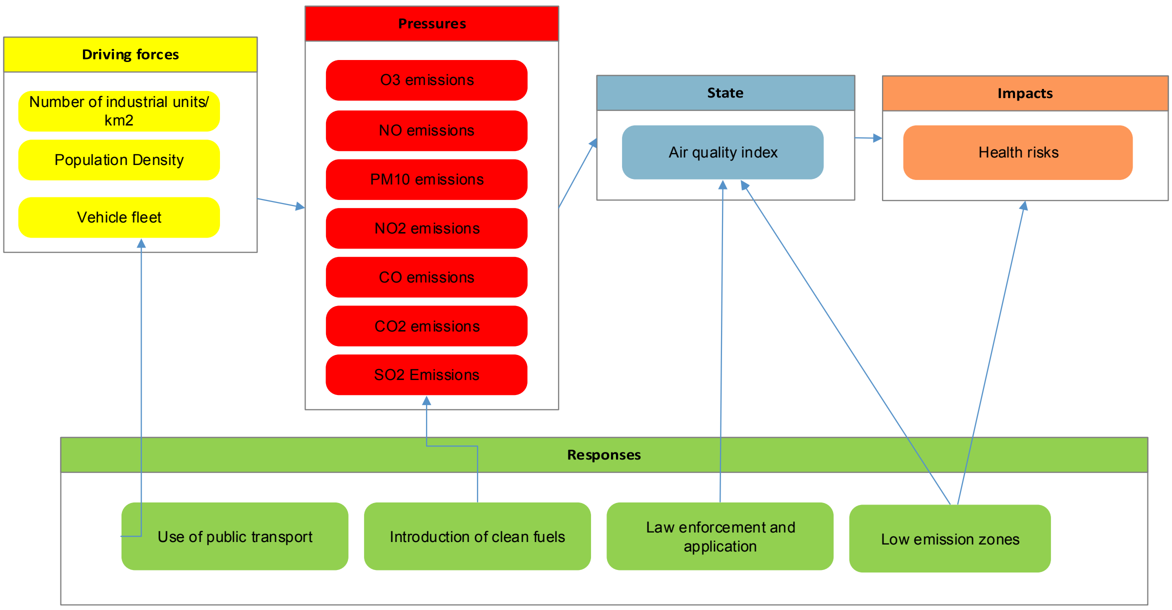


*Figure 2: The DPSIR loop for the air pollution issue*

The knowledge-based approach, leveraging expert knowledge, seems to be very helpful to managers and stakeholders, because it brings together data and expert heuristics in an attempt to tackle decision making, planning and policy formulation.

## 2.2. Collaborative data collection and exchange through a web portal

The environmental management functions are mainly based on the access to complete and quality data, enabling the information system to carry out its tasks. However, there are different providers of environmental information in Morocco. This is generated by a variety of public and private institutions like ministries, hydraulic basin agencies and urban agencies. Therefore, a network of regional stakeholders and partners has been established to ensure dynamic sharing and exchange on historical data and to guarantee an efficient and regular data collection in order to feed and update the regional information system.

Stakeholders and partners actively contribute in the production of environmental information, through a web portal for the upward transmission and circulation of the information to the Department of the Environment (DE) without further moderation. The web portal was designed and built as a Rich Internet Application so as to provide state of the art user experience and ubiquitous access to the environmental information stored in the EDSS. The backend was built according to the Model-View-Controller design pattern leveraging standard frameworks.

### 2.3. Dissemination of information in a participatory approach

Public participation and the right to have access to environmental information were instructed by the Moroccan Environmental Charter. This makes environmental information sharing an important element of the environmental decision support system.

A dynamic GIS web mapping application was used as an inexpensive means for publishing environmental data and sharing it with a wide audience of users. By maximizing the use of the Internet for sharing, information accessibility is significantly improved compared to conventional paper distribution of maps. Users can query the database of indicators and choose layers of statistics in different geographical divisions that are cross-referenced to point to ESRI Shapefiles.

An Android mobile application was developed to allow users collect air quality status in their location, using the convenience of a mobile device. The application makes it easy for people with respiratory complications to determine when extra caution is advisable or when they should limit the outdoor activities. The user implication in environmental matters is also encouraged with an option to report air quality violations, like smoking vehicles or any evidence of hazardous waste.

| Indicator threshold values | $SO_2$ emissions ($ug/m^3$) | Industrial units ($number/km^2$) | Health risks (%) |
|---|---|---|---|
| **Low** | 0 - 159 | <3 | 0-1 |
| **Average** | 160 - 249 | 4-5 | 1-3 |
| **High** | 250- 349 | >5 | 3-100 |
| **Very high** | 350- 549 | | |

*Table 1: Sample indicator threshold values used in the air pollution DPSIR loop*

### 2.4. Uncertainty handling using fuzzy logic

In modeling environmental problems, experts often fail to provide a clear knowledge because of the lack of common standards and hence ecological systems would be described with knowledge that is ambiguous or imprecise to a certain extent. Uncertainty defies the reliability of the obtained results' effectiveness in the decision making process. To deal with ambiguities and uncertainties, Fuzzy logic, which was first introduced by Zadeh [10] was very convenient in conciliating observations due to using multiple experts which is a desired feature in running FCM sessions, whether in describing indicator threshold values or the cause-effect relationships between them. Fuzzy logic allowed us to develop a natural language system that makes use of linguistic variables, where the universe of discourse of an indicator is divided into a number of fuzzy sets with a linguistic description attributed to each one. The same set of linguistic terms was used to describe the relationships between input indicators and outputs using fuzzy if-then rules. In spite of the underlying knowledge acquisition complexity when fuzzy logic is used, it allowed us, besides the handling of uncertainty, to establish a more natural user interface since results can be communicated in numerical formats or in natural language terms. Another advantage is the ability to combine individuals' knowledge and beliefs in an easy and meaningful way. The result of the aggregation of individual's FCMs is sometimes referred to as a "social cognitive map"; it is perceived as a representation of shared knowledge and has been used in a wide spectrum of applications and scientific fields in order to support decision making processes. The aggregation of expert knowledge helps in gaining a more comprehensive understanding and reaching consensus among experts about complex systems [11].

| **Fuzzy Rules** |
|---|
| ***Link : Pressures transport -> Air quality*** |
| IF Transport emissions is low THEN influence ON Air quality is low<br>IF Transport emissions is medium THEN influence ON Air quality is high<br>IF Transport emissions is high THEN influence ON Air quality is very high<br>IF Transport emissions is very high THEN influence ON Air quality is very high |
| ***Link : Air quality -> Health impact*** |
| IF Air quality is good THEN influence ON Health is low<br>IF Air quality is medium THEN influence ON Health is medium<br>IF Air quality is poor THEN influence ON Health is very high<br>IF Air quality is very poor THEN influence ON Health is very high |
| ***Link : Clean fuels -> SO2 emissions*** |
| IF Clean fuel introduction is low THEN influence ON SO2 is low<br>IF Clean fuel introduction is medium THEN influence ON SO2 is low<br>IF Clean fuel introduction is high THEN influence ON SO2 is medium<br>IF Clean fuel introduction is very high THEN influence ON SO2 is medium |

*Table 2: Sample rules built to model the causality links in the air pollution DPSIR loop*

## 2.5. Stakeholder involvement

In collaboration with the Regional Environmental and Sustainable Development Observatory (OREDD) and the Environment Department (DE), we conducted a pilot deployment in the region of Meknès-Tafilalt by capitalizing on a previous work that resulted in the identification of key sustainable development indicators and the establishment of a network of regional partners and stakeholders for data collection and monitoring. The project was conducted to allow local authorities to have an overview on the state of the environment in the region of Meknès-Tafilalt, to know the consequences of the population on ecosystems and have an action plan that aims to improve the environmental situation while remaining in articulation with programs and projects and taking into account the institutional arrangements and financial support measures. The project is organized around four main missions: 1) establishment of a network of regional partners for data collection, 2) establishment of a database of environmental indicators in use in the region, 3) integrated assessment of the environment and development of the regional report on the state of the environment, and 4) proposition of action plans for the protection and restoration of the regional environment.

An iterative and incremental approach was adopted, conducted in a collaborative spirit with some amount of formality. The idea was to generate a quality product while taking into account the changing needs. Potential areas of environmental concern along with the set of indicators to be used were identified by performing a close study through a number of consultations and discussions with specialized environmentalists.

## 3. Challenges faced

In spite of the recognized importance of the EDSS in environmental management and evaluation, there have been a number of challenges that we faced during the different project phases. We discuss the perhaps most problematic set of challenges: elicitation of needs, scarcity of data and knowledge, and failure to define a set of criteria to frame the selection of relevant indicators.

### 3.1. Elicitation of the needs and communication with end users

One of the challenges we faced and also discussed in [12], is that the requirements, initially, were not clearly detailed or even understood by the end users themselves. What complicates the problem further is that the EDSS project was funded by DE, but subcontracted by private consulting companies and implemented by academic researchers independently of the originally intended end users, which created a problematic communication setting for the EDSS developers. To mitigate somehow the problem, we adopted an approach that is iterative, adaptive and interactive. We built a number of prototypes that served initially to validate the requirements and provide suggestions, however the process was very costly and time consuming.

### 3.2. Data and knowledge quality

Applying the DPSIR framework to an environmental issue should be strengthened by a solid knowledge base; the result highly depends on quality data and knowledge availability. Unfortunately, in the EDSS, the DPSIR is usually applied in the early stages of any project, because this is where it seems the most effective. However, this step is performed independently on the data collection process. The main effort deployed in designing the DPSIR loops was spent on retrieving data from different partners separately, but little effort was spent on data transformation and integration from different sources to match, for example, the *Impact* indicators with the *State* or *Pressures* constituting a single DPSIR loop. Moreover, in an integrated evaluation approach, availability of knowledge in the different areas of the DPSIR model cannot be assumed. Learning trends and knowledge extraction was quite hard too because of scarcity of data. For example, in the pilot region of Meknès-Tafilalt, we noted that 85% of indicators have no history, and that only 10% of indicators contribute to the available data with a filling percentage lower than 40%, which means that there is missing data for many indicators and for many periods. Another factor that contributes to the problem is the underlying acquisition cost of non free data. This situation has pushed DE to put pressure on the different stakeholders in order to maintain the level of interest and funds required to collect the necessary data.

### 3.3. Environmental data and indicator framework

Given the complexity and the interlacing nature of environmental issues, the list of indicators to be used in the integrated environmental evaluation has not been finalized as yet up to today. The project failed to handle the actual complexity of environmental issues because of the lack of scientific consistency and the failure in defining and adopting a clear framework or criteria for choosing the indicators that best describe a specific ecological problem. It is felt that a procedure for environmental indicator selection should be adopted. The procedure should have clear criteria and also present a method to evaluate the indicators against the chosen criteria. The set of indicators need to capture the complexities of an ecosystem but yet be simple, easily monitored and measured. They should also be relevant to the policy life cycle and help decision makers take informed decisions. The result of this process should then be used as a baseline for data collection and environmental monitoring.

## 4. Conclusion

In this paper we described the background, tools, attributes and challenges of an EDSS developed to support the Moroccan national strategy for environmental protection and sustainable development. One of the major assets of the EDSS is that it was designed and deployed within a framework that includes stakeholder participation and expert knowledge. This linkage was maintained within the frame of a national project conducted by the Moroccan Environment Department. Applying the DPSIR framework by integrating ecological indicators and socio-economic indicators is very important in an integrated evaluation of the environmental situation and in reaching the targets of sustainable development. However, it remains very challenging to mobilize enough expertise pertaining to inter-related domains of a given environmental issue. The knowledge-based approach was proposed to clearly define the network of causal links between indicators and in associating the qualitative and quantitative data, which are all necessary activities in the modeling process but lacking in the DPSIR framework.

It can be concluded that, in EDSS development, it is of a tremendous importance to define a formal and transparent framework, with clear criteria for selecting and assessing the set of considered indicators in order to obtain the ones that are very representative of a specific ecological problem, and yet can be easily monitored and measured. It is also very important that the EDSS developers, not only focus on functionality, but should also engage in elaborate usability and user oriented process models in order to ensure correct elicitation of the end user needs and their involvement in the different stages of the project.

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# Towards an Environmental Information System for Semantic Stream Data

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## Abstract

The future of the earth's environmental systems will to a major extent be decided in cities as already more than 50% of the population is concentrated there. Pervasively available sensors and the data they generate can help to address pressing environmental challenges in urban areas by making crucial information available to researchers and decision-makers. However, environmental data is at present typically stored in disparate systems and formats, which inhibits reuse and recombination. Furthermore, the large amounts of environmental data that stream in continuously require novel processing approaches. So far, however, research at the intersection of environmental sciences and urban data to overcome these barriers has been scarce. To address these issues, we develop a novel framework using semantic web technologies. We apply ontological concepts and semantic stream processing technologies in order to facilitate combination, comparison, and visualization of heterogeneous data from various sources. The platform for environmental data stream analysis introduced in this paper can inform and support decision-making by non-expert users. We propose and discuss a three-step framework and outline initial results.

## 1. Introduction

By 2010, the share of the global population living in urban areas had surpassed 50% for the first time in history [1]. Therefore, one can argue that the future of our environment is, and will be, decided in cities. Methods and technologies developed in computer science have strong potential to improve the understanding of our environment and contribute towards solving environmental challenges [2]. Most harmful developments in urban areas are directly linked to people's behavior, which affects air and water quality, waste disposal problems, noise pollution, and the climate. One motivation for this work is to help address such negative environmental effects of urbanization with IT-based methods. [IT, for instance, can assist in analyzing combinations of traffic and air pollution data streams and thus deduce optimized traffic routing or support city planners' decision making.

Another motivation for this work is the increasingly ubiquitous presence of sensors that generate data streams. From an environmental management perspective, this can be seen as a major advantage of cities compared to rural areas. Research towards the exploitation of the data generated by such devices may lead to innovative citizen services and may ultimately help to trigger change in how we interact with the environment [3]. Means to exploit the continuously generated data, however, are still scarce. Availability of raw data can only be a first step, which has to be followed by enrichment with contextual information and careful processing to extract relevant insights.

Support efforts to provide public access to environmental information is a final key motivation for our work. The European Union (EU) Directive on public access to environmental information [4] mandates public access to and systematic distribution of environmental information through, for instance, Information and Communication Technologies (ICT). However, there are serious

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technical barriers that inhibit citizens from readily accessing environmental information. These barriers include (i) distribution of data among different agencies and lack of a single point of access, (ii) heterogeneous storage without standardized presentation, (iii) focus on static data without accounting for the increasing importance of real-time data, and (iv) lack of embedding of data within its “context”, that is, providing and utilizing additional information based on the surroundings of the data is currently not possible.

A platform that solves these challenges should exhibit characteristics including timeliness, accuracy, usability, scalability, and modularity. To the best of the authors’ knowledge, there is currently no solution for the semantic integration of heterogeneous environmental data sources in (near) real-time. Taking advantage of semantic technologies in this context appears particularly useful since it facilitates both data integration and query-driven reasoning based on formalized vocabularies.

This paper outlines the architecture of a web-based platform for managing workflows and dataflows of semantically enriched environmental data. The goal for the resulting information system is to show that Semantic Web technologies – ontologies to ensure data homogeneity and RDF stream processing techniques to obtain real-time information – are suitable tools for addressing information needs in the environmental domain.

As an example imagine moving to a big city, where nonstop traffic and pollution are a given fact. It would be useful to get insights in different air pollution data, i.e., carbon monoxide, ozone, or particular matter, based on real-time values, even being able to do comparisons among each other, or combine them with other static, e.g., traffic routes, or dynamic, e.g., weather parameters, knowledge. This could help finding new insights in how our immediate environment reacts on certain events. For instance, this could lead to changes in traffic behavior or even to traffic recommendations based on deduced facts. We propose a platform that is able to tackle such questions in a novel way by exploiting and combining Semantic Web Technologies and stream processing techniques. Our vision is a Smart City system capable of measuring, sensing, analyzing and presenting the environmental “pulse” of a city, i.e., measured via characteristics such as air quality, noise pollution, water quality, and traffic information.

We tackle three main challenges in this paper, i.e., to (i) provide data in (near) real-time to support informed decisions, (ii) integrate data originating from different sources and formats, and (iii) facilitate semantic querying of the integrated stream data following Linked Data principles.

The presented work shall be seen as “work in progress” since the corresponding platform[2] is still in its early stages [5]. Nonetheless, we proof our concept by means of initial use cases based on environmental data. The remainder of this paper is organized as follows. Section 2 introduces the architecture of the platform; initial results are described in Section 3 and Section 4 discusses related work. Finally, we provide conclusions and provide an outlook on future work in Section 5.

## 2. Architecture

The platform for data exploitation that the contributions of this paper are built upon is called *Linked Widgets Platform.* The term *Linked Widgets* was introduced by Trinh et al. [5] to describe an extension of standard widgets [6] with a semantic model, following the Linked Data principles. This semantic model describes the input and output graph of widgets and facilitates discovery and composition of widgets into mashups. The current paper extends the architecture of the platform [7] by introducing stream processing mechanisms embodied in *Linked Streaming Widgets*.

[2] See http://linkedwidgets.org (Accessed 17 July 2014)

Our framework rests upon semantic annotations that describe the data using domain vocabularies that can be used to integrate heterogeneous environmental data. Whereas the design of this platform is domain-agnostic, we focus on real-time environmental data and the particular challenges and requirements that arise in this area in the present paper.

Figure 1 depicts the architecture, including extensions that make the platform suitable for stream data. The constituent components can be grouped into three stages, i.e., (i) data acquisition responsible for tying in polling- and streaming-based data sources, (ii) data transformation where raw data is converted into time-annotated RDF triples, and (iii) data streaming which provides streams to end-user applications.

Widgets are used to register continuous queries at the processor component. Hence, they will subscribe to RDF streams and receive corresponding data. Linked Streaming Widgets, therefore, are defined as widgets that support continuous queries with added parameters used to subscribe to data streams.

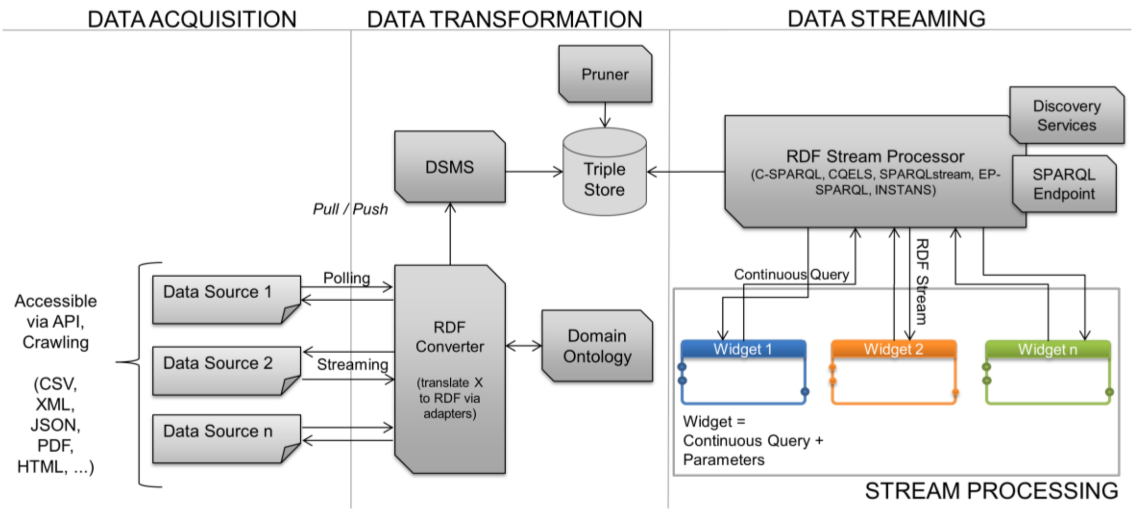


*Figure 1: Linked Streaming Widgets Architecture*

## 2.1. Data Acquisition and Data Transformation

Environmental data is available from various repositories, each providing unstructured, semi-structured, or structured data. In many cases, data is presented only on a webpage or via non-standardized interfaces. To allow for timely provision of data via our platform, such data has to be crawled on a regular basis. Data available in (semi)structured formats is more straight-forward to handle, but still needs to be converted into JSON-LD, a recent W3C recommendation [8] that we use as our internal data exchange format.

After conversion the data is fed into a Data Stream Management System (DSMS) and the triples are stored in a triple store. The RDF converter uses domain ontologies to enrich incoming data sources with semantic knowledge, which later will be utilized for features such as stream processing, or contextualized sensor discovery. The DSMS is dependent on the RDF stream processor implementation. Currently, we intend to use C-SPARQL as a stream processor which requires a semantic-aware DSMS, hence, the corresponding representation in Figure 1.

Data sources differ in type (rdf, json, xml, csv, pdf, html) and access (API, file download, manual crawling). As a means to overcome the resulting heterogeneity, ontologies have been used for many years. In the context of our proposed framework they are a valuable tool to define a comprehensive and standardized semantic model which is a prerequisite for semantic search as well as knowledge extraction from sensor-generated data.

Furthermore, differences in number and range of observed properties as well as update frequency (varying from stream data, i.e., real-time updated data, to hourly updated data) result in large variation in the amounts of data provided which has to be taken into account when evaluating implementation candidates for the RDF converter.

### 2.2. Data Streaming

Stage 1 results in semantically annotated observation data, i.e., RDF streams that can be presented to end-users. In the second stage, we provide (near) real-time data to the user.

We make use of the publish-subscribe design pattern, which controls what messages are sent by entities that publish data to receiving entities [9]. In the context of the proposed framework the main advantages are (i) loosely coupled widgets can act as publishers and subscribers, and (ii) by supporting parallel operations, message caching, and routing this pattern provides the scalability needed to handle flexible stream compositions on our platform. Consequently, it solves the first step in providing environmental data streams to users by allowing clients to subscribe to data streams dynamically.

Furthermore, due to the continuity and large size of data streams, storage is a key issue. To avoid bottlenecks in subsequent procedural steps, we need to define when data becomes outdated and can be deleted. The combination of static data sources (e.g., geographic maps, point-of-interest data etc.) with dynamic data streams improves the quality of new knowledge that can be deduced. However, this blending is non-trivial and major advances still need to be made in this area.

Finally, the architecture offers flexible exploration of the data as depicted in the stream processing area of Figure 1. We achieve this by allowing users to combine small information units, i.e., widgets. This enables users to answer questions based on environmental data. Via drag and drop, these widgets can be combined into mashups. A mashup can answer information needs, e.g., display points of interest that satisfy certain air quality criteria. Widgets can be combined in many different ways leveraging the modeled semantics.

We apply stream reasoning techniques provided through SPARQL extensions, i.e., windowing functions and federation of static data with dynamic streams and combine them with a widget-based approach. One widget represents a corresponding data stream. A web-based graphical interface allows users to assemble these widgets and set parameters for their processing functions. In doing so, users will have the power to efficiently explore arbitrary data streams.

These processing widgets have encoded queries based on stream-specific criteria, e.g., time windows or aggregates (*sum*, *count*, *average*, etc.), and therefore return RDF triples that answer this query, ultimately allowing hands-on combination of data streams. Presentation widgets provide mechanisms to visualize the intended output via, for instance, maps, bar charts, line charts, pie charts, or histograms. This step covers three aspects of leveraging data streams: (i) analyzing via continuous stream queries, (ii) publishing via returning RDF graphs, and (iii) visualizing via corresponding presentation interfaces.

### 2.3. Semantic Modeling of Stream Data

The semantic model acts as a component which is used to annotate data streams based on domain ontologies dependent on the field the data is coming from. For the environmental domain we have already identified special vocabularies and investigated possible integration into our framework as follows.

Since ontology reuse is one important principle of the Semantic Web vision, we evaluated existing ontologies in the field of sensors and measurements. Numerous ontologies were proposed with the goal to model sensor observations. Two approaches stand out: First, the Semantic Sensor Network ontology [10], which is the result of the Semantic Sensor Networks Incubator Group at W3C. This ontology aims at a top-down approach to model whole sensor networks including sensors, observations, sites, measurement capabilities, properties, features of interest, etc. Second, the RDF Data Cube Vocabulary has been widely adopted since its promotion to a W3C Recommendation, making it an official Web Standard [11]. This vocabulary is designed for modeling observations and measurements.

In our work, we will create a new vocabulary that combines these two approaches. There is some overlap in the available concepts of both ontologies (e.g., *observations* and *properties*). These can be used to link the vocabularies. For interlinking instance data, we consider well-known domain ontologies such as the Time Ontology [12], the Basic Geo Vocabulary [13], and SWEET [14].

## 3. Mashup Based On Linked Streaming Widgets

Figure 2 displays an example of a mashup that uses air quality data streams, i.e., carbon monoxide and ozone, as an input. The widgets on the left hand side act as a data source. Since they are used to register a continuous query at the stream processor (see Figure 1) the necessary parameters have to be defined. The size of the window (range) and the update frequency (step) can be specified. Moreover, the user can decide whether the returned values of the query should be aggregated (min, max, average). The *Stream Merger* is needed to fuse two data streams into a single result stream that can be handled by different visualization widgets, i.e., in this case the *Line Chart* and *Google Maps Widget*. The fusion process can also be used to apply additional processing steps, e.g., transformation, aggregation, or enrichment of the incoming streams. This mashup serves as a motivating example and therefore forms the conceptual basis for our proposed framework.

By applying this approach to environmental data streams, the platform can focus more on the needs and interests of users, e.g., streams can be discovered and used based on contextual information extracted from the stream's semantics. As a result the user may discover data in his proximity, based on his/her interests, time constraints etc. and combinations of these (e.g., air quality sensor observations of the last 30 minutes within 100m of the user). Discovery based on current values, aggregates (*sum*, *median*, *mean*, *mode*, *min*, *max*, etc.) or trends (increasing, decreasing, or stagnating) is another interesting opportunity. For instance, one may be interested in analysing and comparing the pollution values (air, water, noise) near his/her appartement based on a daily or hourly basis, hence, being able to identify dynamics inherent to the data.

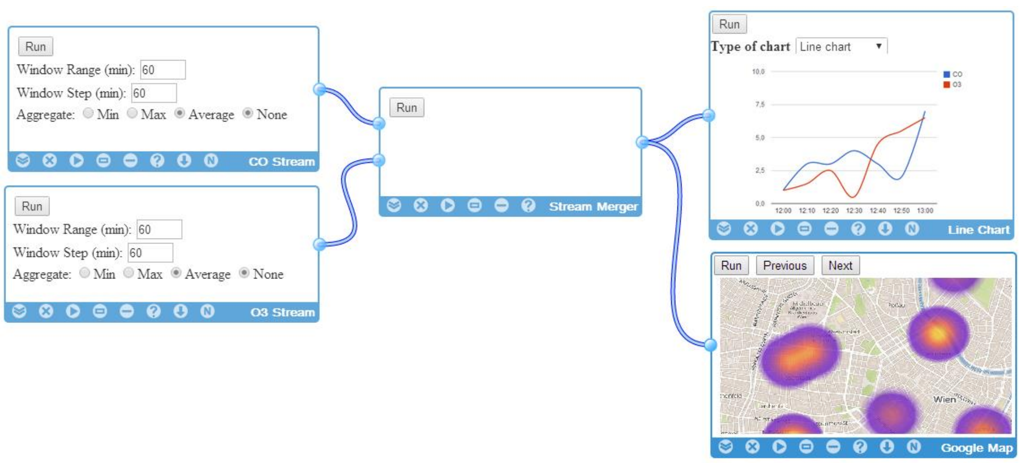


*Figure 2: Example of a Mashup based on Streaming Data*

## 4. Related Work

The amount of research in the field of semantic stream processing has been expanding rapidly in recent years. To this end, efficient means to process data streams based on semantic technologies are required in order to provide a powerful ontology-based query language utilizing continuous queries. Several approaches have recently been proposed: C-SPARQL [15], CQELS [16], SPARQLstream [17], EP-SPARQL [18], and INSTANS [19]. Moreover, a W3C RDF Stream Processing Community Group[3] has been formed to develop a definition of a common model for producing, transmitting, and continuously querying RDF streams. However, there is no complete system that supports the whole process from data acquisition to data utilization and enables flexible and efficient use of generic streams.

Balduini et al. [20] present an approach to identify events in a city leveraging a Streaming Linked Data Framework. In contrast to our work, they focus on social media, i.e., Twitter postings, as a data source. This both simplifies the semantic modeling of the data, and makes their approach dependent on geo-tagged tweets. Lastly, they do not fuse multiple social streams, but analyze a single stream at a time.

Lécué et al. [21] predict the severity of road traffic congestion using real-time heterogeneous data streams. The proposed approach is similar to ours, but focuses strongly on the traffic domain and on predictive reasoning, whereas our goal is to provide a generalized system that supports a larger spectrum of use cases.

Tallevi-Diotallevi et al. [22] present a real-time urban monitoring framework implemented for the city of Dublin. The authors extend CQELS and C-SPARQL to facilitate merging of CSV and RDF streams. Integration of other formats is not supported and explicit semantic enrichment and its subsequent utilization is not covered.

## 5. Conclusion and Future Work

In this paper, we propose a widget-based framework to explore environmental data streams in an urban context. We divide the approach into three stages and identify important issues that need to be addressed. These include defining a new vocabulary for environmental stream data deduced from already existing and well-adopted ontologies, and applying semantic stream processing methods to facilitate reasoning. Prototypical examples of interconnected widgets, i.e., a mashup, are explained and discussed and an architecture for a platform is outlined.

In the future, this system should serve as an open data platform for citizens of a “smart city”. The Linked Widgets Platform shall bring together both mashup developers and mashup users. For each of them, it should be as easy as possible to create, (re)use, modify, and execute available or newly created mashups. As a consequence, citizens will be enabled to interact with the available data sources, e.g., open data, linked data, tabular data, without having to worry about technical barriers such as unnecessary complexity while accessing data in different formats. New knowledge can be deduced and created by enabling creative (re)combination of available data. The vision is to provide a platform for dynamically building applications that leverage semantically enriched environmental data in a timely manner. Ultimately, this could lead to a better understanding of the environment in a local context of a city.

Future work will include implementation of a richer user interface that covers a larger number of use cases. Correspondingly, additional data sources and data input for the platform will be made available and integrated. Next to these implementation-oriented goals, we will need to find means to combine different types of data. We will also develop mechanisms to decide how long outdated

[3] http://www.w3.org/community/rsp/ (Accessed 8 July 2014)

triples will be stored and when they will be pruned. Balancing this tradeoff between being able to compare current values with historic data and the detrimental effects on performance represents an interesting challenge. Discovery Services for finding relevant sensors and data streams will be crucial as well. We will, thus, put our focus also on this aspect. In addition, as the RDF Stream Processing Group at the W3C is currently making progress towards defining a standard model for RDF stream data, we will follow this process closely.

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# Collaboration in spatial planning. Assessing the suitability and application potential of information and communication technologies

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## Abstract

This paper deals with the category of so-called wicked problems, characterized by a great deal of complexity and uncertainty. Problem-solving strategies focus on participation of stakeholders and on transdisciplinary approaches. In this context, communication and information technologies will play a crucial role. The paper describes the technological options and how they can be used under different conditions.


## 1. Introduction

Dealing with land use conflicts in the context of the “Energiewende”, finding a balance between competing claims or use for the available land for agriculture, nature conservation and residential development, the challenges associated with the introduction of new technologies or the development of climate adapted and resilient infrastructure systems are classic examples of so-called "wicked problems" - problems for which there is a low common understanding among stakeholders and also no clarity regarding the strategy to respond to such problems. Hence there will also be no "right" or "wrong" solutions, but only better or worse results [1-3]. Traditional planning and regulation approaches which are mainly based on a clear definition of objectives, an analysis of cause and effect relationships, forecasting and monitoring, seem to be less suitable to solve these problems [3-5]. To be successful, solutions must therefore be composed of a wide range of coordinated actions to respond to the multi-causal relationships.

Strategies have to take into account the strengths and weaknesses as well as opportunities and risks of the conflicting issues [6]. Such approaches have according to [7] the following distinguishing features:

- “holistic, not partial or linear thinking
- innovative and flexible approaches with a focus on creating a ‘learning organisation’
- the ability to work across agency boundaries
- effectively engaging stakeholders and citizens in understanding the problem and in identifying possible solutions
- additional core skills e.g. communication, big picture thinking and influencing skills and the ability to work cooperatively
- tolerating uncertainty and accepting the need for a long-term focus, no quick fixes, solutions may need further policy change or adjustment.“

In the context of the problems outlined, technical solutions will play a less prominent role in the future. The focus will be more on institutional and social concepts. In dealing with problem

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complexity and situations characterized by uncertainty and risks, new planning approaches arise, relying on cooperative procedures and transdisciplinarity. This holds especially for climate adaptation measures, which in general are more locally and regionally based compared to climate mitigation. An effective climate adaptation particularly depends on the participation of local actors and on the opportunities to exploit their specific knowledge and experiences. The need for a transdisciplinary approach obviously is quite clear, but so far the questions how such participatory processes should be organized and which supporting tools can be used, has not been analysed systematically [8]. It is evident, in this context to think about the use of information and communication technologies and new social media. But there have been very few studies dealing ssystematically with the questions whether, under what conditions and in what stages of a participatory process what technical options can be meaningful and purposeful. In the following sections these issues will be discussed in the context of the so-called living labs concept, a new and promising approach of transformation management.

## 2. The Living Lab Approach

The living lab approach is an emerging approach, which tries to tackle aforementioned challenges and to find answers to them. A literature review on living labs revealed that the living lab approach is mainly based on strong civil society (user) integration, strong involvement of many relevant stakeholder groups from science and business (transdisciplinarity) as well as the consideration of real life contexts through the examination of socio-ecological relations from different perspectives [9-12]. Living labs are platforms for research and innovation and for implementing practical solutions within real societal contexts (e. g. cities, districts, regions) and challenges (e. g. climate change, demographic change etc.) applied to the co-creation of policies, technologies, economical, socio-cultural as well as ecological solutions. They provide an institutionalized framework for transdisciplinary work between different stakeholders (e. g. residents, users, policy makers, local citizens, industry representatives as well as academics) with various concerns and interests. The aim is to develop solutions reasonable for the society, taking into account present conditions and future developments [11, 13].

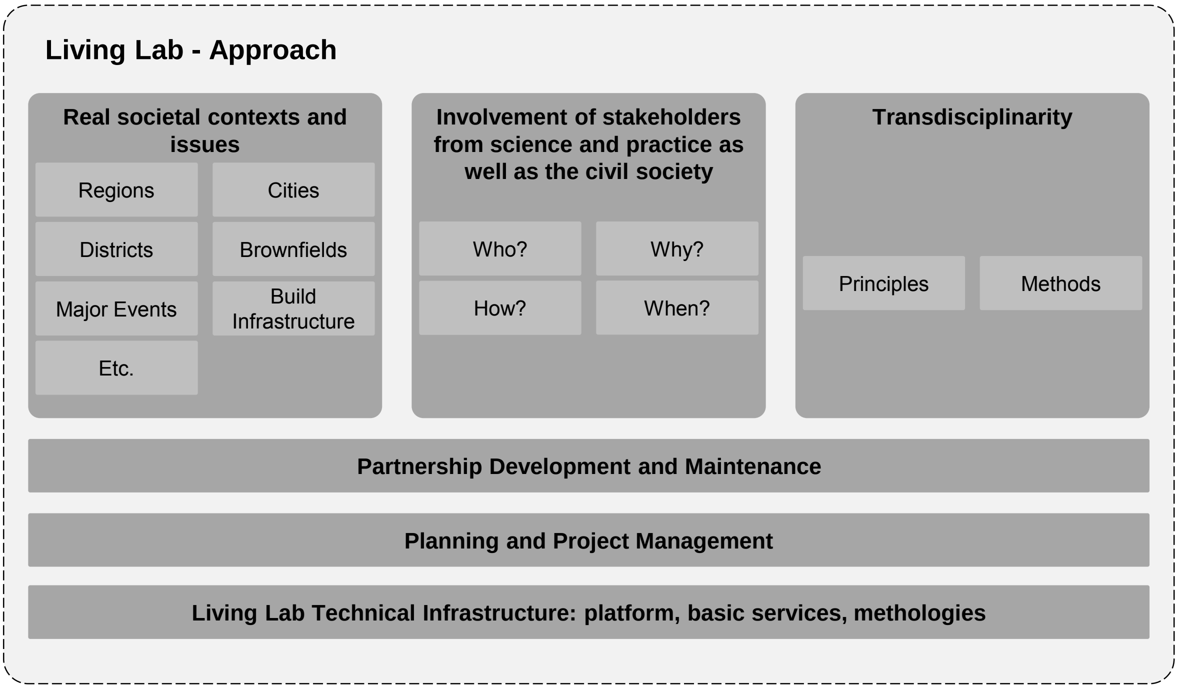


*Figure 1: Living lab components*

The platform in the context of living labs supports and arranges the innovation and planning process through value added activities. In doing so, the platform ensures time and space for innovation, the organization of innovation and planning activities, it supports the stakeholders in searching for and in the development of partnerships as well with the project management. Furthermore, the platform also provides the technical infrastructure, which facilitates the knowledge-transfer and collaboration amongst stakeholders. Finally, such a platform assists in elaborating the organizational, financial and cooperative arrangements between the participants [12, 14].

## 3. IT in the context of living labs

As previously shown the engagement of different stakeholder groups is one of the core elements of living labs. Especially land-use conflicts are characterized by heterogeneous stakeholder constellations and for this reason also by divergent interests: stakeholders from different industries and political levels, scientists from different disciplines, the civic society or planners to name but a few examples of possible constellations which come along with conflicts of interests, different knowledge and information stands, divergent perspectives and beliefs [15, 16]. In the light of the variety of possible stakeholder groups the question arises which stakeholders should be involved why, when and by which means [17-19]. During the consideration about the technical infrastructure of living labs it is obvious to examine to what extent the decision-making and the collaboration between stakeholders could be supported through information and communication technologies. On the one hand, decision support systems could be used to foster the decision-making process in order to ensure societal reasonable solutions, despite a diverse knowledge and database as well as interests amongst participating stakeholders. On the other hand, information and communications technologies could be used to facilitate the cooperative process itself. These technologies are primarily used for the knowledge and information transfer as well as for the mediation between stakeholders, to assure as much as possible social, ecological and economical concerns from different perspectives with the result of consensus-oriented and legitimized decisions [20]. These include software systems like groupware, collaborative software, e-collaboration, social software, e-participation etc. [21]. In order to not exceed the limits of this paper the focus hereinafter is on the latter category of technologies.

The application of information and communications technology in the context of cross-organizational co-working is especially in theory attributed with positive characteristics. These positive attributes are the increase of productivity and efficiency in the co-working, cost reduction, bridging of time and space dispersions, integration of several relevant stakeholders, absorption of suggestions from users, easier knowledge and information transfer etc. [21-23]. In reality, in 70 % of cases the application of collaborative information and communication technologies fails. According to [23] this is due to a lack of goal definitions and implementation strategies during the introduction of such software or technologies. Other reasons are the ignorance of already existing applications, the low controllability by users or simply the ignorance of critical aspects. Hence a systematically approach for the right chose of process and organizational relevant technologies seems to be necessary [21-23].

### 3.1. Selection criteria

Each phase of the living lab process is concerned with different stakeholder constellations and therefore with different knowledge bases and requirements in general, which need to be considered during the process [24]. Therefore, it is critical to consider in which way the different stakeholders are going to participate during the process, which time and space disparities have to be overcome and which of the potential tasks can be supported by collaborative technologies [21, 25].

Stakeholder participation can happen in different ways. According to Arnstein´s ladder of participation [26],[17] distinguish between five participation levels: presentation and explanation of the project to the stakeholders (inform), stakeholders can make suggestions which are not taken into account (consult), stakeholders can make suggestions which are taken into account (collaborate), stakeholders cooperate with each other towards an agreement for solutions and the implementation (co-decision) and the decision process can be delegated to the stakeholders during the entire process (empowerment). Each participation level has implications for decisions pro or contra a certain technology, like blogs, wikis, project management software, share points, e-participation etc.

Besides the participation level it is also crucial time and space disparities, which are possible during the process. The cooperation, for example, can take place within the same spaces or across different spaces. Collaboration between stakeholders can also be synchronous (at the same time) as well as asynchronous (at different times). The combination of time and space implications results in the time-space matrix diverse requirements to the collaborative application [27].

Different use cases are only one aspect for the decision for or against a certain application. Application assessment should also be performed at the organizational-technical as well individual-technical level. At the organizational-technical level it is about how the application meets the needs of the potential tasks and of the organizational environment, does the organization have the required resources to buy and to run the software, to conduct training courses or even to moderate the application. In the context of the individual-technical level it is crucial to consider if the project employees and the potential operator are willing and able to apply a certain application and what could be possible barriers to use the application on the individual level [21, 28].

### 3.2. An approach for the technology selection

A decision for or against a certain collaborative application should not only rely on its technological attributes, but rather consider several aspects as mentioned in the previous section. In the literature several approaches exist to assess a certain technology. Most of these approaches set out from the technology´s point and therefore only examine how the technology meets the requirements of a certain task [21]. Several scientists stress that the assessment of so called "technological fit alone" is not appropriate to justify the application of a technology during a collaboration or participation process. Rather it is essential to consider the availability of existing resources on the individual as well as organizational level. Therefore, they propose the application of the fit-viability approach [21]. The fit-viability approach was development in the e-commerce sector and later adopted for the application of mobile technologies as well as web 2.0 applications in the entrepreneurial context [21, 28, 29]. Such an approach includes two important components: a) Consideration of the possibilities, which come with the usage of a certain technology and b) assessment of the required realization aspects and of the potential challenges, which could appear if a technology is implemented [21,28]. In accordance with [21] the following procedure is suggested to utilize the fit-viability approach:

- **Analyse existing technologies:** Examinating which collaborative technologies exist, what are the contexts to utilize them, which resources and infrastructures are necessary and what are the advantages and disadvantages of a certain technology;
- **Determine the collaboration context:** Here it is useful to draw on the data from the stakeholder analysis as well as on the conceptual approach of the project. The objective is to anticipate which stakeholder groups participate when and in which way during the project and what are the requirements of the collaborative application;

- **Determine the fit between technologies and the collaborative tasks:** At this level the insights from both previous phases are consolidated. Thereby it is possible to use a scoring system to assess how far a certain technology meets the requirements of the collaborative tasks;
- **Analyse economic viability of the technology:** After the first screening an assessment of the economic viability is conducted. It is essential not only to consider the procurement costs, but also the costs of possible trainings, costs of maintenance, the compatibility with existing software tools etc.;
- **Identify necessary IT infrastructure:** Verifying to what extent the existing infrastructures are sufficient to run a certain technology. If the existing IT infrastructure is not sufficient, when it is necessary to identify which adjustments are needed to run an application. Here it is imperative to consider the infrastructure of all potential participants;
- **Examine the human factors:** Even if a technology makes sense from an organizational point of view, it is crucial that for potential users the need and advantages are also evident. An implementation of technologies is useless if the users are not ready or able to utilize it. Training courses could be useful to overcome technology inhibitions or to foster the acceptability;
- **Define a deployment strategy:** Here, a plausible implementation plan and the performance measures are developed. The previous phases provide here a guiding framework. Basically one can say: A technology with a low rated fit should not be implemented; at a high fit and low viability it is necessary to consider which measures could increase the viability;
- **Evaluate the technologies:** Finally, the application of the technology should be evaluated. In addition to the results, the evaluation design should also assess the process itself. While the results measure the effectiveness, the process evaluation measures, if and to what extent the collaboration process contributed to the efficiency of the process and to the satisfaction of the participants with process.

Using the recently introduced approach it is possible to assess the need and the applicability of collaborative technologies within cross-organizational projects. The approach presented here is intended to be used and evaluated within the cross-border and cross-organizational project "Climate Adaptation in Living Labs: Integrative Spatial Strategies".

## 4. Climate adaptation in living labs: a project proposal

"Climate adaptation in Living Labs: Integrated Spatial Strategies" is a pilot project with the focus on the conceptual foundations for a long-term oriented, cross-border cooperation between the Netherlands and Germany. This INTERREG IVB project is supported by three German and Dutch municipalities and by two research groups. The common problems studied are land use conflicts due to the growing demand of the agricultural sector, the energy and water industries, new infrastructure projects and nature conservation commitments. In the future, decisions on land use will be more complex due to new challenges caused by climate mitigation and climate adaptation. Current plans include, inter alia, the construction of new tidal polders to reduce the risk of floods in the Ems region. This of course would increase the pressure on the land market and will face both policy-makers as well as land owners with new challenges.

The objective of the "network project" is to create the foundations for a cross-border long-term knowledge sharing and new forms of cooperation under real laboratory conditions. A network of spatial planners, policy-makers, the local population, of the economic representatives and of scientists has to be set up to establish a concept for a cross-border real lab, in which innovative strategies, new procedures and standards as well as new planning approaches can be tested and implemented. Intensifying the transfer of experiences and knowledge is seen as a way to better understand the specific challenges in conjunction with risk management, climate change impacts and adaptation to climate change and the demand for regionally-specific optimization. It is of central importance to the realization of the project idea that the participation and cooperation between stakeholders each with different experience levels, decision-making competences and interests and integrated in very different political and institutional structures and planning philosophies can be implemented in a systematic way.

These challenges are also reflected in the project structure. First, a kick-off meeting means that the cooperation of all players will take place at the same time in one location. The focus of the project is on workshops on both sides of the border; that means that meetings will be organized at different times and spatially separated. The exchange of information and experience across the border and between different actors therefore should be organized by using a kind of virtual platform. The challenges resulting from this project structure will have an impact on the technologies that could be used as part of the platform. The approach presented in the chapters above, can be used to determine and to select the appropriate technologies. The use of blogs, wikis, forums and other social media is conceivable to involve as many stakeholders as possible. The integration of the local population can also be supported by the implementation of e-participation applications. The use of groupware applications will be helpful for project management. On a conceptual level it needs to be clarified:

- which of the potential actors should use this platform;
- which functions and what degree of participation the platform should provide or allow (inform, consult, collaborate);
- and whether the use of the platform can be restricted to the lifetime of the project or should be implemented as an instrument of long-term, institutionalised cooperation.

Finally, the special challenges and barriers regarding the feasibility of the approach have to be taken into account. Due to the limited duration of the project, the technical options should be put into practice quickly and easily and the platform should by moderated by a project partner so that there is no need for the use of experts. From an economic point of view, it should be checked carefully, whether there are potentials to use the platform in other applications outside the project.

Particular challenges may arise from the fact that in rural and economically weak areas the technical prerequisites do not exist (access to broadband) and in general the willingness to use and the acceptance of an internet-based cooperation could be low. In this particular project linguistic barriers may exist, but due to a great deal of experiences of cooperation this should not be an obstacle to a successful cross-border activity.

## 5. Conclusion

The paper’s objective was to make clear that current and future land use conflicts constitute a problems that are characterized by a great deal of complexity and exhibit characteristics of wicked problems. Based on the project proposal different ways to use information and communication technologies in participation and collaboration processes have been discussed. It remains to be seen how the use of these technologies will develop under practical conditions. It is important to point out the need for a systematic analysis of the underlying problem and to present an overview of the relevant stakeholders; their interests and interrelationships in order establish the framework conditions for the use of the new technologies and not to implement them only because they are available.

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# Regional Carbon Footprinting for Municipalities and Cities

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## Abstract

This paper describes a methodology to account and attribute greenhouse gas emissions on a regional level. Regional greenhouse gas (GHG) inventories support the development and monitoring of climate change mitigation and adaptation strategies and policies for municipalities and cities. However, information and scientific expertise on climate change impacts are complex and a consensual and consistent methodology on formation of regional GHG inventories is still missing. Available methodologies and calculation tools mostly fail to balance scientific adequacy and usability from a pragmatic perspective. Within the project Regional Carbon Footprint (RCF), software that allows data management (i.e. for bottom up data) in order to calculate regional greenhouse gas inventories and to report about regional carbon footprints has been developed. Efforts needed for data collection turned out to be the main bottleneck for application from a practitioner's point of view. The RCF approach overcomes these shortcomings by closing this gap with the use of top down data taken from statistics.

## 1. Background

In May 2013, the carbon dioxide emission level passed 400 ppm for the first time since measurements began at Mauna Loa Observatory in Hawaii[3]. Several emission forecasts found that trends in GHG emissions are likely to cause global warming in the range of 3.5 to 5 degree Celsius by 2100 [1] [2] [3] which is related to “dangerous” and “extremely dangerous” climate change impacts [4]. In recent years, the European Union and several countries set relatively ambiguous targets for GHG reductions that consequently affect policies at the regional and local level. An increasing number of cities and regions developed climate change policies and climate action plans, e.g., within the framework of the Leipzig Charter on Sustainable European Cities, the Covenant of Mayors or the European Energy Award. However, regional and local climate change actions require observing GHG emission sources in order to identify potential reduction measurements and to monitor their implementation. While there are complex models on anthropogenic climate change available on the global scale, there is no consensual and consistent methodological GHG accounting standard for smaller regions. Various existing tools fail to balance scientific adequacy and pragmatic usability. For that purpose, the present paper describes a “Regional Carbon Footprint”-software as a basic instrument for local and regional climate change management and energy concepts.

## 2. Methodology

The methodology to calculate Regional Carbon Footprints (RCF) refers to the indicator carbon footprint that is used to indicate the amount of greenhouse gas emissions related to the life cycle of products or to activities of organizations, individuals or – as in case of RCF – populations. Carbon footprints refer to the global warming potential (GWP) of different greenhouse gases and are given

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in $CO_2$ equivalents. The GWP characterizes the effectiveness of a certain GHG in influencing radioactive forcing and absorbing infrared radiation reflected from the earth surface [5]. The conversion to $CO_2$ equivalents allows comparing the effect of specific GHG relative to $CO_2$. According to the IPCC methodology for national greenhouse gas inventories [5], the RCF is calculated in different sectors (energy, electricity and heat, transportation, industrial process emissions, agriculture and aggregated sources, waste, atmospheric deposition) according to

$$RCF[tCO_2] = activity\ rate\ \cdot emission\ factor\ . \quad (1)$$

The activity rate describes relevant anthropogenic or natural activities causing emissions of GHG [kg $CO_2$ equivalents], i.e., electricity demand [kWh] per household, kilometres driven by car [pkm], renewable energy converted by PV [kWh] or production output [kg]. An emission factor is a coefficient, expresses the GWP [kg $CO_2$ equivalents] of this activity, i.e. GHG caused by electricity demand and so on. Emission factors are given by different institutions, while there is no convention how to select which emission factor.

## 2.1. System boundaries, scopes and sectors

Obviously it is necessary to define system boundaries and scopes before calculating carbon footprints. The temporal system boundaries usually enfolds the period from the recent year back to 1990. All calculations are therefore related to the year 1990, which refers as base year also in most international conventions and regulations such as the UNFCC. The spatial system boundaries are given by territory of municipalities or administrative districts. However, it is necessary to determine boundaries related to the question (i) which and (ii) whose emissions will be included in the analysis.

*Ad (i): Which emissions are included?*

In order to calculate the Regional Carbon Footprint, an inventory of anthropogenic emissions is needed. Although there are also natural effects, the global climate systems, e.g. clouds and water vapour, have both major effects on radioactive forcing.

| **Greenhouse Gas** | **GWP-100** | **GWP-100** | **Applications/sources** |
|---|---|---|---|
| Carbon dioxide ($CO_2$) | 1 | 1 | combustion of fossil fuels in electricity generation and transportation, production and consumption of cement and other mineral products, production of steel and iron and ground chemicals |
| Methane ($CH_4$) | 25 | 28 | production, processing, storage distribution of natural gas, digestive processes of domestic livestock (cattle, sheep, goats), storage of manure, emissions from landfill waste and treatment of wastewater |
| Nitrous oxide ($N_2O$) | 298 | 264 | Use of synthetic fertilizers, breakdown of nitrogen in livestock manure and urine, byproduct of nitric acid production, burning of transportation fuels |
| Hydrofluorocarbons (HFCs), haloalkanes | 124-14800 | 59-12400 | flame retardants, fire extinguishants, insulating foams, refrigerants, propellants, solvents, and pharmaceuticals |
| Perfluorocarbons (PFCs) | 6500-9200 | 7390-17700 | fluoropolymers, refrigerants, solvents, medical uses (anesthetics, liquid breathing, blood substitute, contrast-enhanced ultrasound, eye surgery, tattoo removal), cosmetics, organic rankine cycle, flourous biphasic |

| | | | |
|---|---|---|---|
| | | | catalysis |
| Sulphur hexafluoride ($SF_6$) | 22800 | 23500 | tracer gas, insulator gas in high-voltage switchgears and microelectronic circuits, filling gas in insulating glass panes and sport shoes |
| Nitrogen trifluoride ($NF_3$) | 17200 | 16100 | DRAM computer memory production, manufacturing of flat panel displays, large-scale production of thin-film photovoltaic cells (Prather 2008, Tsai 2008) |

*Table 1: Greenhouse Gases covered by the Kyoto Protocol after Doha Amendment [6] [7]*

However, only man-made emissions of greenhouse gases (GHG) covered by the Kyoto protocol are considered here. GHG originate from a variety of anthropogenic activities (see Table 1), which are classified in different sectors and subsectors:

- Energy (electricity and heat)
- Mobility and transport
- Industrial processes
- Agriculture and forestry (digestion, fertilizer consumption, land use and land use change, atmospheric deposition and aggregated sources)
- Municipal waste and waste water treatment.

The most important sectors, and therefore the ones to put most attention to in terms of feasibility of data collection, are energy and mobility. The other sectors are rather specific and not in every municipality or city applicable or of importance. Therefore, the emissions on those sectors are roughly estimated based on statistical data from national GHG inventories.

*Ad (ii): Whose emissions are included?*

In order to use the results of a RCF study in regional politics and decision making it remains unavoidable to become aware on responsibilities according to the “polluter-pays”-principles as well as about the possibilities, i.e. the scope and freedom of action that is given to a municipality. There are different accounting approaches in use to assign emissions to the origin or initiator [8] [9]:

- *Approach (A)* is taking into account all direct GHG gases emitted in the region based on an emission register. Imported and exported goods and related GHG emissions are, however, left unconsidered. This form of source-oriented-accounting (so called “Quellenbilanz”) is based whether on production data or emission registers such as E-PTER. It allows conclusions regarding total GHG emissions caused mainly by energy conversation, combustion of fuels or production processes in a defined territory. However, only little reference is made to opportunities mitigating climate change by political measures, as individual and collective behaviour (i.e. consumption of energy, choice of mobility modes etc.) are not considered.
- *Approach (B)* is focussing on GHG emissions that are consequences of consumption (and not production). GHG emissions are calculated based on end-user consumption, i.e. final energy consumption, electricity and heat. It is therefore an activity-based-approach (“Verursacherbilanz”), based on consumption.

The territorial approach (approach A) is common to be used in international and national statistics. However, there seem to be drawbacks as illustrated within the energy sector: If in a certain region less energy is consumed than produced, all GHG emissions are allocated to the region itself, although the electricity generated in the region is exported and consumed elsewhere. For example, a large scale coal power plant such as Vattenfall Europe’s “Schwarze Pumpe” (1600 MW) emits around 12 billion t CO2 annually[4], while the share of electricity consumed in the region is merely about 6% [10]. To avoid this castigatory allocation, it is therefore necessary to combine both methodological approaches at least in the electricity sector. Basically, it remains to be an "activity based approach", but actual GHG emissions are considered by applying emission factors corresponding to the regional or national electricity mix. GHG are also occurring for so called low-carbon technologies such as photovoltaics or wind generators. Thus, emission factors for those technologies are applied, too. The amount of electricity from renewable sources is considered to be consumed within the region and allows distributing a "green bonus". Citizens, regional decision makers and stakeholders only have limited potential to mitigate emissions caused for example by large power plants in the territory. Respecting the limited mitigation potential and/or the feasible scope of action of a municipality, the concept of scopes is common in GHG accounting of organisations. The following scopes are considered in this paper:

- Scope 1 compromises only GHG emissions that are directly linked to activities by the public authorities, such as energy consumption in public buildings, fuel consumption by car fleet etc. This scope is obviously.
- Scope 2 includes all direct GHG emitted in the region, including generation of electricity from fossil and/or renewable sources; inventories are developed according to approach A.
- Scope 3 includes indirect emissions which result from individual and collective activities in the region such as consumption of electricity and fuels, heating etc.

It might be useful to add another scope in order to integrate exported/imported goods and other indirect emission into a more reliable assessment of GHG emission caused by human activities. Again, the scope of action of municipal decision makers is limited as local authorities can hardly control or influence those indirect emissions caused for example by private cars or industrial production.

### 2.2. Sector energy

Energy conversion, i.e. combustion of fossil resources and consumption of electricity and heat was responsible for 42% of all GHG emissions worldwide in 2011 [11]. Due to this fact, climate mitigation policies focus on de-carbonisation of this sector, i.e. by fostering a fuel switch to renewable and therefore climate neutral or nuclear energy carriers and sources. According to the general formula, GHG emissions are calculated as

$$RCF_E\,[tCO_2] = \left(C_{e,mix} \cdot EF_{e,mix}\right) - B \qquad (2)$$

with

$RCF_E$ Regional Carbon Footprint, sector electricity,

$C_{e,mix}$ consumption of energy [kWh],

$EF_{e,mix}$ emission factor, electricity mix and

$B$ bonus for electricity generation from renewables.

The activity rate represents whether production or consumption of electricity and heat [kWh] is based on specific data from local suppliers or from statistics and is then multiplied with specific emission factors. Local authorities require that local generation of electricity by renewable resources should be integrated in the calculation of the GHG inventory. Therefore a "green bonus" or "green credit" is given, that is calculated as

[4]according to E-PRTR; beside other air pollutants such as HCl, Pb, Hg, Cd, As

$$B\ [tCO_2] = \sum G_i \cdot EF_{e,i} \tag{3}$$

with

$B$ bonus for electricity generation from renewables [t $CO_{2\text{-eq.}}$],

$G_i$ electricity generation from renewable energy [kWh/a] and

$EF_{e,i}$ emission factor, specific for the energy carrier.

The following assumptions apply [9]:

1) Electricity generated from renewable resources which is fed into the low and mid-high-voltage grid is considered as being used in the region. An adequate bonus as green credit is given without taking into account any electrical line losses, which leads to an inherent bias, as losses depending on the voltage level amount up to 6% [12]. Taking renewables from the region into account is, however, not compliant with the approach by the Conveyant of Mayors [13], which includes only generation facilities which are owned or controlled by local authorities. Still, fostering green energies are presumably the major contribution to regional climate mitigation, though the contribution of municipal decisions is controversial.
2) If electricity generated in the region, i.e. by large scale power plants, exceeds local production, the difference is calculated with a specific emission factor, depending on the conversation technology, conversation efficiency and energy carries used.
3) If there is no large scale power plant in the territory under consideration, the difference between local production by renewables and electricity demand is considered as correlation with a national emission factor according to the national electricity mix. Double counting, i.e. local electricity generation from renewables and the share of renewables in the national electricity mix are considered as marginal [9].

GHG emissions related to the consumption of space heating occur mainly due to fossil fuel combustion (i.e. natural gas, LPG, hard coal, lignite or oil). CHP facilities within municipalities, which are producing electricity and heat for district heating systems, are also included by applying a specific emission factor $EF_{h,i}$. This emission factor comprehends different energy carriers according to a distribution formula, which represents heating systems structure in Germany,

$$RCF_H\ [tCO_2] = \sum C_h \cdot S_i \cdot EF_{h,i} \tag{4}$$

with

$RCF_H$ Regional Carbon Footprint, sector heat,

$C_h$ heat consumption in the municipality [kWh],

$S_i$ share of energy carrier/ heat production system of total heat consumption in Germany [%],

$EF_{h,i}$ emission factor specific to the energy carrier or heat production system.

GHG emissions considered here include merely heating in buildings by small-scale heating installations and meso-scale district heating systems. However, emissions due to water heating and cooking are not included as they are considered as marginal. Process heat used in industrial processes, i.e. steam, is supposed to be provided by large scale CHP generation plants and is therefore considered in the subsector electricity.

## 2.3. Mobility and transport sector

The transport sector is responsible for 22% of global GHG emissions. Emissions from ground transport have increased drastically by 52% since 1990. They accounted for about 75% of all emissions in this sector in 2011. A robust assessment of mobility related GHG emissions would make it necessary to include the extent, i.e. kilometres driven by each mode of transport (i.e. ground transportation by different means such as public transport by trains, trams and busses as well as individual transport by cars and freight transport, aviation and cargo transport by ships), which is very specific to the regional context, i.e. demographic development, urban or rural region, availability and attractiveness of public transport. An empirically sound and regional specific data set would be desirable which is based on regular traffic counting. However, there are different approaches to allocation and attribution of responsibility, related different methodologies of source-oriented-accounting and activity-based-accounting. It remains controversial, how commuter transport or long distance freight transport should be attributed to different territories. In the light of controversial methodological approaches, limited availability of context specific data, and limited scope-of-action of municipalities, a more generic approach is sufficient and rational. Transport sector emissions are therefore calculated based on the number of registered vehicles $N_i$ in the municipality, average annual mileage $M_i$ and mode specific emission factors $EF_{t,i}$ according to

$$RCF_T\ [tCO_2] = \sum N_i \cdot M_i \cdot EF_{t,i} \tag{5}$$

with

$RCF_T$ Regional Carbon Footprint, sector transport and mobility,

$N_i$ number of vehicles in category $i$,

$M_i$ milage in category $i$ and

$EF_{t,i}$ mode specific emission factor.

### 2.4. Remaining sectors

The remaining non-energy sectors are very specific and not in every case directly related to the municipality or city under analysis. The effort for collecting data to compute emissions is comparably high, but the relevance for decision making is limited. If there is, for example, not much industrial or agricultural activity causing GHGs, it is rational to minimize efforts in quantifying the emissions. If it can be expected that GHG emissions are decreasing anyway, e.g. waste legislation in Germany prevents land filling of organic material and resulting methane emissions, it is rational to assume declining emissions in this sector without further need for action. However, these sectors should not be neglected as they are of relative importance with a share of approx. 30% [14]. Therefore the recent version of the RCF software applies a top-down method to capture GHG emissions from the following sectors:

- industrial processes, i.e. due to production of mineral products such as cement, usage of solvents, insulating foams, refrigerants or filling gases in switchgears or applications in microelectronic circuits, usage of bitumen in asphalt coating and roofing, glass and ceramic production, etc.;
- agriculture and forestry (i.e. digestion, fertilizer consumption, land use and land use change, atmospheric deposition);
- municipal waste and waste water treatment.

The specific GHG emissions in those sectors are estimated by downscaling statistical trends at national level [15] via the number of inhabitants for each year

$$RCF_x\ [tCO_2] = \left(\frac{E_{total,x}}{P_{GER}}\right) \cdot\ P_{region} \tag{6}$$

with

$RCF_x$ GHG emissions in a sector $x$ [t $CO_2$],

$E_{total,x}$ total GHG emissions in a specific sector [t $CO_2$].

$P_{GER}$ number of inhabitants in Germany [N] and

$P_{region}$ number of inhabitants in the region [N].

The main disadvantage of this top-down approach is obviously that municipalities are accounted for GHG emission also if there are no industrial facilities or agricultural activities. However, a burden-sharing-principle is executed implicitly, when the overall emission from the sectors is allocated to all inhabitants in Germany. Although credibility and accuracy of the results is therefore rather low compared to bottom up calculations with specific regional data, the estimations at least contribute to the requirement of completeness of the GHG inventories. Suggestions for a more sophisticated treatment of the sectors are given in [9].

## 3. Implementation

The regional carbon footprint software, including the calculations described above, has been implemented as a prototypical web application [16]. The current software prototype is basically a data management tool, consisting of three main parts. First, there is an administration environment for municipalities, including master data maintenance. Second, there is a representation of the data input process. Third, there is a report generation module. The input by the user is based on the sectors described in Section 2. Due to the persistent storage in a database, it is possible to monitor the progress over the past years and track any improvements. For calculation, there are several statistical information and background values required, which are available in the system's database for recent years. Therefore, a management environment within the RCF-software is needed to update these values for upcoming years. By finishing the input process, a comprehensive report, which is available in different formats, is automatically generated. The basic data model has a dynamic nature, so it is always possible to add additional input fields easily via the administration environment, e.g., a new type of renewable power plant. By doing so, the software adds both, the report input fields and an appropriate background value administration depending on the sector to which it was added. Thus, it is possible to adapt the elementary report to future conditions within existing sectors without further implementation effort.

## 4. Conclusion and future work

A capable methodology and corresponding software solutions to calculate GHG inventories are essential to achieve climate goals. In the project described in this paper, we developed a methodology to calculate regional carbon footprints. It turned out to be particularly complex to find a good trade-off between scientific adequacy and good applicability of such a strategy. The model has been implemented as a prototypical web-application and has been applied for several municipalities in Saxony.

Future work includes the development of methodological extensions and their implementation as supplementing software modules. This comprehends the implementation of a scenario analysis component in order to allow projections of potential benefits of climate action plans. Scenario analysis is particularly important for evidence-based decision making processes, concerning the future developments and provisions in municipalities or cities and for the further reduction of the GHG emissions. Further, the direct integration of remote monitoring facilities of municipal buildings is intended.

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# Extending Energetic Potentials of Data Centers by Resource Optimization to Improve Carbon Footprint

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## Abstract

The electric power is one of the major operating expenses in data centers. Rising and varying energy costs induce the need of further solutions to use energy efficiently. The first steps to improve efficiency have already been accomplished by applying virtualization technologies.

In this paper, we address the problem of energy efficiency in data centers. Efficient and scalable power usage for data centers is needed. We present different approaches to improve efficiency and carbon footprint as background information. We propose an in-progress idea to extend the possibilities of power control in data centers and to improve efficiency. Our approach is based on virtualization technologies and live-migration to improve resource utilization by comparing different effects on virtual machine permutation on physical servers. It delivers an efficiency-aware VM Placement by assessing different virtual machine permutation.

## 1. Introduction

The IP traffic increases year by year worldwide. New Information and Communication Technology (ICT) services are coming up and existing services are migrating to IP technology, for example, VoIP, TV, radio, and video streaming. Following these trends, the power consumption of ICT obtains a more and more significant value. In the same way, data centers are growing in number, size, and their share of electric power consumption in order to comply with the increasing demand. The data center's power consumption has doubled in the period 2000-2006 [13]. Energy costs rise continuously and the data center operators are faced with customer questions about sustainability and carbon footprint while economical operation is an all-over goal. The electric power consumption has become one of the major expenses in data centers.

A high performance server in idle-state consumes up to 70% of its peak power [14]. To reduce the quantity of servers in idle-state, virtualization technologies are used. Virtualization technologies allow several virtual machines (VMs) to be operated on one physical server (PM). In this way the number of servers in idle-state can be reduced to save energy [9]. However, the rising energy costs lead to a rising cost pressure and further solutions are needed.

This paper is organized as follows. Section 2 motivates and defines the problem of energy efficiency and integrating renewable energy in data centers. Section 3 gives background on approaches relevant to energy efficiency, virtualization technology and improving the carbon footprint. In Section 4 we present the resource-efficient and energy-adaptive approach. Lastly, Section 5 concludes the paper with comments on our progressing work.

## 2. Problem definition

The increasing amount of IT services places even greater demands on data centers and energy costs are rising. These conditions induce the need to operate a maximum number of IT services with

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minimal employment of resources, since the aim is an economical service operation. Therefore the effectiveness of the invested power should be at a maximum level. In this paper, we focus on the server's power consumption and define the efficiency of a server as the work done per energy unit [11].

In the related work part of this paper, we show different kinds of approaches in the context of energy consumption, energy efficiency, and integrating renewable power. In this research approach, we want to explore, which further options exist to use energy efficiently and how we can take effect on the data center's power consumption and, finally, to adapt to volatile renewable energy. The share of volatile renewable energy increases which causes a larger dynamic of the available power. To deal with variable power availability we need an approach that ensures controllable power consumption beyond general energy efficiency. We need to improve the efficiency of the data center using an intelligent and efficient VM placement in order to adapt to volatile energy availability, and improve carbon footprint while keeping the overall goal to use the invested energy as efficiently as possible.

Some approaches use geographically-distributed data centers to schedule the workload across data centers with high renewable energy availability. This methodology is only suitable in big, geographically-spread scenarios and the overall power consumption stays not affected. Hence, we do not pursue these approaches. In general, many approaches are based on strategies with focus on CPU utilization because CPU utilization correlates with the server's power consumption directly [5]. The utilization of other server components does not have such an effect on the server's power consumption. However, the application performance depends not only on CPU usage, but all required resources are needed for optimal application performance. Hence, the performance relies on other components too and we also want to focus on these other components such as NIC, RAM, and disk I/O to improve the efficiency, especially if their utilization does not have an adverse effect on the server's power consumption. Our assumption is that the optimized usage of these resources is not increasing the power consumption.

There are different types of applications; some applications work stand-alone, others rely on several components running on different VMs. The components of the latter communicate via network and the network utilization takes effect on such distributed applications. In our approach we want to include these communication topology topics. However, the applications' requirements are changing during operation, sometimes in large scale and in short intervals. Therefore, we need an online algorithm that acts at runtime to respond to changing values. We need to keep obstacles at a low level by acting agnostic to the applications. The capable approach should be applicable without need to change the operating applications.

## 3. Related work

Power consumption and energy efficiency in data centers is a topic on which a lot of work has already been done. In this section we give an overview of different approaches.

The usage of low-power components seems to offer solutions for lower energy consumption. Meisner et al. [7] handled the question whether low power consumption correlates with energy efficiency in the data center context. They discovered that the usage of low power components is not the solution. They compared low power servers with high power servers and defined the energy efficiency of a system as the work done per energy unit. They achieved better efficiency with the high power servers and found that modern servers are only maximally efficient at 100% utilization.

Another potential for improvement is to let IT requirements follow energy availability. There are some approaches [2, 4, 6] that use local energy conditions. They migrate the server workload to data center destinations with renewable power availability. These ideas are finally only suitable for distributed and widespread data centers. Data center locations at close quarters typically have the same or not significantly different energy conditions.

A different idea is mentioned by Krioukov et al. [3]. A scheduler has access to a task list, where the task with the earliest deadline is on the top. This is an earliest deadline first (EDF) schedule. If renewable energy is available, the scheduler starts tasks from the top of the task list to use the renewable energy. If less energy is available, tasks get killed. In such approaches, we have to deal with application-specific topics. To build a graded list of tasks to schedule, we need to know how long a task needs to be processed and we need a deadline for each task to be processed. Tasks get killed at less availability; this leads to application-specific issues to resolve afterwards.

Tang et al. [1] propose thermal-aware task scheduling. The ambition is to minimize the cooling requirements and to improve the data center efficiency in this way. They set up a central database with server information, especially server heat information. An EDF scheduler is placing tasks with the earliest deadline on the coldest server. Thus they avoid hot spots and the cooling requirement can be decreased to improve efficiency. The usage of a graded task list is also needed with the same disadvantages as described before. To avoid handling with application-specific topics the virtual machine is a useful container to place IT load instead of explicit application tasks. In many approaches, for example Corradi et al. [9], power consumption is reduced by concentrating VMs on a fewer number of servers, and switching off unused ones to save energy. Chen et al. [11] describe the power consumption of a server as the sum of its static power consumption and its dynamic power consumption. The static power consumption is the consumption of the server in power-on state without workload. This amount of power can be saved with this approach. The dynamic part of server’s power consumption correlates with its CPU utilization as described by Pelley et al. [5]. Thus, most methodologies are only focused on CPU utilization. Dalvanadi et al. [8] and Vu et al. [10] pointed out that network communication can also influence the overall performance of an IT service and network-aware VM placement is also an important and challenging issue. Hence, they embrace network traffic so as to minimize power consumption.

As described, many approaches use virtualization technologies to concentrate VMs on a small number of PMs. While migrating VMs onto a PM, the size of the random access memory (RAM) is a limiting factor. If the RAM-size of the PM is exhausted, further VMs cannot be migrated onto this PM. This can be an adverse effect, especially if resources such as CPU are still underutilized or unused. The memory sharing technology offers the possibility to condense the redundant memory pages on a PM to one page. Unneeded physical memory can be freed to improve the VMs memory footprint. The VMs run on top of a hypervisor, which is responsible for allocating the physical resources to individual VMs. The hypervisor identifies identical memory pages on the different VMs on a PM, it shares them among the VMs with pointers. This frees up memory for new pages. If a VM's information on that shared page changes, the hypervisor writes the memory to a new page and readdresses a pointer. The capacity of the PM can be increased to concentrate further VMs on the PM and to achieve higher server utilization. Wood et al. [12] present a memory sharing-aware placement approach for virtual machines that includes a memory fingerprinting system to determine the sharing potential among a set of VMs. In addition it makes use of live migration to optimize VM placement.

## 4. Resource-efficient and energy-adaptive approach

In this section the in-progress idea for resource-efficient and energy-adaptive VM placement in data centers is proposed. To optimize the server utilization, many data center operators already use server virtualization technologies and operate several virtual machines on one physical server. This technology is the base for our further optimizations. In our approach, we are at the point that the first steps of optimizations have already been done. Hence, we are running a set of VMs concentrated on a small number of potential servers. Unused servers are already switched off. As further input we get the target power consumption.

It is generally accepted that applications that can access all required server resources operate ideally. With the aim of improving the data center's efficiency, resource-competing VMs should not be operated on the same physical server together. Our approach is to create a VM allocation that concentrates VMs with suitable resource requirements on the same physical server for ideal application performance and efficiency. In this constellation, each application has access to the required server resources and operates ideally. Finally, the overall server resources are more utilized than before and the efficiency rises. These effects include the CPU utilization, so the power consumption increases, because CPU utilization is the most reliable factor regarding server power consumption as mentioned before. This situation leads to more efficiency, but also to a higher power consumption and application performance. This scenario is suitable for times of high energy availability. Following the idea of green energy usage, this technology is also capable of reducing the data center's power consumption in situations of less green power availability. Therefore the methodology can be used to explicitly reduce resource utilization by combining resource-competing applications, leading to lower power consumption but also potentially to a reduced application performance.

In data centers, applications induce specific power consumptions by their evoked server load. This required amount of power is understood as a fixed and restricted value. Our concept is to let this amount of power become a controllable value by applying a corresponding VM allocation. Hence, the power consumption is controllable; it can be increased in times of high energy availability and decreased otherwise.

Our approach is based on virtualization technology and the possibility to live-migrate VMs. The methodology is agnostic to the operating applications. This is an advantage compared to other task scheduling-based algorithms since these have to deal with task execution times and other application-specific topics. In our approach, the applications are untouched and the technology is non-invasive regarding the applications; it only takes effect on the availability of server resources. The variable availability of server resources is a usual setting that applications are confronted with. As described in the related work part of this paper, the PM's RAM can be a limiting factor while migrating further VMs to the PM. We make use of the technology to share RAM across the VMs to increase the number of VMs operated on a PM.

The following diagrams illustrate the practice, how the methodology's strategy migrates VMs between physical servers.

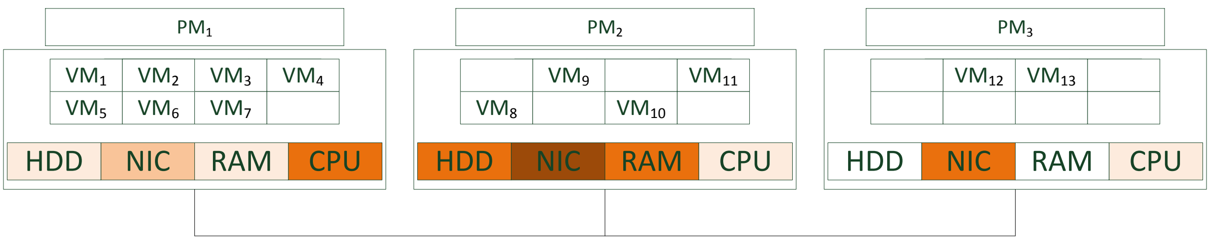


*Figure 1: Schematic VM on physical server diagram: initial situation*

In Figure 1 the initial, non-optimized situation is displayed showing a set of VMs operated on three physical servers. The resource utilization is highlighted (lighter colors meaning low, darker colors high utilizations). On $PM_2$, for example the performance is affected by high network utilization.

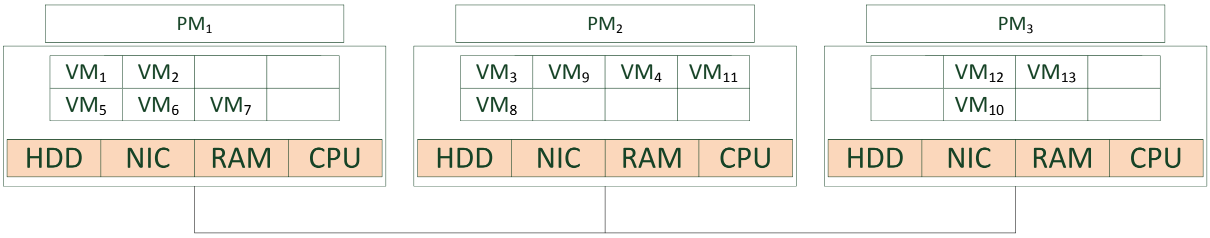


*Figure 2: Schematic VM on physical server diagram: optimized situation*

After the methodology is deployed, an equilibrium allocation regarding the resource utilization, as shown in Figure 2, is the result. This leads to an average utilization of all involved resources. Hence, the approach increased efficiency and power consumption by resource optimization.

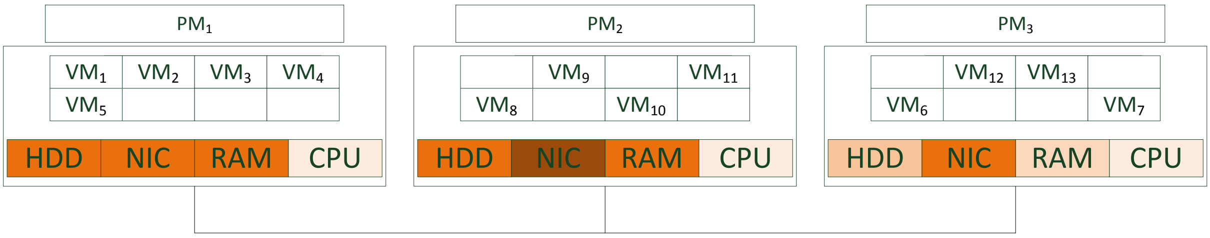


*Figure 3: Schematic VM on physical server diagram: aim of reduced power consumption*

The situation shown in Figure 3 is the result with reduced power consumption objectives. The CPU utilization is reduced to likewise reduce the power consumption as well while the utilization of other resources is balanced. The result is the most effective constellation at reduced power conditions.

### 4.1. System Model

In Figure 4 a component model of the entire system is shown. We have an application-monitoring component that delivers information about the applications and servers to the service level management (SLM). The SLM component contains all service level agreements (SLAs) and calculates new power target values for the data center to observe the SLAs. These values are propagated to all optimizers, working on every physical server. The optimizer compares the new incoming target values with its own actual value. If the difference is in range of a predefined hysteresis, the optimizer does not take action. Otherwise it starts optimization. If the target is not in the predefined range and the actual value is lower than the target, the optimizer resolves resource competing constellations and hosts additional VMs from the offer pool. In the offer pool, all the optimizers can announce VMs, for example, if they don’t fit to their actual placement strategy. The VMs in the offer pool are represented with their resource requirements that are the base for later VM placement swaps. If the actual value is higher than the target, the optimizer arranges a resource competing allocation to reduce the power consumption.

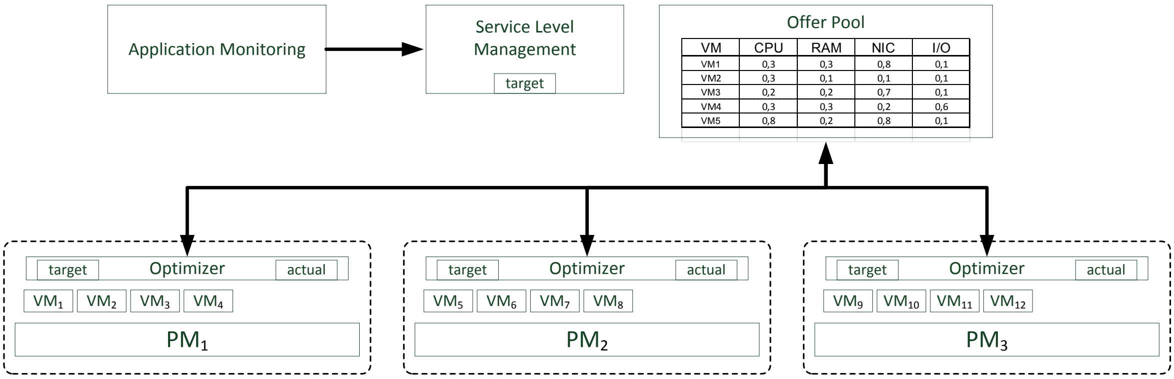


*Figure 4: Schematic System Model*

## 4.2. Algorithm

CPU utilization is the most effective value regarding power consumption as mentioned before. In other words, the overall CPU utilization is the value to increase or decrease to take effect on the data center's power consumption. Our approach uses competing resource allocations to slow down applications and in series the CPU utilization. Consolidating VMs on a PM that utilize the same resources except the CPU can accomplish this. Consequently, the CPU utilization and power consumption decreases. This practice affects the application's performance and we need a feedback that is sent from the application-monitoring component to the SLM component to ensure the SLAs. With the information about the SLAs and actual application's performance, the SLM component is able to calculate power consumption target values that achieve the economical data center objectives.

The target power consumption is broadcasted to all PMs. The PM has got an optimizer component that receives the target and compares it with its actual value. If the target is similar to the actual value, the optimizer does nothing. Otherwise it starts optimizing. While doing this, the focus is kept on balanced resource utilization. Hence, the overall CPU utilization is reduced or increased but all other resources are used as efficiently as possible. Balanced resource utilization is always the goal except for CPU utilization and resources that are used to build the competing resource situation. Just the attainable CPU utilization is a variable and implicit value.

Every PM's optimizer strives to reach the target value by optimizing its own situation. We have an offer pool of VMs, which can be accessed by every PM's optimizer. The optimizer is able to read out the offered VMs from other PMs or even to offer VMs. If the target value is greater than the actual value, the optimizer removes suitable VMs from the pool to host until the target value is reached. If the target is lower than the actual value, the optimizer offers VMs to the pool to reduce the own value. Furthermore, additional VMs can be hosted from the pool to create competing resource situations to reduce the CPU utilization and to reach the target value. The process of reaching a suitable VM placement and the behavior of the optimizer is demonstrated by the following pseudo code:

**Input:** ***t*** target power consumption

**Input:** ***p*** actual PM's power consumption

**Output:** VM placement that reaches target power consumption

1. receive new target ***t*** given by SLM component
2. ***if t*** > ***p*** and the PM's CPU utilization is 100%, offer VMs to other PMs via offer pool

3. ***if t*** > ***p*** and the PM’s CPU utilization is lower than 100%, and all other resources are underutilized, the PM invites VMs to shelter from other PMs with high CPU utilization
4. ***if t*** > ***p*** and the PM’s CPU utilization is lower than 100%, and other resources are strong utilized, offer VMs to other PMs to solve the competing resource situation
5. ***if t*** < ***p*** and the PM’s CPU utilization is lower than100%, and other resources are strong utilized, invite VMs to shelter from other PMs with high CPU utilization
6. ***if t*** < ***p*** and the PM’s CPU utilization is 100%, invite VMs to shelter from other PMs to create resource competing situation
7. ***if t*** = ***p*** do nothing

### 4.3. Future Work and Experiments

Our primary goal is to increase the data center’s power efficiency. The essential research work is to analyze the different reachable effects by combining further methodologies, for example RAM-sharing and integrating further resources (such as RAM, NIC, and HDD) into the approach as described before. Afterwards, a VM placing strategy has to be found.

The problem of determining an efficient VM placement can be formulated as an extended bin-packing problem, where VMs (objects) must be allocated to the PMs (bins). In the bin-packing problem, objects of different volumes must be fitted into a finite number of bins each of the same volume in a way that minimizes the number of bins used. The bin-packing problem has an NP-hard complexity. Hence, a global bin-packing solver will not be able to deliver a VM placement for an online acting approach. In further experiments we will point out the major effects to reduce the complexity. Finally, we have to prove the additional efficiency and to compare our methodology with the results of other existing approaches in virtualization and consolidation. We will point out the further effects of extending the algorithm’s scope beyond CPU utilization.

## 5. Conclusion

We pointed out the raising data center demand, the increasing energy costs, and the requirement to handle volatile energy availability respectively. In the related work part of this paper we presented different approaches related to energy efficiency, power consumption, and usage of renewable power in data centers. We defined the problem of energy efficiency and proposed a resource-optimization approach that improves overall energy efficiency and also allows controlling actual data center power consumption without application-invasive measures. We will point out the potential of this methodology in our ongoing work, especially including further resources beyond CPU and technologies such as RAM-sharing.

Our approach is an instrument to increase efficiency and to adapt to renewable power availability; both have positive effect on the carbon footprint.

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# Combining the analysis of resource demand and Ecological Footprint

Georg Kanitschar[1], Andreas Gassner[2], Paul H. Brunner[1]

## 1. Introduction

In this paper, the utility of the Ecological Footprint method to assess the environmental impact of a public transport system is discussed, and a new method to supplement the Ecological Footprint to consider resource demand is shown. The method was used to determine the Ecological Footprint of the biggest provider of public transport in Vienna, namely the Wiener Linien. The study assessed the contribution of the individual modes of public transport -subway, tram and bus- as well as the impact of management and service infrastructure by defining and analysing three distinct scenarios. In this paper, we will show the contribution of the business categories –electricity and fuel; buildings; mobile and immobile assets; consumables; vehicles; buildings- to the Ecological Footprint of the Wiener Linien, and supplement that information with data on resource demand. In our study, we compared three scenarios. The first scenario set the reference for “business as usual”, the second scenario added one subway line while the third scenario significantly expanded tram-service. While the Ecological Footprint, normalised for seat-km, stays about the same, a considerable difference in resource demand, normalised for seat-km as well, was found. For this study we followed a data-heavy bottom-up approach for data acquisition, which will be presented in this paper as well.

## 2. The Ecological Footprint

The Ecological Footprint method, as defined by Wackernagel [3], aims at measuring the impact of goods and services on the environment based on a calculation of the land used for providing said goods and services of interest. The main advantage is the aggregation of complex information into an easy to understand unit (“area”) and number, enabling e.g. the communication of environmental issues in a widely understandable manner. The drawback is that the Ecological Footprint is a rough simplification, and that there are some specific issues with the dominance of $CO_2$ on the result of the Ecological Footprint. For one, the resulting Ecological Footprint is highly sensitive to variations of the sequestration-rate for $CO_2$ – which is an empirical entity. Additionally, the area obtained by using a sequestration-rate for the absorption of $CO_2$-emissions does not correspond to an area in reality. The area needed to absorb a certain amount of $CO_2$ varies over different regions, whereas $CO_2$ is spreading globally.

Another issue is the environmental impact of resource production being dwarfed by energy consumption. In context of public transport, the Ecological Footprint contribution of producing the materials for, e.g., a public bus is irrelevant compared to the energy used during the lifetime of the bus. So the major contribution to the Ecological Footprint stems from the energy used in the public transport system. Whereas in reality, significant environmental issues, which are not $CO_2$ related, arise with during the production of resources. Direct land use is considered in the Ecological Footprint, but the emission of hazardous substances does not have an impact on this indicator.

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Knowing which resources are being used keeps those hazardous substances in the foreground of the assessment.

When using the Ecological Footprint to assess environmental impact, information on the kind and amount of resources – together with the hazardous substances incorporated in them - used is nearly lost. Even when infrastructure is considered separately, $CO_2$ is the dominant factor, as the production of cement commonly leads to massive emissions [2].

## 3. Grasping Resource Demand

To supplement the dominant information on $CO_2$ emissions, the most important materials used are sorted into five categories. This way, in addition to the Ecological Footprint, the amount of concrete, steel, aluminum, copper and plastics necessary to provide the public transport systems infrastructure and mobile assets is included in the assessment, too.

In the context of public transport, this methodology enables the user to evaluate a public transport system in two ways:

1) The Ecological Footprint – dominated by fossil $CO_2$ emissions – mainly shows energy use for operation of the public transport system. Even though the "grey energy" that was used to produce the materials incorporated in the public transport system is allocated to the material itself, the category "fuel and electricity" is contributing >85% to the Ecological Footprint of the Wiener Linien. (Figure 1; left column) Thus, when comparing different traffic solutions using scenarios, the comparison will effectively be between the fuel and electricity consumption. This in return gives the choice of the source of electricity the single most impact on the evaluation of the scenarios, although the underlying traffic system itself stays the same.
2) Resource information on the other hand enables the comparison of different public transport solutions regarding Infrastructure and vehicle intensity. The amount of concrete stays the same, whether it is bought "green" or not. Therefore, the result of the environmental assessment is not affected by management-decisions on the energy supplier. To change the (projected) resource demand of a traffic solution, the actual scenario has to be designed differently. While there is no doubt on the importance of an energy-assessment, a discussion about material intake and substance flows has an equal importance for the environment.

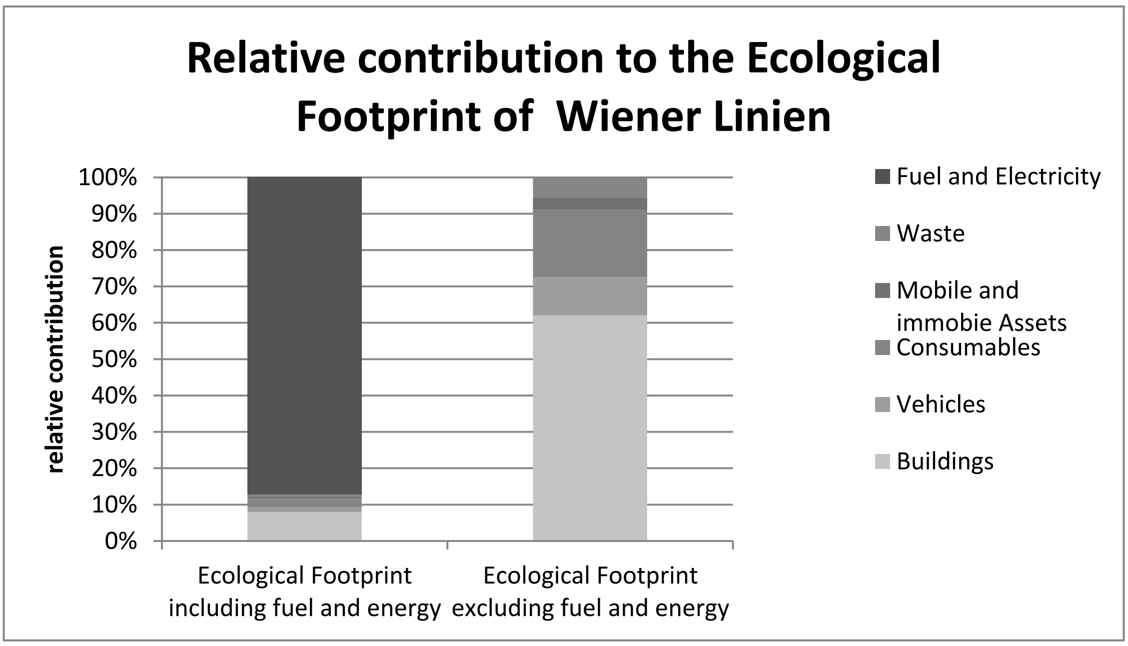

*Figure 1: relative contribution to the Ecological Footprint of the Wiener Linien, inclunding (left) and excluding (right) fuel and electricity*

In our study for the Wiener Linien we saw that for three different scenarios, the Ecological Footprint is about the same (Figure 2).

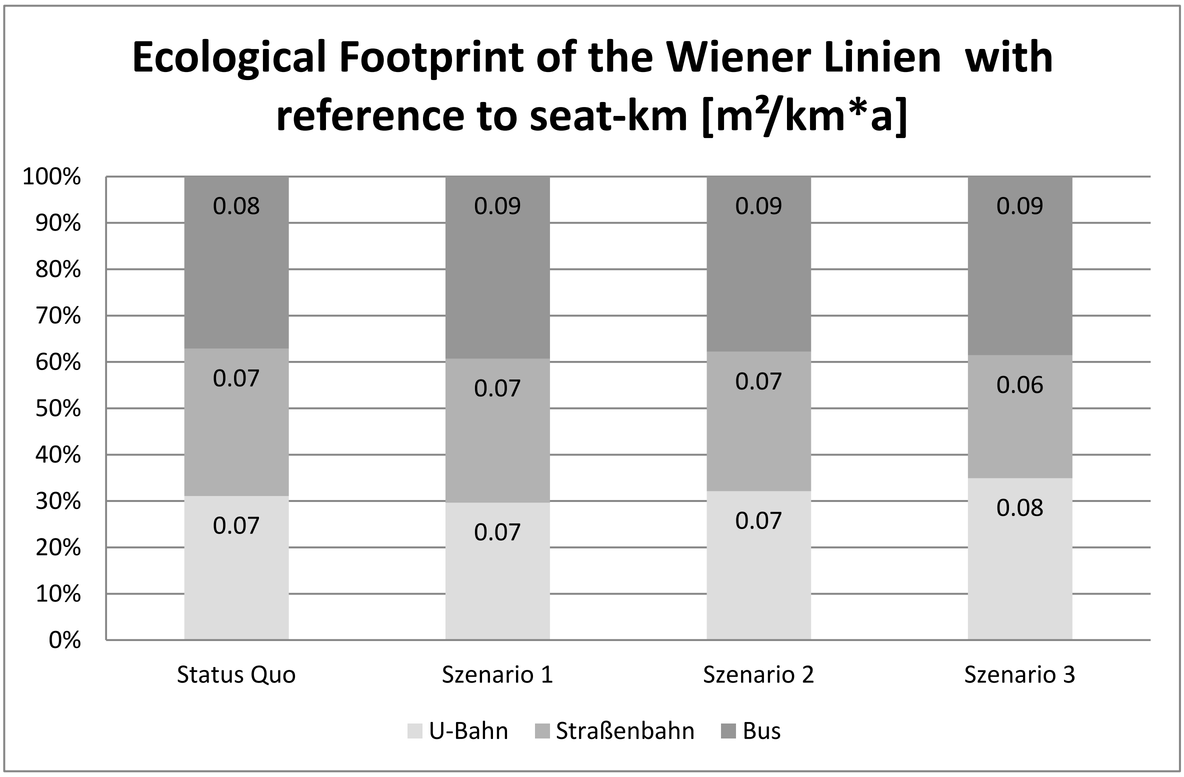


*Figure 2: Ecological Footprint of the Wiener Linien with reference to seat-km for the Status-Quo of 2012, as well as for three scenarios projected for 2035. The sections represent (from top to bottom): bus, tram and subway.*

Considering resource demand for the same scenarios, the picture is quite different. (Figure 3) Here, an increased resource demand for Scenario 2 can be seen. This increased demand on resources was not visible with the Ecological Footprint. The way we set up the scenarios, Scenario 1 describes "business as usual" – only started projects are finished, with no further investments. Comparing Scenarios 2 and 3 to this reference, the relative difference between the scenarios becomes evident. (Table 1)

| **Resource category** | **Relative resource demand Scenario 2** | **Relative resource demand Scenario 3** |
|---|---|---|
| Concrete | +290% | +106% |
| Steel | +236% | +49% |
| Aluminum | +74% | +3% |
| Copper | +154% | +32% |
| Plastics | +54% | +10% |

*Table 1: Relative resource demand of Scenarios 2 and 3 compared to Scenario 1*

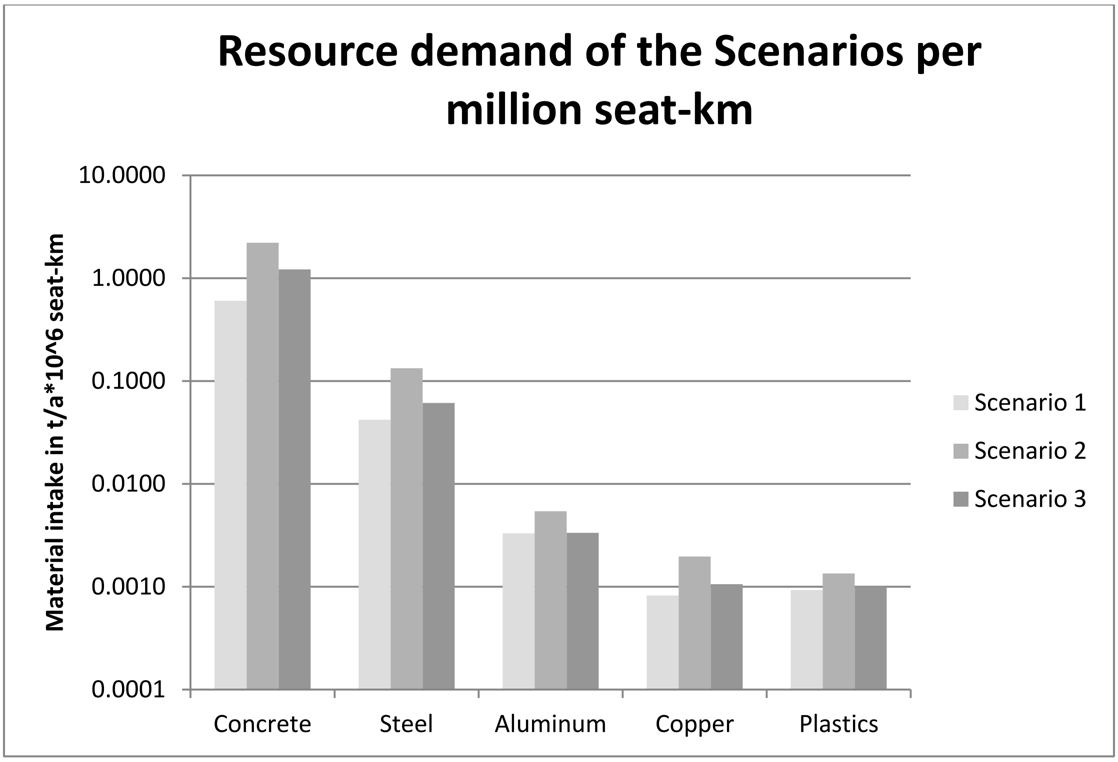


*Figure 3: Resource demand per scenario- logarithmic scale*

While the scenarios look equivalent regarding the Ecological Footprint, the difference in resource demand is considerable.

## 4. Data acquisition

Analysing a public transport system requires reliable information. This can be obtained by careful analysis of the inventory data of the public transport systems provider. A previous study (Lederer et al, 2010), which dealt with the extension of the subway line U2, proved that such a methodology requires a large amount of data, even if only a small part of a public transport system is investigated.

In the current study, the scope encompasses the Wiener Linien as a whole. The amount of data provided by the Wiener Linien required us to cut some corners in order to keep the workload on a practical level. Especially the database on mobile and immobile assets and the database on consumables were too big as to account for the Ecological Footprint or resource demand of every item separately. Of 22.000 physical assets, 4.000 were excluded due to low weight or low numbers. The remaining 18.000 assets were distributed to 160 categories.

To get a realistic estimate of the material inventory of the Wiener Linien, the categories were connected with assumptions on the average mass and material composition of that category – e.g. the “average printer”. For this step, the ecoinvent database contributed first estimates [1]. This first inventory analysis then enabled us to identify where the major resource stocks are and where to investigate with priority, thus allowing a heavy reduction of the amount of goods to consider in the second step. In the study we found that for mobile and immobile assets, five categories accounted for more than 50% of the Ecological Footprint of mobile and immobile assets. In the case of consumables, 10 categories contributed over 80% of the Ecological Footprint of all consumables. This procedure was carried out for the buildings, the rolling stock and all waste as well.

A typical distribution of contributions to the Ecological Footprint of a business section is shown in Figure 4. For all business sections we found a similar resemblance of important categories. This list functioned as a priority for our in depth-research to improve data quality. Additionally, these rankings are useful for internal decision making as well.

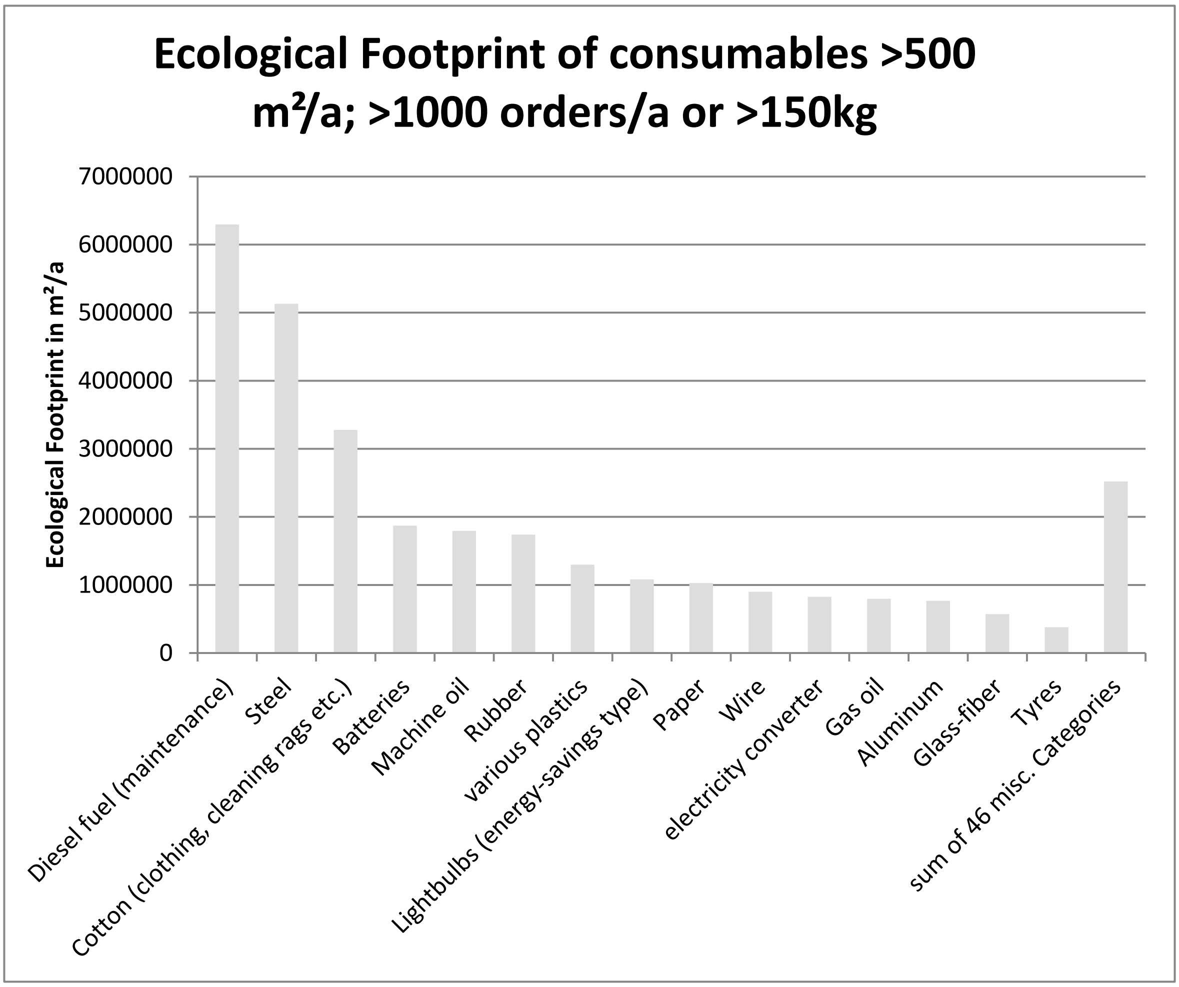


*Figure 4: Generic display of the contribution of individual categories of consumables to the Ecological Footprint of all consumables. The ten largest categories contribute about 90% to the total.*

The inventory data on the biggest categories was then reviewed and updated. This methodology to reduce the amount of data to manageable levels provides a ranking of the relevant goods. For large stocks more thorough investigations are needed. This results in the data of the biggest contributors to material consumption having the least uncertainty.

## 5. Conclusion

Overall, supplementing the Ecological Footprint with data on resource consumption mitigates some weaknesses of the Ecological Footprint – namely simplification through aggregation and domination of fossil $CO_2$. The data on resource consumption enables informed decision making in ecological and economic terms. Knowing which resources are necessary for providing public transport is a piece to the puzzle of planning for the future.

The material inventory, as well as the data on resource consumption is highly valuable in aspects such as resource recovery and environmental protection as well. In the future, when trains and busses are being replaced, information on what materials are inside these assets waiting to be recovered leads to an ecologically and economically effective management.

Furthermore, rising efforts in information gathering related to Urban Mining profit from extended resource stock information. Especially underground networks embody large amounts of recoverable steel, aluminium and copper. If underground networks need to be renewed, these material stocks may turn into valuable resources.

The interpretation of data about traffic systems is not trivial. Just as the energy requirements vary dependent on the mode of transport, not only in quantity, but also quality – electricity, heat, and fossil fuels – each mode of transport is different in resource requirements. But this view is not suitable for assessing a public transport system. A public transport system relies on the interaction of the different modes, in the case of Vienna these are subway, tram and bus. Assessing the individual modes may lead to the suggestion of providing the whole capacity of the public transport system with the mode which effects minimal resource demand or $CO_2$-emissions. A system designed in this way would not be effective in any way however. Only the interaction of different modes fits the needs of a modern city. Social and political acceptance, as well as financial practicability all stand besides ecological concerns.

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# Evaluation of complex system structures in maintenance processes at offshore wind farms

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## Abstract

The evaluation of complex system structures has to address the question "Can the model give a true and correct view of the real situation?" The model has to be investigated with regard to functionality, completeness, correctness, reliability and usability.

The offshore wind farm in maintenance status is an example for complex system structures. Furthermore the offshore wind farm is not organised as one single company with usual business processes. It is the enterprise offshore wind farm with a lot of stakeholders which help to operate and maintain it. So the requirements for process management are really special. In this paper the process structure of an offshore wind farm is shown firstly. Suitable evaluation criteria for demonstrating the correct view on the offshore wind farm processes in maintenance status are selected. The review and evaluation by business experts as well as the case and field study are the best evaluation methods in the project environment and for proving the criteria. The evaluation shows that the results for OWF structures and models are appropriate for transfer and application at offshore wind farms.

## 1. Introduction

At the end of each project results and products have to be investigated with respect to project aims, benefit for user, quality and effectiveness. Appropriate evaluation methods have to be selected. But what are the best evaluation methods and what are criteria which fit to the system under investigation? This depends on the research disciplines, the used research methods and the kind of the developed results and products. In principle proper criteria of evaluation must be selected and an evaluation matrix has to be determined. Possible criteria are functionality, completeness, correctness, reliability or usability. [In accordance to 12, 19]

In particular the evaluation of models for complex systems has to address the question „Can the model give a true and correct view of the real situation?" For more transparency complex systems have to be structured in smaller subparts. But the subdivision of the system involves the risk to falsify the reality, e.g. by lost crosslinking of system elements.

The paper discusses the evaluation approach for the structure of complex systems at selected offshore wind farm maintenance processes. It describes the subdivision of the system offshore wind farm in hierarchical process levels down to the process models firstly. Moreover the process characteristics of the structure like the throughput time or the number of staff of an activity will be shown. The quality criteria for evaluation of this OWF structure and their evaluation matrix will be explained. On this basis proper evaluation methods will be selected to improve these criteria. Using this evaluation the image of the model of OWF maintenance processes` structure is proved. The model limits, like level of detail or static display of processes, are described. Furthermore the

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easy comprehension of the model is given for involved parties, like strategic and operational management or service provider.

## 2. Models of complex systems

### 2.1. General

Complex systems have a high number of components which are connected. These components can contain subsystems. [5] Complex systems have to be divided in communicable, transparent and comprehensible sections for a better understanding and system design. Therefore the system will be clearly isolated from its surrounding environment and converted into a model. The system limits have been reviewed under the following headings: determination of the application perspective and objectives of process definition as well as determination of process limits and essential objects within the company, which have to be defined in their behavior. [15]

The model is an image of the reality and reflects the characteristics of the system clearly under consideration of investigation purposes [in accordance to 11, 4]. For this the process modeling of a system is of particular importance. The process models describe the interaction of human, equipment, material, methods and information within the system. On the one hand they reduce the complexity and they underline relevant system elements on the other hand. [20] The modeling finishes with sufficiently complete, detailed and correct depicted parts of the system under consideration of the application case. [15, 8]. Objectives of system modeling are derived from company or project aims. Examples are the business process optimization or the development of a specification sheet. [2] The modeling leads to systematized and transparent processes. Hence, hierarchical structures can be reduced and the communication in and between companies can be improved. [20] The model quality depends on the reflection of the reality in the model and the consideration of the modeling objectives as well as the clearness of the model depiction. Furthermore the chosen modeling language is important for clearness and comprehensibility of models. [8]

### 2.2. The Offshore Wind Farm

An example for a complex system with complicated process structure is the maintenance process at offshore wind farms (OWF). More than 30 stakeholders and different infrastructures are involved which interact in numerous ways and in a wide range of processes. [10] Furthermore the operation and maintenance of OWF in the 20 years operation phase is cost intensive within ranges of 12-19 €ct/kWh [13]. The cost effectiveness has to be improved by reduction of operation costs. One approach is the optimization of process designs of operation and maintenance (O&M) because of potential losses from defective and uncertain processes [18]. The process design means the organizational and organizational process structure of O&M. Today this process design will be not paid enough attention in the planning and development phase as well as during the operation phase, although it affects the availability of OWF and the maintenance costs significantly. The experiences at OWF operations show that the maintenance processes have a lot of stakeholders with a complex interconnection structure and spontaneity as well as lack of plannability. So an effective and efficient process design for maintenance processes is required.

**Modeling requirements and objectives**

OWF maintenance processes cannot be characterized as usual business processes of one company with focus on the internal commercial processes. A lot of different stakeholders are involved in the maintenance processes of an OWF. They are highly interconnected and the processes can be very complex. Modeling has to reflect on this specific situation.[in accordance to 6]

The modeling objective will be defined as: Development of an OWF-independent, transparent and structured depiction of all processes, parties involved, infrastructure and interfaces in maintenance. The model has to be comprehensible and readable for the parties involved. It is the foundation for further process optimization by risk analysis and process simulation. The risk analysis needs information about the processes like parties concerned, activities with their duration time and resources, interactions, used material, machines and work method as well as environment. This affects the selection of process modeling language.

**System structure**

The maintenance operations at OWF include a large number of processes. The processes have to be structured and incorporated in a process hierarchy. This OWF specialized process hierarchy (fig. 1) is based on regulations and standards of the offshore wind industry, engineering industry and quality management in particular.

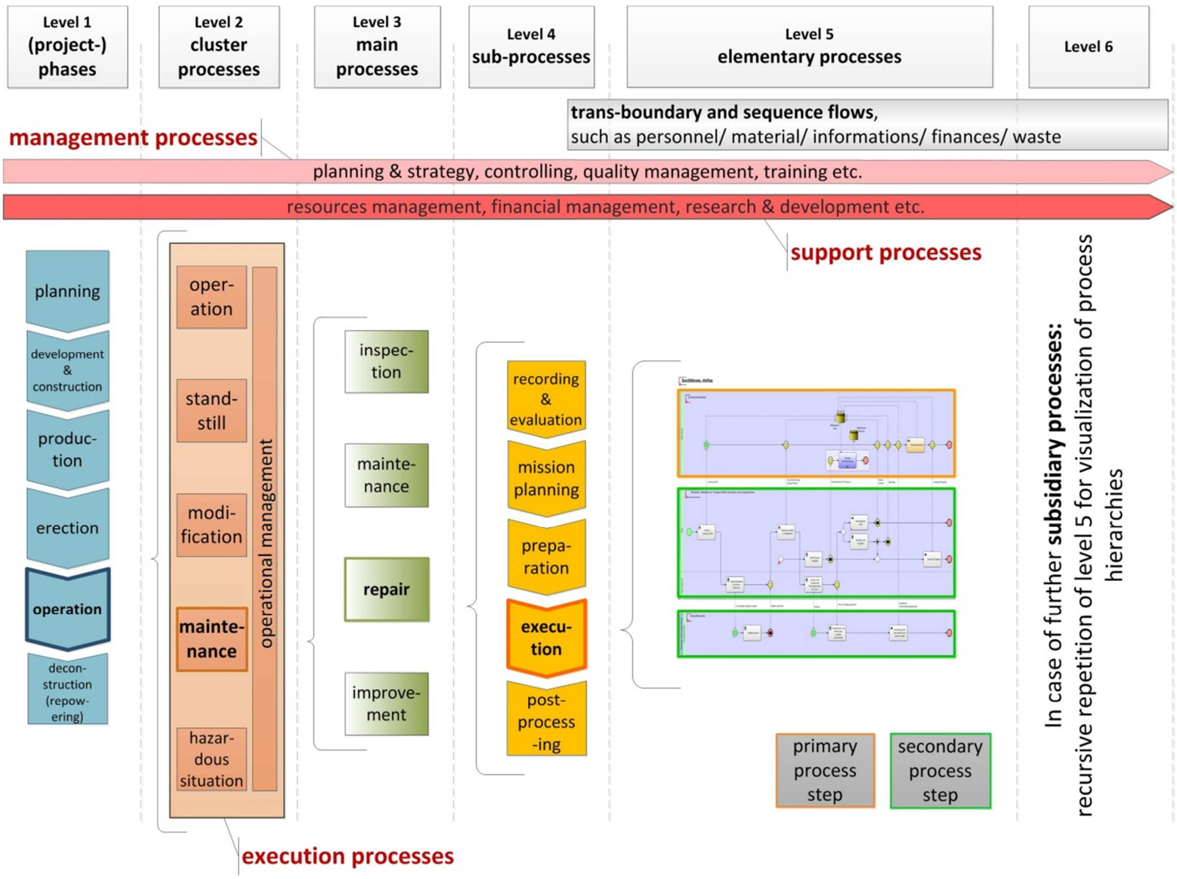


*Figure 1: OWF-specialized process hierarchy*

The status “maintenance” of an OWF contains the four main processes inspection, maintenance, repair, improvement [7]. All these main processes are further divided into the sub-processes determination of requirements, mission planning, preparation, execution, inclusive outward journey / residence, execution on-site and return journey and post processing. [14]

The structure of stakeholders, infrastructure and interconnections of the offshore wind farm in maintenance is shown in figure 2. It is divided into onshore and offshore sections. The icons are parties concerned and infrastructure. The arrows between them are on the one hand the interfaces and the interactions on the other. The interactions are defined as staff, material, waste, finances and information.

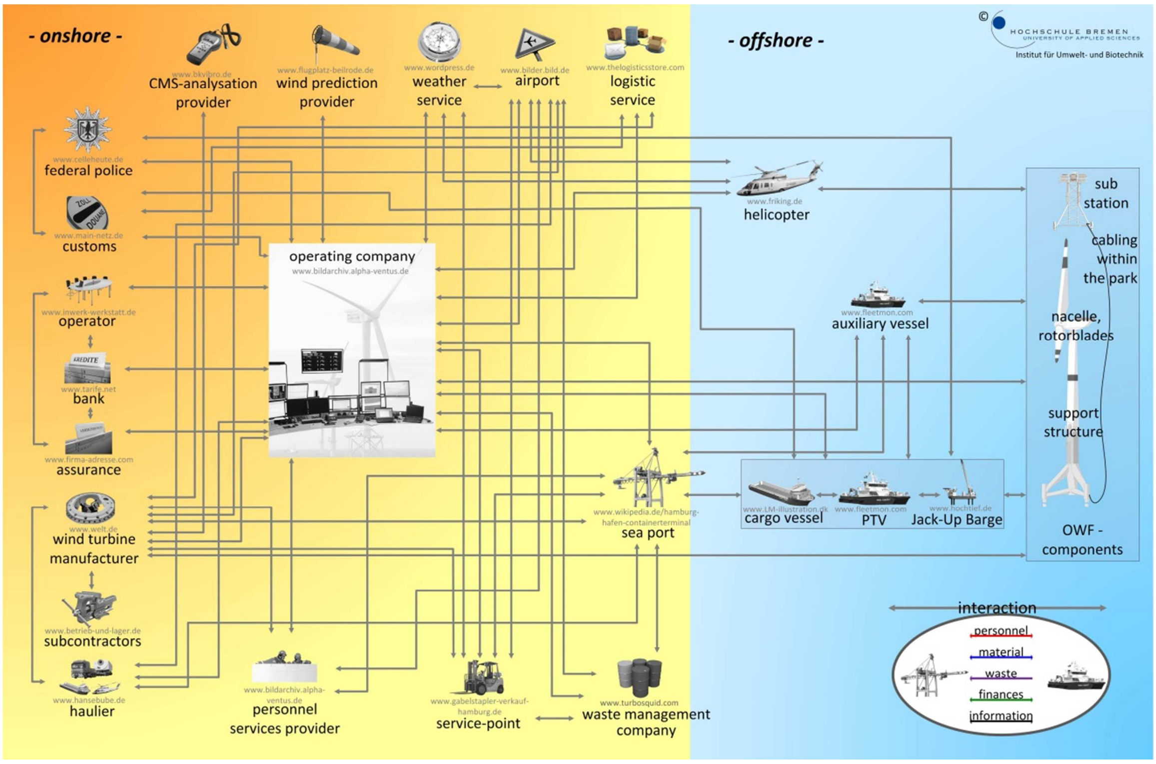


*Figure 2: Extract of the system offshore wind farm in maintenance status [1]*

The process map of OWF maintenance (fig. 3) shows the structure of maintenance sub processes. The actual picture of sub processes is based on the individual requirements and demand of work as well as different transport devices (blue boxes). The example “Repair of small components process by using a personnel transfer vessel (PTV) and executed on-site by wind turbine manufacturer” is displayed in deeper blue colored boxes. [10]

The sub-processes are modelled in the process modeling language Business Process Model and Notation (BPMN 2.0). The language is a standardised graphical process notation, which can be used for process automation also. It is developed for easy readable process models as a communication basis between business and ITexperts. [9] Because of the different OWFstakeholders comprehensible process models are a requirement for the process depiction of an OWF. As an example figure 4 shows the process model for return journey by using a personnel transfer vessel.

Each party concerned is displayed in the pools (blue lanes). A deeper division of them in different departments or persons is also possible, as such captain and crew of sea haulier. The pools are commented with the tasks of the different companies. Each pool begins with a start event and finishes with an end event. Activities are running sequentially among them. The different interactions of an OWF in maintenance status are marked in defined colors, such as black for information flows. The detailed models are backed up by information about human and technical resources, time intervals and durations.

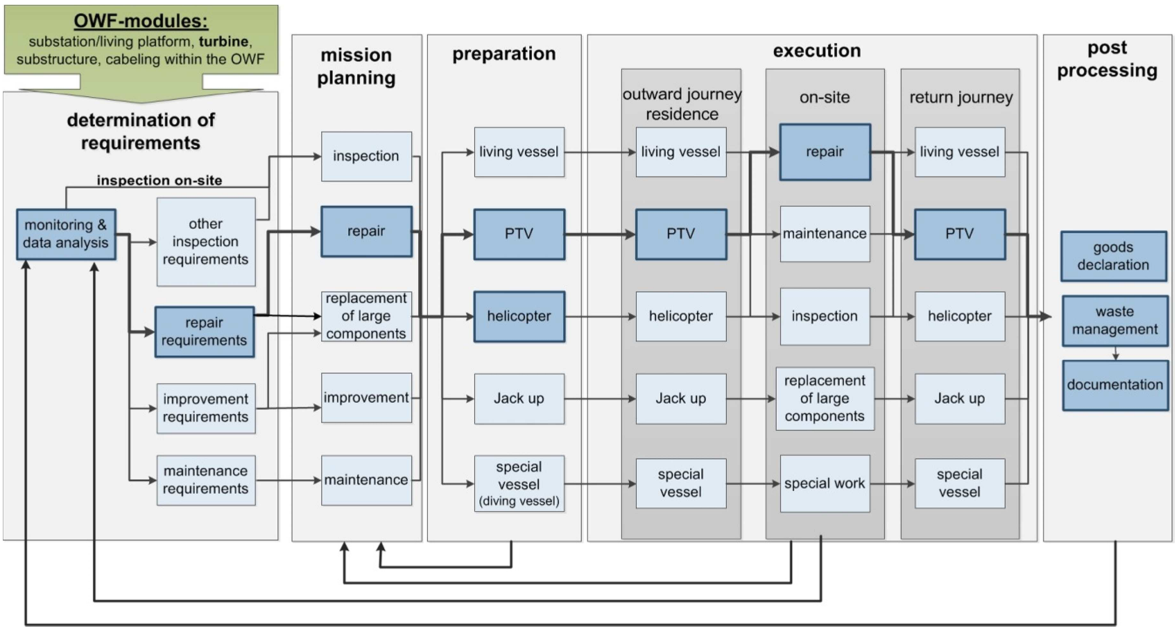


*Figure 3: Process map with highlighted "repair of small components by using a personnel transfer vessel (PTV) [1]*

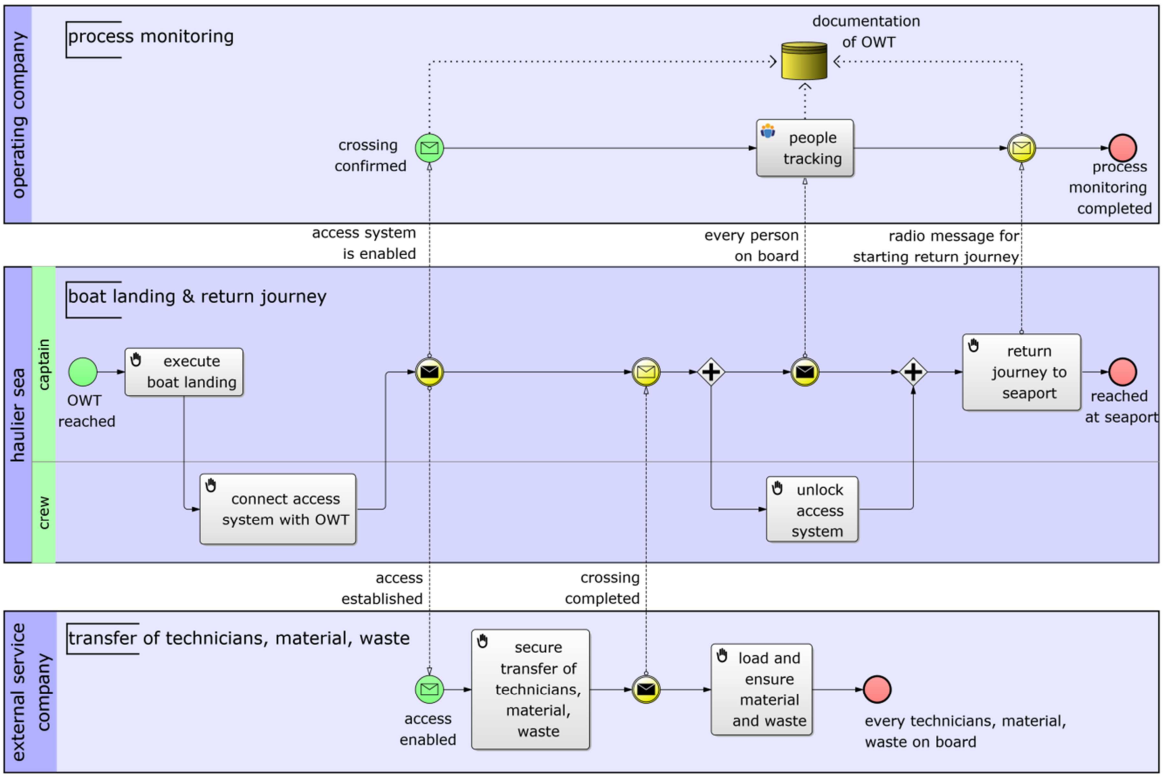


*Figure 4: Extract of process model of Return Journey by Personnel Transfer Vessel [1]*

## 3. Evaluation criteria and methods

Evaluation tests if the models reflect the real behavior of the investigated system with sufficient correctness. That means: Do we have the correct model in consideration of the modeling objective? [16] The most important evaluation criteria of models are completeness, consistency, accuracy, currency, applicability, plausibility and clarity [16, 12]. The principles of good modelling are reflected by these criteria. The validity check of models can be worked out by many different techniques. For choosing the correct technique the expenditure of evaluation, the purpose and the objective of the modeling as well as the characteristics of the model and the knowledge of users or availability of information have to be considered. [16, 12] The evaluation criteria and their central questions are combined in Table 1.

| Evaluation criteria | Central questions |
|---|---|
| Completeness | Are there any missing information or requirements?<br>Are the models sufficiently precise in consideration of requirements? |
| Consistency | Are the semantic relations coherent?<br>Is the structure conclusive?<br>Is there a consistent terminology? |
| Accuracy | Has been the modeling correctly and carefully conducted? |
| Currency | Is the information valid in time and content for their application?<br>Are the models valid for the task? |
| Applicability<br>(Functionality, Usability) | Are the models suitable, accurate und usable for their intended use?<br>Are the models appropriate for the task?<br>Have the models a good performance?<br>Are the models usable for the users? |
| Plausibility | Are the relations suitable?<br>Are the models appropriate for the application? |
| Clarity | Are the models comprehensible and readable for the user?<br>Is there a transparent model?<br>Are the models clearly formulated? |

*Table 1: evaluation criteria for system models (in accordance to 16, 12)*

## 4. Evaluation of the OWF process model in maintenance

The evaluation of the OWF process model has to address the question „Can the model give a true and correct view of the real situation?” For more transparency the OWF system was structured in smaller subparts. But the subdivision of the system involves the risk to falsify the reality, e.g. by lost crosslinking of system elements. The modeling objective is “OWF-independent, transparent and structured depiction of all processes, parties involved, infrastructure and interfaces in maintenance as a foundation for process optimization by risk analysis and process simulation.” This was achieved by the hierarchical process structure for operation and maintenance (fig. 1), the system OWF in maintenance status (fig. 2), the process map for variable combination of sub-processes (fig. 3) and the process models in BPMN 2.0 (fig. 4). The project environment with a full scale offshore wind farm as a case study for evaluation and a lot of contact persons in industry allows a review and evaluation by business experts as well as a second case study at another OWF. Furthermore the models will be developed with a comprehensive literature review during the modeling as well as iterative discussion with different business experts. All evaluation criteria can be investigated with these methods. Table 2 shows the evaluation results of the different sub-models in consideration of the most important evaluation criteria (mentioned above).

The **hierarchical process structure** reduces the complexity of processes in the enterprise OWF at maintenance. This establishes a framework for process definition. It was developed and completely applied for the operation and maintenance processes of one full scale offshore wind farm. The hierarchical structure is used in business working groups. They transfer it to other life cycle phases of OWF.

The **system offshore wind farm** gives an overview about all stakeholders, infrastructures and their interfaces as well as flows between them in particular but without any dynamic aspects. With this interfaces between stakeholders can be defined and tasks can be assigned. Furthermore, it shows the complexity of the organizational structure. The picture has to be continuously updated and specifically adapted to individual offshore wind farms and specific processes or sub-processes.

The **process map** enables the combination of process steps based on specific maintenance requirements and necessary logistics. For the simulation of processes it provides the composition of process variants. It has to be continuously updated and specifically adapted to individual offshore wind farms.

The **process models** are the foundation for risk analysis. They offer the essential information about the processes like resources, duration, used material and machines and other influential factors. Effects of failures in the processes can be derived. The modeling and the discussion motivate the stakeholders to critically and reflectively think about their processes and interfaces to others. Because of the high amount of stakeholders the BPMN 2.0 is appropriate to model the different activities in an understandable way. The processes have to be continuously updated and specifically adapted to individual offshore wind farms, too.

## 5. Conclusion

In conclusion the structured and modeled offshore wind farm at maintenance status could be validated, but any models are really specific and give only an idea for modeling enterprises and processes with varied structure and stakeholders. The application of this model to other industries or OWF life cycles has to be done.

The evaluation by review and evaluation by business experts as well as the case study are appropriate to prove the question „Can the model give a true and correct view of the real situation?” in the documented research project. On the one hand there were a lot of stakeholders and project partners which are available for structure development and evaluation. On the other hand two different full scale OWF, one for development and one for evaluation, have been used.

## Acknowledgement

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# Towards Collaborative Green Business Process Management

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## Abstract

Sustainable and efficient energy management poses a major challenge for organizations, as well as the whole society. Organizational strategies for saving energy are currently largely coined by two main courses of action: Green process optimization and investing into more energy efficient infrastructure, or energy campaigns or feedback mechanisms. We show how both approaches face limitations concerning the scope of intervention and carve out the necessity for an integrated approach on fostering sustainability in organizations and envision a Collaborative Green Business Process Management. Such modell should integrate all stakeholders, thus bridging the gap between strategic planning and everyday work in order to manage sustainability strategies more effectively and efficient. We conclude in laying out a research agenda, which we seek to address in course of an ongoing research project within a long term cooperation with several different organizations.

## 1. Introduction

Sustainable and efficient energy management poses a major challenge for organizations, as well as the whole society. Politics starts recognizing the need for a regulation of industries' environmental footprint in order to manage energy turnaround and implement incentives, too. The German government, for example, has enacted tax reductions for organizations introducing a holistic energy management system based on ISO/DIN EN 50001 [1]. This legislation explicitly calls for introducing a continuous improvement process based on analysis of energy consumption information [1].

In order to achieve these goals, strategies are currently largely coined by two main courses of action: On the tactical-strategical level, strategies often based on green process optimization and investing into more energy efficient infrastructure [2]. Both measures are part of organizational structure that needs to be implemented and adopted to become effective [3]. On the operative level, strategies target the individual worker motivating green behavior via energy campaigns or feedback mechanisms [4]–[6].

Both approaches, however, face limitations concerning the scope of intervention. Though most management-driven approaches claim to provide holistic energy management tools, in solely relying on information of organizational structure, they face two problems: Firstly, such approaches tend to underestimate the relevance of actual work practices on energy consumption, which only can be influenced to a certain extend by the organizational structure [7]. Secondly and even worse, management-driven BPM is inclined to define inefficient processes, if they conflict with the needs of the situated working practices. Hence: "*at the end of the day, it is people that will make processes function effectively and efficiently, no matter how much they are automated. If you do not*

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*get the people 'on board' with the project and new processes, then they will find a way to ensure that the processes either do not work or do not work efficiently"*[8].

Behavioral sustainability campaigns, on the other hand, explicitly target the informal or operative behavior, which is usually left out by methods of sustainable process definition [5], [6] (c.f. figure 1 middle). Behavorial approaches, however, typically do not include strategies of perpetuating effects in terms of (re-)designing processes of an organization. This is one of the reasons, why they remain a one-time intervention with diminishing effects over time [5]. So in order to address the gap between the structural, organizational level and the informal practice level different stakeholders need to be considered when remodelling and living green processes.

Process design usually involves the creation of graphical representations of processes [9]. These process models are used to not only display the current as-is state of a process, but also serves as a means to discuss potential modifications. Thus, they also act as a planning tool for organizational change before actually applying it. In most approaches workers are not directly involved in the design process itself, but are rather limited to provide information. In contrast, collaborative modelling aims for a direct integration of them to co-develop improvement strategies and finally introduce accurate changes, fitting both process and workers perspective [10]–[13]. It increases the motivation of people to actually change their behavior. It also supports the reflection about the actual work, thus creating an opportunity to uncover potentials for more efficient processes and practices that otherwise been uncovered.

Involving stakeholders directly through introducing **Collaborative GreenBPM** is thus not only expected to motivate people involved in processes to alter their behavior with respect to energy consumption. It also is expected to uncover potentials to save energy that would not have been uncovered when people focus solely on improving their own energy consumption based upon observations that are limited to the scope of their workplace. We thus do not aim to introduce a whole new BPM standard, but instead want to sensitize existing standards, to extend their models concering environmental information and understanding green processes as a collaborate enterprise. Thus moving from GreenBPM to **Collaborative GreenBPM** and show implications brought along with such an extension.

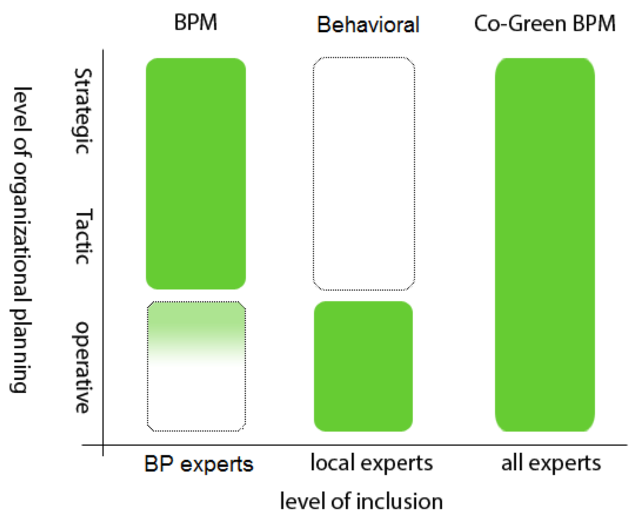


**Figure 1: Comparing the two dominant approaches to increase organizational sustainability and introducing Co-GreenBPM**

## 2. Sustainability in BPM and organizational development

### 2.1. Energy feedback for behavioral change

In course of the oil crisis in the 1970's research of enviromental psychologists started to take an interest into the influence of behavior on energy consumption and investigated into consumption feedback as a means of encouraging energy conservation [14]. Alongside, a body of theoretical approaches emerged within environmental research, seeking to understand individual's (un-) sustainable behaviors. Early and most common approaches adopted rational choice theory [15], arguing that energy relevant behavior is conceptualized as an act of informed decision-making by consumers. Over time, other theories (like Stern's Value Belief Norm Theory [16]) emerged, consider e.g. subjective norms, beliefs and the influence of social surrounding. Both, concepts of norms and rational behavior provide theoretical ground for persuasion and feedback campaigns, which nowadays are the most widespread methods of trying to implement changes to behavioral energy consumption [17], [18]. In particular, design concepts such as providing direct feedback, enabling social comparison and supporting goal setting were inspired by these theories [19].

Strategies inspired by enviromental psychology are mainly applied in the domestic context. In organizational settings, there are only few experiences and guidelines, where the most rely on monetary incentive schemes. Evaluative studies suggest, however, that other factors such as the design concepts of feedback may be of more relevance [20], [21]. Following this, several best practices and guidelines for campaigns, buildings of public administration and companies alike have been created [22], [23]. These typically focus on classic materials like posters, flyers, information brochures and letters from superior authority. They also give some advice on how to use emails and web-sites, but suggestions for using smart technologies most commonly are not addressed in such toolboxes.

More recent research tries to make use of such existing ubiquituous sensing technologies in developing feedback solutions for organizations [24], [25]. First general design guidelines and wireframe sketches were developed by Foster et al. [26] using focus group sessions. Based on a literature review about techniques of intervention appropriate for the workplace, Yun et al. [27] implemented a first functional prototype of an energy-dashboard.

The few studies evaluating eco-feedback in organizational context show mixed results. Carrico and Riemer [8] show that providing monthly feedback with a motivating message has a positive effect on energy savings of university workers. Installing eco-feedback applications on the desktop of university workers, Murtagh et al. [28] also found a significant reduction of consumption. However, they noticed a complex relationship between feedback and behavior and found a manifold of reasons exist 'not to switch things off'. Using smart metering technology in a research institute, Schwartz et al. [29] observed significant positive effects too, but only on short-term, with conservation fading successively over time.

While feedback generally shows effects, it remains an open challenge to establish long-term feedback systems and embed them into organizational routine. This in turn, reduces costs of one-time interventions and at the same time supports sustaining effects and learning about energy efficiency. Combining energy feedback for workers with common change management methods, which are most often in place in organizations today, thus poses an interesting opportunity.

### 2.2. BPM for organizational sustainability

Nowadays, the optimiziation of organizational practices often is managed through business process management approaches. The literature contains very diverse approaches and lifecycles in context of business process management methods. These approaches often involve various phase models that are repeated iteratively, to achieve a continuous improvement process (CIP).

Following van der Aalst [3] for example, BPM iterates through four phases. In the process design phase, business processes are identified and designed/redesigned. The configuration phase includes configuration and selection of the system and implementation of first-phase designs. In the enactment phase the configured systems are used to execute and monitor the operational business processes. Finally, during the diagnosis and evaluation phase, monitored information is analyzed to identify problems and to detect potential room for improvements. Working on practical guidelines, Jeston and Nelis [30] distinguish ten phases, starting from organization strategy phase to ensure that the organizations' strategy is clearly understood by project team members. After a development phase follow phases of implementation, realization of values and sustaining performance to guarantee the continued process agility and improvments.

Typically, approaches base on the deming cycle (shewhart cycle) of plan, do, check and act [31]. Accordingly, it is also legitimate to jump back and forth between this phases. Approaches within GreenBPM commonly refer to this model as well. Therefore, in case of a holistic infrastructure for collecting and distributing environmental information of processes, GreenBPM can adapt to existing BPM tools, instead of having to reinvent the wheel.

This affinity is reflected by the GreenBPM model of vom Brocke et al. [2], which expands the classic dimensions of the BPM model by Becker and Kugeler [32]. The commonality model includes six phases (processes description, workflow definition, workflow instance execution, their monitoring, workflow reporting and entire process reporting) evaluated by dimensions of: cost, quality, flexibility and time. Vom Brocke et al. add "Sustainablility" as a dimension of decision making, arguing for consideration of sustainability objectives in workflows. Deriving a GreenBPM approach from van der Aalst [3], Nowak et al. [33] demonstrate how integrating environmental information into BPM has effects on both general conduct (inclusion of further stakeholders) and design of specific phases (including new key figures). Therefore, sustainability as an issue influences the whole BPM process. Yet, this does not imply adding another stream of information, but sometimes just processing existing information a different way.

BPM-initiatives are commonly created by management as a result of strategic planning. These initiatives are usually driven by a top-down approach, often run by external consultants analyzing existing processes and (re-)designing them with respect to strategic goals. In order to do so, these consultants may gather information about processes in question as well as their surroundings using a number of sources. These sources include, but are not limited to, analysing existing process-documentation, running interviews with process stakeholders or analysing information created in software systems. Based upon the information gathered, each process is then modelled, analysed and altered by aforementioned consultants, aiming at reaching strategic goals set by management. It may be necessary to run multiple cycles until a sufficient stage for the model is reached. This model is then used to implement the process. Within this approach, the individual worker mainly appears in the organizational implement phase where all designed and developed processes will actually be brought to life [8]. Various strategies are used to ensure that people apply new process functions effectively and efficiently. These include: people change management strategies to overcome the not-invented-here syndrome; setup training strategies to overcome information and knowledge deficits; and management and controlling startegies to verify whether the actual process is in line with the process designed.

Approaches like the one described before can be considered a common practice within organizations. However, as this conduct limits the influence of people directly involved in or affected by the processes at stake to providing information, thus not allowing them to directly participate in design, this potentially limits peoples' motivation to adapt to the newly designed processes. Furthermore, by gathering information from single sources and putting it together afterwards, information about the process is only presented from a single perspective, thus leaving out important information.

In order to address aforementioned limitations, different approaches have been created in recent years, which can be subsumed as collaborative modelling [10], [12], [13]. At the centre of these approaches are workshop concepts in which stakeholders together with consultants jointly develop models of processes, analyse them and discuss possible changes. These approaches allow for stakeholders to directly participate in process design, thus potentially increasing their motivation to adapt to process modifications afterwards. Furthermore, these approaches also allow people to exchange perspectives within workshops, discuss alternatives and come up with a more sophisticated solution on which all stakeholders can agree.

Our concept of Co-GreenBPM stands in the tradition of these collaborative approaches. The concept especially targeting the analysis phase within an ongoing improvement processes. This phase is crucial for redesigning green processes since on the one hand it helps innovating organizations, but on the other hand also acknowledges existing organizational needs, contraints, and opportunities. Also, in this phase, key questions such as the following need to be addressed: what (enviromental) information is needed for whom, what (new) sources of information are to be used, and how can existing information sources fill possible gaps; how green process optimization had an impact on which work practices. Such questions, however, could not be answered once and for all, but pose moving targets, depending on individuals, their learning curve, roles within the organization and so on.

Therefore, our concept relies on a bottom-up management approach, which brings changes to the cycles used before in BPM considering the following issues:

1) In contrast to a top-down change management, in a Co-GreenBPM, next to BPM-specialists, all relevant stakeholders are asked for participation. Especially workers should be participate as they are experts of the demands of the situated work practices and opportunities provided by knowledge of the operational level. In general, the diversity of the stakeholder makes the process more complex having a negative impact on the efficiency of process design phase. Yet including a wide array of knowledge generally has a positive impact on the effectivity of the designed process as it takes the constraints and demands of the operational and strategic level into account. In particular to overcome the asymmetries of knowledges among the stakeholdes, modelling should take place in collaborative workshops where all participants are valued as experts for their domain.
2) In a green process the enviromental information are needed by various stakeholders (e.g. the management, the worker, the controller, etc). Hence, information needs to be tailored to the individual demands of different stakeholders. Therefore, providing individualized views on process and energy consumption information will enable stakeholders to use their tacit knowledge to reflect how processes and(!) situated work could be designed in more sustainable ways. Taking the energy's complex nature [34] this, however, raises the question, which kind of information workers need to reflect on their energy consumption behavior in terms of both, their own workplace and the organizations processes. Such tailored feedback for included stakeholders needs to provide basis for decision making when designing sustainable processes.
3) Traditional eco-feedback systems mainly focus on direct feedback to motivate people to act pro-enviromental with the current situation [17], [18]. In context of Co-GreenBPM eco-feedback should additionally empower people to reflect on their work practice with regard to green processes (and visa versa). Moreover, if polluting practices are not caused by a lack of

motivation, but current process design, workers should be empowered to become aware of this and contribute this knowledge to a continuous improvement process. In addition, such information should be accessible in collaborate GreenBPM workshops, so that it could be shared and discussed with the others.

## 3. Envisioning Co-GreenBPM

Taking the aforementioned approaches into account we envision Co-GreenBPM as being an approach that ties together individual energy feedback with mechanisms of collaborative modeling. This approach should make use of existing business process management tools, which have proven effective to change organizational structures.

In order to add to such tools' efficiency, we aim at adding the workers' perspective and local expertise to guide the definition of new workflows by making use of their knowledge on tweaks of everyday working activities. Workshops are in the center of this appraoach, in which people that involved in or affected by processes can discuss about their respective energy consumption, identify potentials and alter processes with respect to tapping these potentials. By bringing people from multiple teams and potentially multiple departments together is expected to foster the identification of energy saving potentials that go beyond individual workplace adjustments. We furthermore envision Co-GreenBPM as being a bottom-up rather than top-down approach. Using energy feedback systems that allow process stakeholders to view their current and past energy consumption in a suitable way for them and not only on an individual level but also with respect to the processes they perform, could enable them to identifiy space for optimization. It should then be possible for them to trigger aforementions workshops. Subsequently, the energy feedback allows assessing the impact of the changes that they made to a process and then may trigger another round of workshops thus at best resulting in a continuous process of improvement.

We, however, also do not neglect Co-GreenBPM being potentially triggered by management. But we argue that even when its being a top-down initiative, worker-level should be involved, thus integrating multiple perspectives and increasing motivation among participants to actively alter behavior afterwards.

## 4. Discussion & Research Agenda

We have addressed the gap between green processes and green practices by combing environmental psychological and organizational theories. We presented Co-GreenBPM as a conceptual framework to bridge the gap taking into account work practices as well as strategic process improvement. We further outlined the key challenges of how enviromental information should be included into a collaborative GreenBPM in order to enable stakeholders to make sense of information, thus tapping the full sustainability potential in organizations.

In the next step we want to enrich our theoretical consideration by empirical work. We further want to investige in more detail on effective ways including environmental information to identify green process improvments and used such information in collaborative modeling workshops.

This covers two main interests: On the one hand, we will investigate on the various views, interests and motivations on green process and what kind of environmental information is needed, both, everyday and at strategic work level. This also includes ways of feeding back such information effectively and efficient to stakeholders in a collaborative BPM process. On the other hand we will research on impact of environmental information on decision-making, processes modeling and process adoption. Concerning this, we are currently approaching a variety of organizations including manufacturing, trading sector and office work. Based on a Action Research Methodology [35] we conduct interviews with different stakeholders within the companies including workers, energy managers and manager. We also measuring the organizational energy consumption information and create first mock-ups how to inform the various stakeholders by providing tailored information.

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# Sustainability Aware Process Management using XML-Nets

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## Abstract

This paper gives a short overview about sustainability aware process management using XML-nets. Sustainability management is one of the upcoming movements in the 21st century. Communal and private organizations are interested in finding and using "sustainable" solutions and practices. But, there is a lack of available solutions and practices. In the 21st century also, software systems and their underlying business processes are ubiquitous and fundamental for most of the organizations of the industrial society. But, until now, sustainability is not sufficiently considered by business process engineering. Hence, to support the transition to sustainability, one must have sustainability (aspects) integrated into the business processes. Consequently, in this paper a holistic approach is presented to support sustainability aware business process management.

To realize such an approach, sustainability aspects must be integrated into the business processes life cycle. Thus, first to assist the stakeholder when modelling, designing, executing, and monitoring the business processes a process model is developed and explained. Second, sustainability aspects are conceptualized and integrated in a business process modelling language.

## 1. Introduction

Sustainability is an important part of society, politics and economics nowadays. Organizations have started to realize that not only cost savings can be reached with sustainability but even long-lasting business success. Thus, next to cost, time, and quality, also sustainability is a goal to reach. A business process is a set of activities that are executed according to certain rules to achieve a predefined business goal in an organization. Thus, if sustainability is not supported this may threaten the execution of business processes. So, when modelling, simulating, improving, and implementing business processes the additional dimension sustainability needs to be taken into account.

Nevertheless, a lot of organizations have problems to integrate sustainability into their daily business ( [1,2]). Even when the companies are aware of the importance the additional effort needed to integrate sustainability management into their daily business seems to high. There exist a lot of frameworks regarding sustainability (e.g. Green Supply Chain Operations Reference (SCOR), Greenhouse Gas (GHG) protocol) and defined Key Performance Indicators (KPIs) (e.g. carbon footprint). But, the approaches so far bear the problem of being transparent, being analysable and (very important) comparable. One of the biggest challenges (next to getting the appropriate data of course) is to measure the sustainability of the specific products (e.g. emissions, water waste etc.) ( [1,3]). One way to solve this resource allocation problem is to use business processes. There, the costs can be directly linked to the activities of the processes [4]. Thus, in order to facilitate the awareness and application of sustainability in daily business an integrated approach of sustainable aware process modelling and simulation approach should be used. The integration of sustainability on a business process level would create a lot of different possibilities

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to understand and change the impact on environment, economies, and society on activity product as well as company level [1].

But, in traditional process management approaches sustainability and processes are not sufficiently integrated. Sustainability is usually not explicitly described in the relevant process models. In order to realize sustainability awareness in process management, one must have the process risks conceptualized and integrated into the complete process lifecycle process modelling, simulation, improvement, implementation, execution, and evaluation.

Thus, I present a methodology of sustainability aware process modelling, simulation, and improvement. To that end, in the following I firstly describe my understanding of sustainability and then I present related work. Next, my methodology for sustainability aware business process management is presented: An approach to facilitate the documentation, modelling, simulation, and evaluation of sustainability alongside a business process. Last, I present my suggestion for the extension of a business process modelling language.

## 2. Sustainability

To clarify my research objective I now explain how sustainability is defined in the given context, what aspects I am taking into account when working with sustainability, and which level of impact (positive and negative) it is referred to when including it in the approach.

In this paper I use one of the most cited definitions of sustainability, the definition of Brundtland from the Report of the World Commission on Environment and Development, saying that we should make sustainable use of our planet by maintaining its function to further fulfil human needs [5]. This definition is actually referring to sustainability as sustainable development and this is what I also refer to (as I am working on an engineering approach). But of course, no single product can be sustainable in the sense of sustainable development because this definition has a global scope (c.f. [6]). Therefore, I use sustainability indicators. Indicators are used to measure and thereby identify actions that are more beneficial to sustainability than others [6]. Indicators themselves are composed of metrics, which in turn are composed of measurements. In the given context sustainability is characterized by two different indicators[2] [6]:

- Resource oriented indicators: These indicators cover the environmental aspect of sustainability. The term footprint is somehow the common used metaphor for resource oriented sustainability indicators (e.g. carbon footprint).
- Well-being oriented indicators: These indicators cover the fulfillment of human needs aspect of sustainability. Here it is difficult to find appropriate metrics to measure the fulfillment of human needs.

Please not that sustainability can only be gained by taking the two aspects into account: one need to fulfill human needs and take care of the global resources [6].

When talking about sustainability it is also important to explain the different levels of impact sustainability can have in connection with business processes. This leads to three levels of impacts: direct impact, indirect impact, and socio-economic impact (based on [6,7]):

- Direct impact: Direct impact refers to the life cycle impact. It includes any impact directly caused by the software system production and use (e.g. energy usage, e-waste production, emissions).

[2] I use indicators to be able to measure any impact (positive or negative).

- Indirect impact: Indirect impact refers to changes on a micro-level. It includes actions that are enabled by using software systems as well as by changes of software systems. These are for example process improvements, media substitution and behavioural or technological changes.
- Socio-economic impacts: A socio-economic impact refers to changes on a macro-level. It includes changes on economic structures and on institutional level.

These impacts are, of course, connected. More precise, indirect impacts are enabled on the basis of direct impacts and socio-economic impact emerges from indirect impact actions and, in turn, influences them. Following, these different levels of impact are discussed in more detail.

Most obvious are the direct level impacts. They refer to the environmental and social impacts caused by the production and the usage of software systems. They can be measured using performance requirements, network bandwidth etc. The direct environmental impact is quite often measured using the Life Cycle Assessment (LCA)3. The total impact could then be allocated to a functional unit during the use phase and can then be allocated to a functional unit [6]. Indirect impacts are already more complicated. They refer to actions that are enabled by changes of software systems on an organizational, behavioural or technical level. This might be for example industrial automation reducing (cost of) capital, energy, and information. Three types of changes are possible; all of them are based on resource substitution [6]:

- Process improvement: Here an immaterial resource substitutes a material resource.
- Media substitution: Here a material resource substitutes another material resource.
- Externalization of control: Here an immaterial resource substitutes another immaterial resource.

Last, the socio-economic impacts refer to changes that lead to substantial changes in the institutional structures such as new laws, politics, or social norms or economic structures such as the networked economy. The above-mentioned levels of impact are all echoed in the now presented model of sustainability aware software system engineering. But, they are enriched with additional connections between them through the explicit integration of business processes and their life cycle. Moreover, also impacts on sustainability triggered by any changes of the business processes are taken into account in the presented model. Thus, changes can be triggered by any level of impact and can have influence on any other level. At business process level, changes are made, of course, on an indirect level. The supporting IT is having a direct level impact and though the culture and strategy of an organization the socio-economic level is also impacting business processes. After having defined sustainability, in the given context, I will next describe the related work on sustainability aware business process management.

## 3. Related Work

The related work can be subdivided into four parts. The first part it focusing on sustainable indicators (e.g. [8,9,10]). In these work indicators (basically only environmental indicators named Environmental Performance Indicators or Key Ecological Indicators) are discussed and their importance to measure process improvements based on sustainability aspects is emphasized. The second group is focusing on how these indicators can possibly be integrated into business process management software systems (e.g. [11]). Here, the focus is especially on BPMN as the modelling

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[3] LCA is a systematic analysis of the environmental impact of a product during its complete life cycle (“from cradle to grave”).

language and on CO2-Emmissions and waste products (e.g. [12]). Another group is work related to the extension of business process management software systems with sustainability aspects and indicators (e.g. [13]). There the authors do not specifically explain how they plan to extend an existing modelling language and the software systems. The extensions are merely on an abstract conceptual level. Last, there is research work on process models on sustainability aware business processes management (e.g. [14]). But, most of the work is focusing on an one time reengineering approach base on Hammer and Champy [15] and not on continuous reengineering based on sustainability. Also, the presented work have found first solutions on sustainability aware business process management, none of the presented approaches is following a holistic approach including the different aspects of sustainability (environmental and well-being), a process model, and a modelling language to model to facilitate the documentation, modelling, simulation, and evaluation of sustainability in business processes.

## 4. Methodology for Sustainability Aware Processes

I present a methodology for sustainable process management (see Figure 1). The proposed methodology starts with a detailed process model, which is developed according to existing risk and compliance standards. Then the model is simulated and improved. At this step relevant sustainability factors (e.g. carbon footprint) are linked to the process activities. By linking the relevant sustainability factors to the process we seek to improve the planning of the process and make the process models comparable. Now, we built sub-processes with the different sustainability factors. These sub-processes can be used to evaluate process improvements by simulation. Finally, the improved process can be implemented and executed. Our methodology includes the following four steps: initial modelling of the original process; linking the process sustainability factors to the process activities; simulation and evaluation of process improvements; systematic selection and transformation of the original process model into an improved process model. In the following, I describe these four steps in detail.

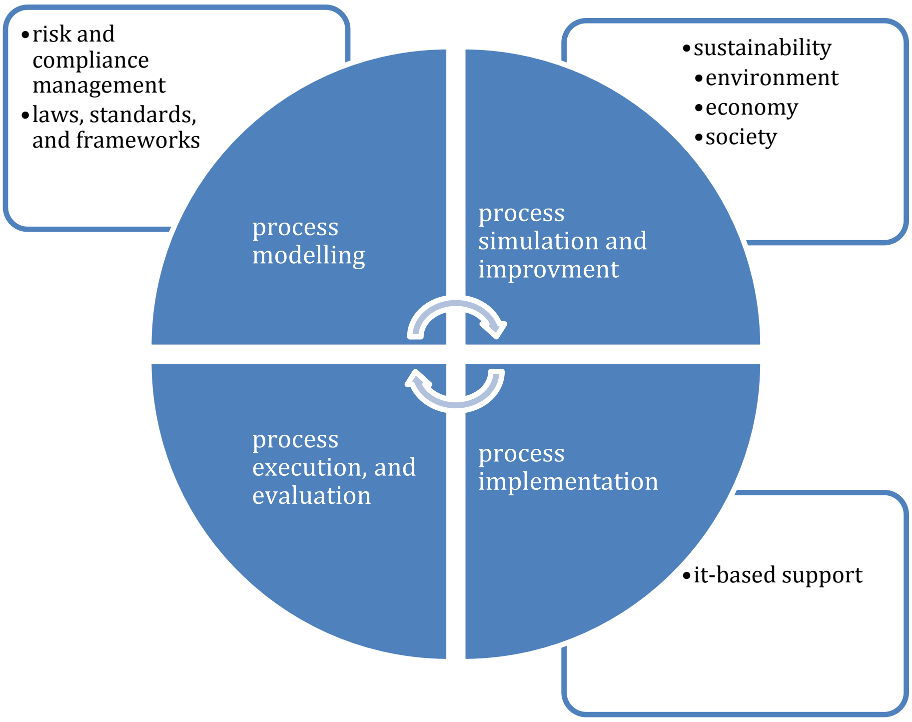


*Figure 1: Sustainability Aware Process Management*

### 4.1. Step1: Process Modelling

Basis for identifying sustainability indicators is a detailed process model because sustainability indicators are related to the elements of this model. Only a detailed specification of these elements can result in a complete identification of the related sustainability indicators. Figure 2 shows the UML conceptual model of a business process and sustainability. The process itself may be composed of various sub-processes. Eventually, processes are defined through a set of linked activities. Carrying out an activity needs various resources, which can be human (so-called actors), or non-human (hardware resources for instance). An artifact can be input or output of an activity. In this step the socio-economic level also influences the process model through the risk and compliance management as well as laws, standards, and frameworks. Also, in this phase, a strategy with regard to sustainability is defined and goals specifications are determined. For example a goal could be to improve the image of the organization using sustainability. The outcome of this step is the basis process.

### 4.2. Step 2: Process simulation and improvement

In this step we assess sustainability. The objective of sustainability assessment is to identify the sustainability indicators and link the to the organizational goals as well as to the business process activities, for example the CO2-Emission or the e-waste of activities. In general sustainability assessment practices are manifold. Possible are analytical methods like for example LCA, checklists, and questionnaires as well as creative methods like brainstorming and expert interviews. We are conducting sustainability assessment in three steps: First, we are identifying the sustainability indicators and then we link them to the business process. Third, we develop process improvements to increase (positive) sustainability impact.

As stated above in a business process reduce the negative impact one can either substitute an immaterial resource substitutes a material resource (process improvement) or a material resource substitutes another material resource (media substitution), or immaterial resource substitutes another immaterial resource (externalisation of control). Thus, the cause of a sustainability impact “the resource” either needs to be substituted or the resource needs to be improved or externalized. For example in case of a non-human resource the hardware needs to be upgraded or the software updated or changed. Each possible process improvement is modeled explicitly by sub-processes and the actual process model will be refined. The basic process and the refined process models have to be simulated to determine the process Key Performance Indicators (KPI) such as flow time (duration) and costs for each sustainability improvement in order to analyze and possibly reorganize the actual process. As stated in [16] this is usually be done by simulation.

To run a simulation the input parameters need to be initialized and the model needs to be tailored to the organization [17]. The data to parameterize the process model must be provided by the organization. We are aware that accurate data is not always available but as stated in [17] useful strategies to overcome these problems are available. But this goes beyond the focus of this paper. All possible process improvements need to be considered. For this reason, different process variants concerning a certain sustainability indicators can be developed. For each of these process variants the values of the KPIs are determined. Therefore we need a quantification of improvement that is related to a sustainability reduction treatment.

### 4.3. Step 3: Process Implementation

In this step the most satisfying process variant in terms of stakeholder preferences needs to be chosen and implemented. This could be an improved one with a sustainability impact improvement included or the basic process. Only the acceptable process variants determined in step 2 are considered. If the stakeholder is able to specify his preferences for increasing cost and flow time by weights then using a weighting function is possible. Also, for further sustainability control, the sustainability indicators need to be directly implemented in the process.

### 4.4. Step 4: Process execution and evaluation

Here, it is important to continuously monitor and further control the process, also additional adapting and further improvement of the processes with regard to the sustainability impact needs to be conducted. Step two to four can literately be repeated. Next we discuss shortly a possible extension of a business process modelling language.

## 5. Suggested extension

A business process is defined as a set of manual, partially automated or automated business activities, executed according to given rules with respect to certain business goals [16]. During execution business process activities need to be coordinated such that the given rules are observed and the business goals are met. Additionally, resources needed for execution of activities have to be provided (see Figure 2). The process itself may be composed of various sub-processes. Eventually, processes are defined through a set of linked activities. Carrying out an activity needs various resources, which can be human (so-called actors), or non-human (hardware resources for instance). An artefact can be input or output of an activity.

The basis of techniques and tools for analysis and simulation of business processes are business process models. There exist several modelling languages for business processes like UML Activity Diagrams, EPC, BPMN and Petri nets. As stated earlier I use XML nets, a variant of high-level Petri nets [18]. Petri nets combine the advantages of a graphical representation of business processes with formal semantics and a mathematical foundation. Numerous Petri net variants have been proposed, which can be subsumed in elementary or high-level Petri nets. In elementary Petri nets, places contain tokens (black dots), which represent anonymous objects, whereas the flow of the tokens simulates the process flow. A transition box inscribed with two vertical bars indicates that the respective transition is refined by another Petri net. Repeated refinement of transitions leads to a hierarchical representation of a process. In high-level Petri nets tokens represent identifiable objects. In XML nets [18], a place is typified by an XML schema. Thus places can be interpreted as containers for XML documents representing process-relevant objects like invoice or sustainability indicators. The edges are labeled with filter schemas and thereby describe the process objects that are relevant for the following transitions or places and the way these objects are manipulated. A transition can be inscribed by a logical expression of the variables that appear in the labels of the adjacent edges. The expression can be evaluated either to true or false for a given instantiation of the variables. The flow of an XML document is defined by the occurrence rule of transitions. A transition is activated if every place in the pre-set of the transition contains at least a valid XML document which observes both of the conditions specified in the filter schema of the adjacent edge and in the logical expression of the transition. Additionally, the generated new XML document cannot already exist in the post-set-places. Then the transition can fire and the generated new XML document will be assigned to places in the post-set of the transition. Simulation of a business process enables process modelers to evaluate the impact of process changes prior to their implementation in real environment. By evaluating dynamic process parameters like throughput, costs, cycle times or resource utilization simulation enhances process performance analysis and provides decision support for realizing process changes. Also, using simulation possible impact of sustainability indicators can be evaluated.

In the following I am describing the conceptual model showing my understanding of sustainability and the connection to business processes as well as the surrounding relevant context (see Figure 2). Sustainability is divided into ecological and well-being aspects and are measured using indicators.

Indicators are linked to process activities. Organizational culture and strategy are influencing the goals with respect to sustainability. Additionally, Sustainability has different levels of impact. The processes are executed by software systems.

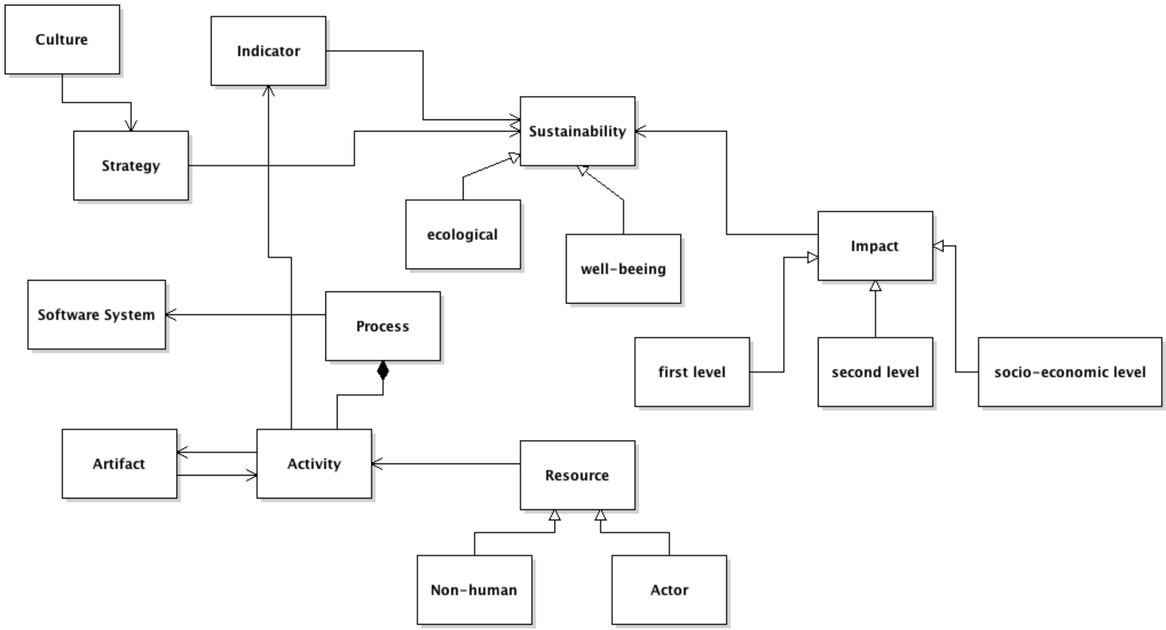


*Figure 2: Conceptual Model of Sustainability and Business Processes*

To reduce the possible sustainability impacts, the sustainability factors need to be managed. To manage them, the context-specific characteristics in respect to the situation, where an (negative) impact occurs and how reduce them, need to be analyzed. Hence sustainability impact reduction during business process execution is directly coupled to the business process and the sustainability indicators. For this reason we suggest an approach based on modelling the business process and the associated sustainability indicators.

## 6. Conclusion

Of course, I am not the first to examine business processes and environmental sustainability. But, business process approaches so far have only concentrated on green aspects and they have not developed a holistic approach. So far only single solutions for example for carbon emissions [1] have been developed and none of the approaches is able to simulate possible different scenarios with the help of a modelling language like petri-nets. In addition, the presented approach can help to improve sustainability in business processes and therefore the organizational performance. Also, the presented approach can even be used for environmental accounting and sustainability reporting as well as environmental risk-assessment.

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# Mobile technologies and personalized environmental information for supporting sustainable mobility in Oslo: The Citi-Sense-MOB approach

Nuria Castell[1], Hai-Ying Liu[1], Mike Kobernus[1], Arne J. Berre[2], Josef Noll[3], Erol Cagatay[4] and Reidun Gangdal[4].

## Abstract

Urban and peri-urban growth is increasing world-wide and Europe is now one of the most urbanized continents in the world. Oslo is one of the fastest growing cities in Europe. This creates pressure on its infrastructure, including traffic and environmental urban quality. Additionally, vehicular traffic is a major contributor to $CO_2$ emissions, which impacts climate change. It is recognized that air quality is a major factor for human health however, although different measures have been implemented, improving air quality and lowering carbon emissions still remains an unsolved problem in Oslo.

The main objective of Citi-Sense-MOB is to demonstrate how using innovative technology to continuously measure environmental data at the road level combined with innovative Information and Communication Technologies (ICT) can help to create a dynamic city infrastructure for real-time city management, access to personalized environmental information and sustainable development. The output from the project will be mobile services for citizens and authorities based on the use of near real-time data on air quality and $CO_2$ emissions at road level.

The societal importance of these services arises from a need to mitigate the effects of air pollution and climate change, and to combat respiratory diseases related to traffic-related air pollution.

In order to motivate citizens to use the information generated by the project, Citi-Sense-MOB will provide them with personalized environmental information, as for instance alerting systems when pollution levels exceed a critical threshold. Customized information will also be provided to authorities consisting of detailed air quality maps at high spatial resolution and an evaluation of possibilities to reduce $CO_2$ emissions by improving driving practices in public urban fleets.

## 1. Introduction

Air pollution is one of the factors negatively affecting quality of life within cities. Many areas of Europe still have persistent problems with outdoor concentrations of particulate matter (PM), nitrogen dioxide ($NO_2$) and ground level ozone ($O_3$).

In cities, road traffic is the dominant local source of pollution, along with domestic combustion, which has been growing over the last few years [1]. At the same time, private vehicle use in Europe is growing, and a further doubling of traffic is predicted by 2025 [2]. Studies show that traffic-related air pollution may cause major adverse health effects in the population living at or near air polluted roadways [3]. More studies are needed to characterize personal exposure to traffic-related air pollution, and to better understand the link between traffic-related air pollution and public health effects [4].

Additionally, traffic emissions also play a key role in carbon dioxide ($CO_2$) emissions. Energy consumption in urban areas – mostly in transport and housing – is responsible for a large

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percentage of $CO_2$ emissions. Because of their larger consumption of fossil fuels, cities emit 76% of the world's energy-related $CO_2$ [5]. Consequently, cities are key players in efforts to reduce $CO_2$ emissions and mitigate the effects of climate change [5]. Monitoring road traffic and associated efforts to devise and evaluate strategies to reduce exhaust emissions from road traffic will benefit both air quality and climate change.

Oslo is experiencing rapid demographic growth. Today motorized traffic in Oslo creates problems with congestion, pollution and $CO_2$ emissions. Figure 1 shows the annual average concentration of $NO_2$ levels in Oslo and other 4 cities in Norway in the last years. Oslo has been persistently exceeding the annual limit value for $NO_2$ established in the EU air quality directive for health protection for the last ten years. The main source of $NO_2$ is road traffic. Sustainable and environmentally friendly mobility is an essential part of Oslo's new vision for green growth and improved quality of life. Developing tools to support green initiatives is crucial. The core objective of Citi-Sense-MOB is demonstrating innovative tools to support sustainable development in Oslo.

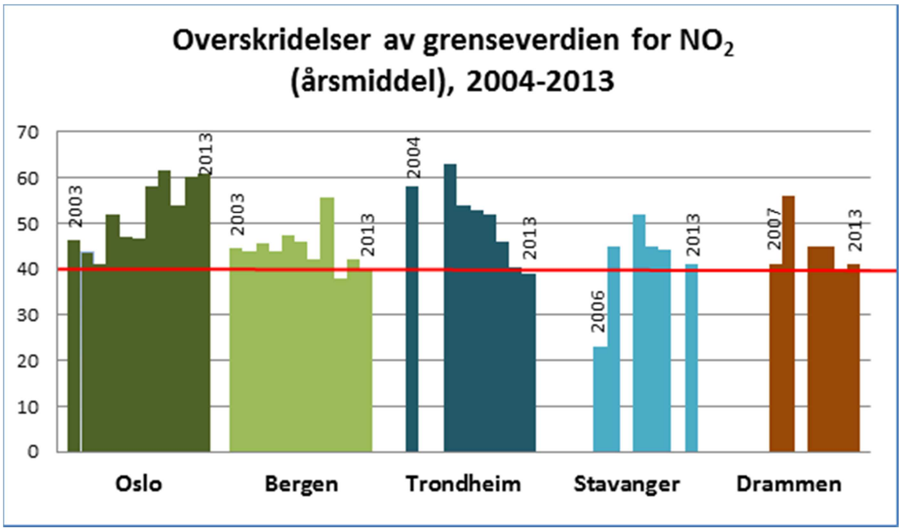


*Figure 1. Annual average concentration of NO2 in five main cities in Norway. The red line marks the annual limit of 40 µg/m$^3$ established in the EU legislation for health protection. Data Source: http://www.miljodirektoratet.no/*

The Citi-Sense-MOB project will develop the infrastructure to continuously monitor environmental data at street level using micro-sensors mounted on mobile platforms, such as buses and bicycles. The project will enable citizens to participate in monitoring their environment by using sensor equipped bicycles, data collected from sensors mounted on buses and by providing their own feeling about the air quality in their surroundings. All data collected will be available to the citizens in a user-friendly and visually informative layout, using both web services and mobile phone apps. The output from the project will be mobile services for citizens and authorities based on the use of near real-time data on air quality and $CO_2$ emissions at road level.

The project will contribute to raising public awareness on the links between climate change and air pollution, and on the impact of air pollution on health. In addition, the project focuses on promoting behavioural changes designed to foment less polluting transportation methods and to help citizens to chose less polluted routes when walking or commuting in the city.

In order to motivate citizens to use the information generated by the project, the project will provide them with personalized and customized information specific to themselves. Such services will include alerting systems when pollution levels exceed a critical threshold, individual exposure along a track and advice on how to mitigate the effects arising from adverse environmental conditions. Citizens will also be able to report how they feel the air quality in their surroundings following a colour scale from green meaning “I don’t have any symptoms” to red meaning “I have severe symptoms and I can’t perform my normal activities”.

The major benefit for the citizen will be access to timely knowledge of air quality levels in their immediate surroundings or at selected locations. This knowledge will help the citizen make the decisions needed to maintain and improve their quality of life.

Customized information will also be provided to authorities consisting of detailed air quality maps at high spatial resolution and an evaluation of possibilities to reduce $CO_2$ emissions by improving driving practices in public urban fleets.

Citi-Sense-MOB will collaborate with the ongoing project CITI-SENSE[5]. CITI-SENSE aims at enabling citizens to contribute to, and participate in, environmental governance by using novel technological solutions. CITI-SENSE will employ static sensors deployed in cities and personal sensors carried by people. The data from CITI-SENSE and Citi-Sense-MOB will be integrated within a common data processing system, utilising an open data approach.

Citi-Sense-MOB will also test the technological solution for urban fleets developed in the framework of the UrVamm project in Spain [6], which combines the collection of air quality information and driving patterns. This solution aims to encourage continuous learning towards more efficient driving practices with a consequent reduction in fuel consumption and $CO_2$ emissions.

Section 2 provides an overview of the project architecture and the data management, from data collection to data dissemination; section 3 discusses the methodology, implementation details and first preliminary results. Finally, Section 4 provides conclusions and details of further work building on the results from Citi-Sense-MOB.

## 2. Citi-Sense-MOB Architecture

The main objective of Citi-Sense-MOB is to demonstrate how using innovative technology to continuously measure environmental data at the road level combined with innovative Information and Communication Technologies (ICT) can help to create a dynamic city infrastructure for real time city management, personalized information and sustainable development. The output from the project will be mobile services for citizens and authorities based on the use of near real-time data on air quality and $CO_2$ emissions at road level.

The Figure 2 shows the architecture of Citi-Sense-MOB. The measuring system is composed of sensors mounted on mobile platforms (i.e., buses and electrical bicycles) to monitor atmospheric gases concentrations at road level (i.e. $NO_2$, NO, $O_3$, CO, $SO_2$ and $CO_2$). The buses will have an additional sensor to gather data on driving practices (e.g. instant speed, acceleration, etc.). The continuously gathered data are then transmitted to a server for processing (e.g., automatic quality control, generation of maps and graphics, etc.). The data from the sensors is complemented with other available data as for instance data from the air quality reference monitoring network, air quality models, sensors from the sister project CITI-SENSE and pollen data. The processed data are presented in a user-friendly and visually informative layout using both web solutions and mobile phone applications. Citizens will also be able to use their mobile phone to upload information on how they feel the air quality in their immediate surroundings. That information will allow citizens to visualize both air pollution and pollen levels and how they are affecting the people.

[5] http://www.citi-sense.eu

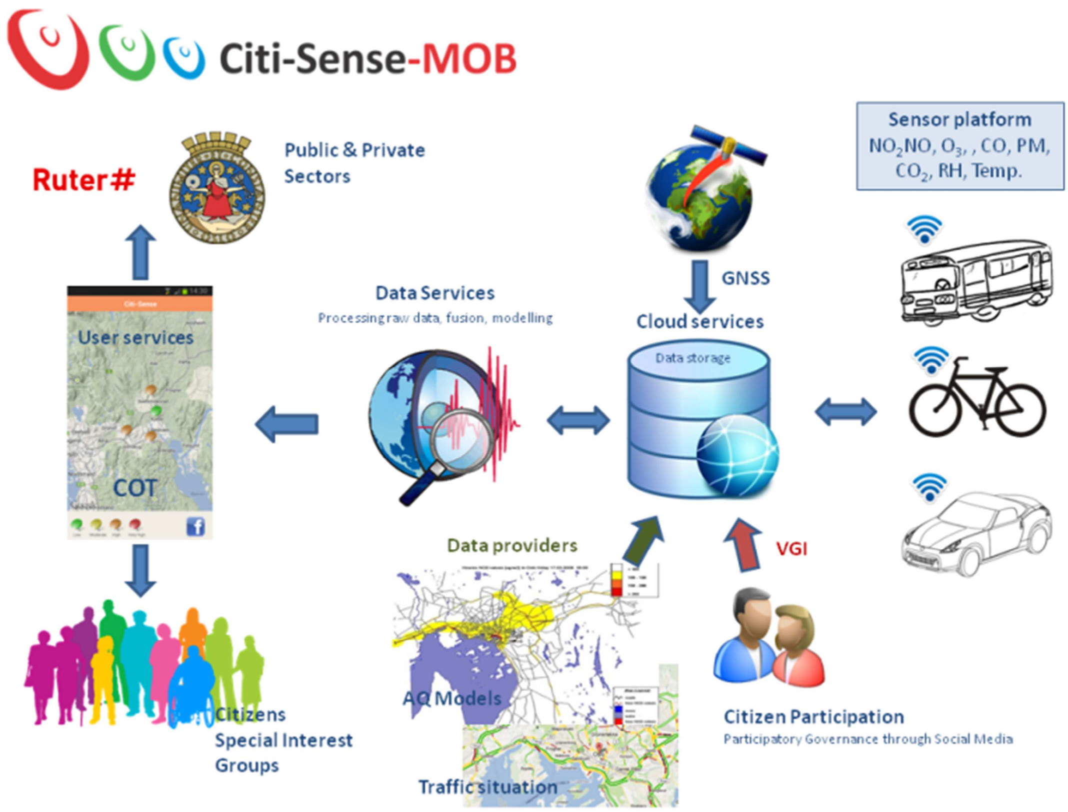


*Figure 2. Citi-Sense-MOB system overview.*

Involving and empowering citizens in environmental monitoring and decision-making is regarded as increasingly important by scientists and policy-makers, aiming to improve our opportunities to observe, understand and take concomitant actions to protect the environment.

Citi-Sense-MOB will develop a series of applications and services with focus on environmental management. In order to understand and address the needs of citizens, local authorities and transport agencies, the project has involved different target groups of users (e.g. health, transport and environment authorities, cyclists, etc.) to provide feedback on the services.

An example of the services of interest of transport agencies and environment authorities is fostering eco-driving practices. Transport agencies are interested in reducing fuel consumption while the environment authorities are interested in reducing $CO_2$ emissions from urban fleets. The sensors deployed in the bus will provide continuous geo-temporally referenced environmental and eco-driving data on fuel consumption and estimated $CO_2$ emissions. This generates feedback to the user, encouraging drivers to drive in a manner that creates less pollutant emissions as well as providing savings in fuel consumption.

A second example of services of interest of citizens will be the possibility of getting personalized air quality information on the mobile phone. The user will be able to check the air quality in their immediate surroundings, select less polluted routes to walk or cycle, and track their individual exposure while moving in the city. To do that, we will link data from the position provided by the GPS of the user mobile phone with air quality data from sensors and air quality models to estimate personal exposure to air pollution or provide information of air quality at the specific user location with the possibility of configuring alerts, for instance when the current Air Quality levels exceed certain thresholds defined by the user. An innovative service is the possibility for the citizens to report on "how they feel". Table 1 shows the colour scale for the Air Quality Index that will be computed using the data from the sensors, the Pollen Index and the feelings and symptoms reported by citizens. The same colour scale will be followed for the three indexes, facilitating their interpretation by the user. The analysis of the big data set generated will help clarify relationships between air quality, pollen, meteorology and health. In the future, the identification of what particular patterns trigger symptoms in a person will help to personalize people's information and provide them with pre-alerts to help them to take the necessary measures to minimize symptoms.

| Colour scale | Meaning AQI | Meaning Pollen | Meaning Feeling |
|---|---|---|---|
| Green | Good | Low | I don't have any symptoms. |
| Yellow | Moderate | Moderate | I have mild/moderate symptoms. I can do my normal activities. |
| Orange | Unhealthy for sensitive groups | High | I have moderate/severe symptoms as eye irritation, problems breathing, etc. It is affecting my normal activities. |
| Red | Unhealthy | Very high | I have severe symptoms. I can't do my normal activities. |

*Table 1. Colour scale employed to represent the pollution levels, the pollen levels and people reported feelings, and its meaning.*

The data gathered will allow us to develop statistics on air pollution along routes, perform comparative studies between alternatives commuting lanes to improve travel times and lower environmental impact of travelling or create a more detailed map of air pollution highlighting the green and hot spot areas regarding air quality. The goal is to motivate citizens and other stakeholders in the measurement of air quality. These measurements can thus be an input to help citizens to select healthier routes, or for city managers to plan cycling paths and kindergarten and school locations, having air quality in mind. Though piloting with a smaller number of transport vehicles, we expect that air quality measurements will become commonplace as part of future transportation systems.

The project will address privacy concerns. The user will control de data about themselves, and they will agree in the terms and conditions the data can be used. Moreover, the data collected won't be related to sensitive personal information but to an agent number. When creating the collective maps a similar solution that the one followed by Drosatos et al. (2014) will be developed creating aggregated maps that respect user-privacy.

## 3. Methodology and preliminary results

### 3.1. Road trials

Citi-Sense-MOB will obtain air pollutant concentrations at road level. To do this, it will install low-cost sensors on mobile platforms, namely, buses and electrical bicycles.

Buses have been selected because they have a very well maintained vehicle infrastructure. Any malfunction on the platform can be detected and fixed when the bus is in the garage. They have well-known routes through the city, facilitating the analysis of the data as it is possible to compare pollution patterns over time. The buses work continuously, thus generating a large amount of data for data analysis algorithms. The data collected can help increase our knowledge about pollutant concentrations at road level.

Additionally, road traffic is one of the main contributors to $CO_2$ emissions. Local authorities and transport agencies have green agendas that aim for a reduction in $CO_2$ emissions. The monitoring platform installed on buses, combining a system for air pollution data collection and monitoring of driving efficiency, will empower the drivers to adopt a more environmentally friendly driving behaviour, helping the bus company achieve fuel savings and the environment authorities to accomplish with the green agendas. Due to the number of buses running continuously in the city, reductions in their emissions should provide significant reductions in urban greenhouse gas emissions.

In addition to the vehicular platforms, sensors will be also mounted on electrical bicycles. Bicycles can cover parts of the city that are not accessible by car, for instance parks and pedestrian areas. Furthermore, bicycle lanes often run alongside the main roads. This will allow to study for instance the gradient between measurements at the centre of the road, and on the side of the road, used by pedestrians.

To guarantee the quality of the data and the near-real-time communication between the sensor platform and the database, a testing phase with a suitable number of sensor units is currently being developed. During the test phase, one air quality sensor is tested on an electrical bicycle and two sensors from UrVAMM have been mounted on buses and tested in their daily routes. This test phase will be a “live” test to identify unexpected issues and verify that the whole system functions as expected before the full deployment study. In the full deployment it is expected to have 10 buses and two electrical bicycles.

The Figure 3 shows normalized CO levels generated during several bus routes. The methodology for the analysis of air quality in Citi-Sense-MOB is based on the generation of a high volume of routes that cover as much of the city as possible. The data gathered will allow assessment of the spatial-temporal distribution of pollutant concentrations in a variety of environments where data are not available, and will help identify areas where elevated pollutant concentrations may occur. The data gathered by the air quality sensors and the position will be used to generate air quality maps at street level.

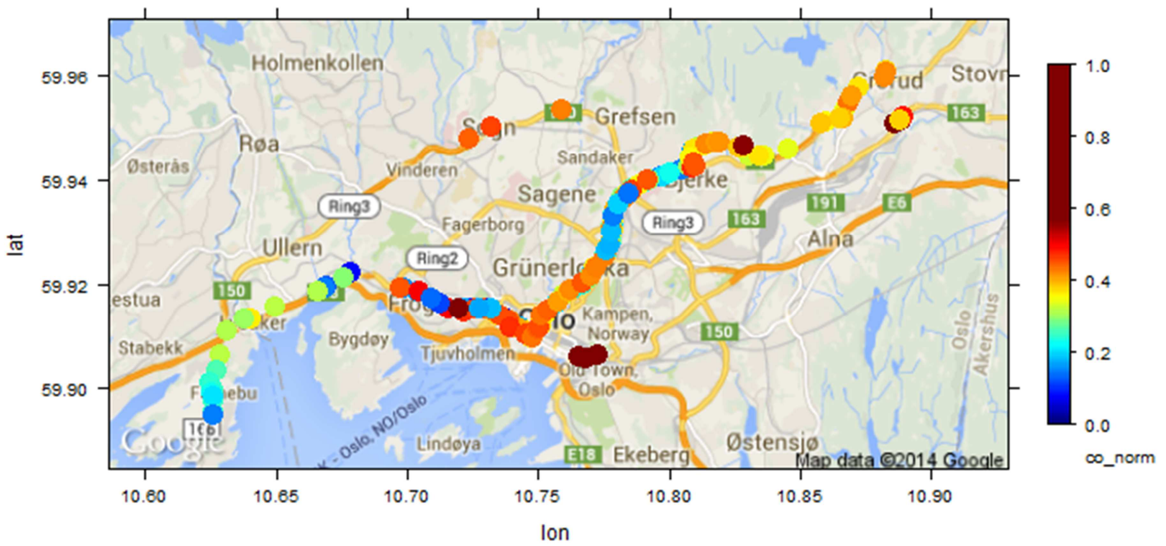


*Figure 3. Normalized CO levels generated during several bus routes.*

### 3.2. On-line data visualization

Citi-Sense-MOB will collaborate with CITI-SENSE and all the information from the sensor platforms will be collected in a central database to be further processed, e.g., automatic quality control of the data, data assimilation, and calculation of air quality indexes. The database will include data from fixed sensor units deployed in the city, mobile units mounted on buses and bicycles, and personal units carried by people. The Information and Communication Technology

(ICT) architecture will be aligned with the Global Earth Observation System of Systems (GEOSS) architecture in order to potentially make that available also through this.

The storage service is designed to support multiple input and output structures. For instance, the storage service must be capable of collecting data from different types of sensors, which may sample different variables and have different data formats. Currently, the central server is based on a Web Feature Service Interface Standard[6] (WFS) server and can support various access mechanisms.

The visualisation of the data will be performed using a variety of techniques. Online Visualisation will be implemented using the open source GIS (geographic information system) Server GeoServer application which will be the backend for both web-based and mobile mapping of the data provided by the project. Initially, for the online visualisation to be carried out in near-real-time, the users will be provided with maps showing the locations and measurements of all currently active sensor nodes. The sensor observations will be shown as points overlaid on a street map (e.g., Google Maps or OpenStreetMap), and thus will provide measurement location information to the users.

The feelings reported by the citizens will also be overlaid on a street map together with the information from the sensors employing a different symbol allowing the users easily differentiate between sensor data and citizen reported data.

For many of the planned applications of the Citi-Sense-MOB project, such as finding the least polluted route through a city or estimating the personal exposure, it is necessary to compute a gridded raster of urban air quality. This can be accomplished by interpolating the individual observations in an intelligent and objective way. In order to be able to produce on-line near real-time maps a technique that can be fully automated and does not require long computational time is required. A data fusion technique using a base map generated with an air quality model and the real-time data from the sensors will be employed.

The visualisation of the data should be user-friendly and easy to understand. It is an objective of the project to provide citizens with the means to understand how air pollution data relates to them personally. This is of special significance for health interest groups, as they need a tool that enables them to take actions to mitigate the adverse effects of air pollution on their health.

### 3.3. Social networks

Citi-Sense-MOB develops various social media platforms to foster communication between the project's partners, stakeholders and users, and to facilitate citizens' engagement, participation and network building. These social media platforms are all about engagement, participation, relationship building and dissemination. Every platform encourages its users to take part, by commenting on what they see and getting involved in conversations with others. This makes it a particularly useful vehicle both for informing users and for gaining their feedback.

The project is using on-line platforms as Facebook, Twitter, YouTube, LinkedIn, Forums and Blogs to disseminate the information and get feedback from citizens. Additionally off-line modes as meetings and workshops, newspapers and magazines, television, brochures and scientific publications are also used to reach people that is not using internet or other stakeholders easier to be reach by off-line modes (e.g. authorities and scientific communities).

For Citi-Sense-MOB, social media is one of the tools for succeeding with collaborative participation and citizens' empowerment. Citizens' empowerment in Citi-Sense-MOB can be regarded as a continuum, from low involvement where citizens receive relevant information to

[6] http://en.wikipedia.org/wiki/Web_Feature_Service

relatively high involvement, where citizens contribute by carrying sensors and reporting information.

## 4. Going forward

The Citi-Sense-MOB project is setting the stage for innovative developments in air quality monitoring and individual exposure assessment. By demonstrating the feasibility of mounting sensor units on mobile platforms and exploring how these data can contribute to a more comprehensive understanding of air quality monitoring, we hope to show that complementing existing air quality monitoring networks is not just feasible, but highly desirable.

Through the direct involvement of citizens, allowing subjective observations as well as contributing with sensor measurements riding the Citi-Sense-MOB bicycle, we both raise awareness and potentially foster a more planned approach to transport usage that will help citizens mitigate exposure to air pollution.

Citi-Sense-MOB is currently within the integration phase and is expected to have the first major results from the 'road trials' of the mobile sensors by the second half of 2014. From autumn 2014 to the end of 2015, full deployment of the sensors will be conducted, and we expect to have the final results and overall evaluation of the project by the end of 2015. At that time, the full potential for ubiquitous, mobile sensor deployment and their integration into static monitoring networks will be known and we expect to demonstrate positive results for both citizen engagement, exposure assessment and city management.

## Acknowledgements

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# 3D Visualisation of continuous, multidimensional, meteorological Satellite Data

Richard Lutz[1]


## Abstract

Ten years of earth observation by the MIPAS instrument aboard the European environmental satellite Envisat [1] led to a considerable amount of measurement and processed data, which has to be managed and visualized by powerful and flexible software tools. This paper gives an overview about new concepts, tools and methods for the 3D visualisation of continuous, multidimensional, meteorological Satellite Data, which are realised with WISA (Wissenschaftliches Informations-system für die Atmosphärenforschung – Scientific Information System for atmospheric Research). A major goal of the visualisation is the recognition of correlations between different trace gas concentrations (e.g. ozone, chlorine nitrate, chlorofluorocarbons, etc.) and the visualisation of trace gas distributions where the main focus was laid on the polar areas.


## 1. Introduction

Envisat was launched in 2002 with 10 instruments aboard and at eight tons. It is the largest civilian earth observation mission which ended in 2012. One of the instruments was MIPAS, the Michelson Interferometer for Passive Atmospheric Sounding, which measures atmospheric emissions [2]. The final processing of the MIPAS measurement data, performed by IMK (KIT Institute for Meteorology and Climate Research), leads to a huge amount of vertical concentration profiles for more than 30 atmospheric trace gases. The Envisat data is captured continuously along a given satellite orbit which covers the whole earth's surface. Figure 1 shows two single orbits, each of them requires 100 minutes and is repeated after 36 days (left side) and the earth coverage of Envisat/MIPAS for September, 2002, using small blue lines for about 32.000 datasets.

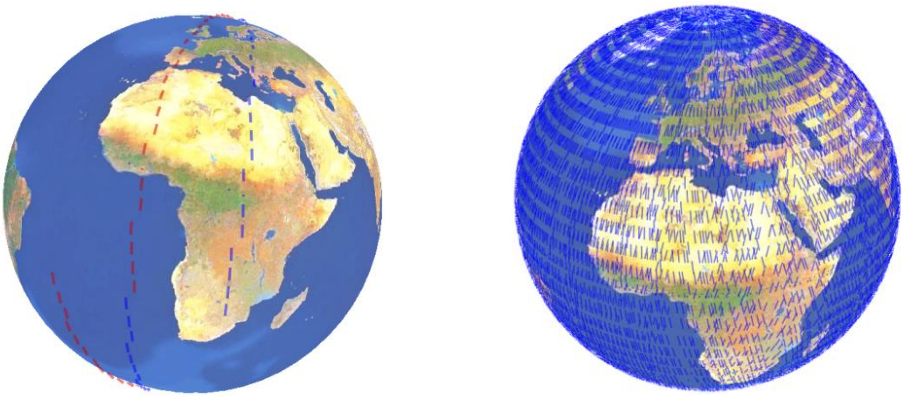

*Figure 1: two single orbits and the earth coverage of Envisat/MIPAS data.*

Each dataset consists of several trace gas profiles with values at given heights and references a geographic location on earth. In order to show several trace gas profiles in parallel for a selected orbit or area, the use of the most common 2D diagram types, which are used mostly in meteorological publications, are not appropriate. For this reason, a new concept and new methods were developed, which are presented in this article.

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## 2. The Envisat/MIPAS Data Structure

MIPAS delivered datasets which are related to a geographical location and to different altitudes. The number of altitudes and their values depend on the actual configuration of the instrument. The given altitudes can vary between 5 and 150 km, the vertical step size may be at least 3 km. The final processing of the MIPAS data corrects the real sloped vertical dataset, caused by the continuing flight of the satellite, to a vertical profile with a singular geographical location. Figure 2 shows the dataset given by MIPAS, and the processed *DataSet3D* element. Each *DataSet3D* element consists of a bundle of trace gases at several altitudes. If a value is not available for a given altitude, the position is marked with 'NaN' (Not a Number).

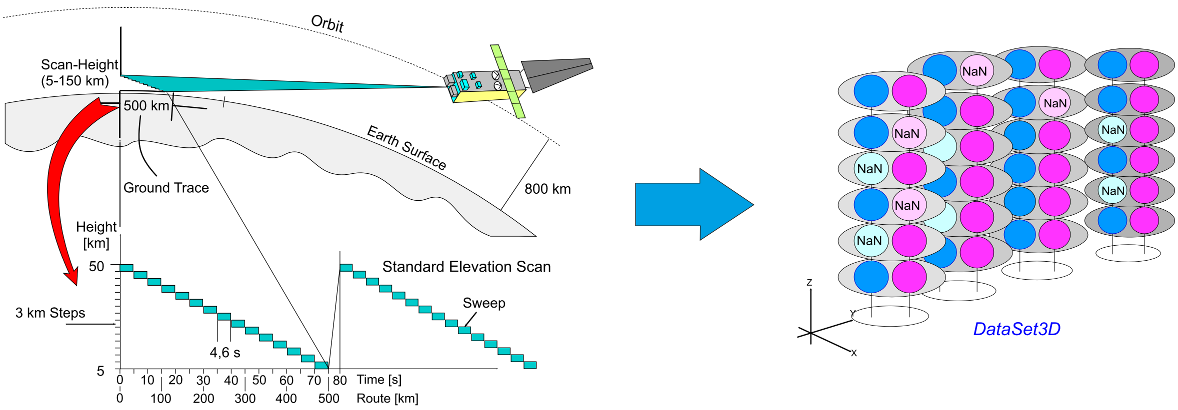


*Figure 2: Structure of MIPAS data, during generation and after processing*

## 3. Requirements for the Visualisation

In order to achieve an effective visualisation of measurement data, application-specific requirements must be fulfilled. The following aspects represent some of the most important requirements:

- Simple and fast selection of desired datasets with the use of extended search facilities.
- Visualisation of real data, i.e. no automatic approximation or interpolation to perceive slight visual differences, too, and to recognise data anomalies.
- Numerous interactive tools are needed to adapt the visualisation to the user's needs, e.g. colours, views, distances, sizes, proportions
- The feasibility to interactively select each trace gas profile contained in the selected dataset for visualisation and comparison.

## 4. Related Work: Visualisation of multidimensional Data Sets

Most publications about this subject comprise the use of traditional visualisation techniques for the visualisation of a given complex data set, like Parallel Coordinates, Scatterplot Matrices, etc., combined with automatical data analysis approaches. Multidimensionality is regarded as the join of different data (attributes) with a geographic location [3]. The location is mostly bounded to 2D and the third dimension is omitted or regarded being constant. Furthermore, the majority of given data does not change continuously. This allows the use of traditional 2D charts for multiple attributes without spatiotemporal animations.

There are only a few concepts in 3D visualisation for multidimensional data. One well-known concept is the use of surfaces overlaid with a colour map, which is able to visualise two parameters. Other promising approaches can be found at [7] where net diagrams are used in 3D for relatively small time series or a 3D approach at [5] for chemical data sets.

## 5. Why not using common Charts in 2D?

There are several 2D chart types which promise to show multidimensional data. This is true for a single multidimensional dataset. But when a number of multidimensional datasets must be visualised simultaneously, important information is lost in most cases due to the lack of a third dimension (local or temporal). This problem could be overcome by applying a 3D scene or an animation concept. Additionally, 3D scenes can be easily enriched with visualisation effects like shading, perspectives, etc.

The following 2D chart types can be basically used for multidimensional datasets: point and line diagrams, Kiviat graphs (net diagrams) which use colours and line thicknesses to distinguish the data (dimensions), bar charts, histograms, pie charts (circle graphs), and data jacks. Stick figures are an option, which use colours, line thicknesses and angles between the extremities. Stick figures seemed to be a very worthwhile approach for the given datasets, because they are used mostly for multidimensional big data sets. Finally, *Parallel Profiles*, developed by [4], which makes anomalies in profile arrays directly visible, can be used in 3D to exploit the rendering effects and to show their geographic location.

## 6. Satellite Data Visualisation by moving 2D Diagrams to 3D

Based on the structure of the processed data, the idea was developed to use common 2D charts for each height of a *DataSet3D* element and move them into 3D space. In this way, new 3D structures can be used to oppose a trace gas profile (e.g. ozone) to another one (e.g. chlorine nitrate) to visualise correlations, gradients and distributions. Figure 3 shows some common diagram types realised in WISA to visualise the data. In this article, the use of bar charts, circle and line diagrams, scatter plots, stick figures, and *Parallel Profiles* is presented. All of them can be considerable enriched using spatial and/or temporal animation which is realised in WISA, too.

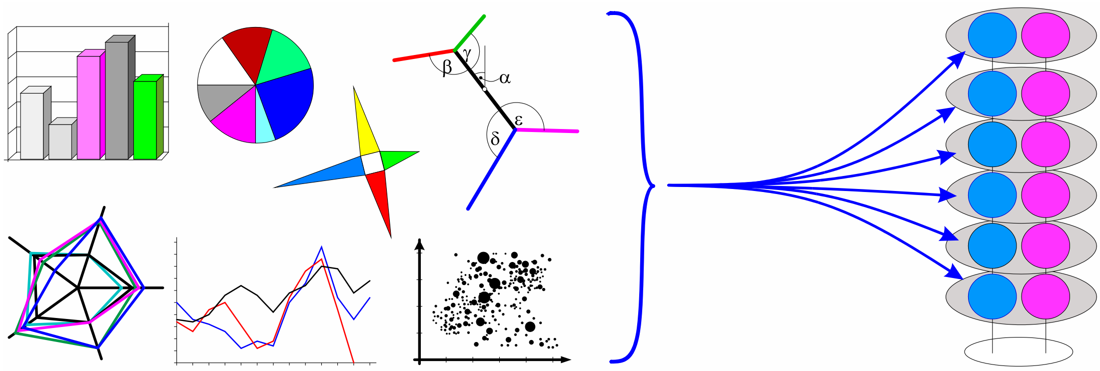


*Figure 3: The use of common 2D charts in 3D to visualise DataSet3D elements*

Using 2D diagrams in 3D is much more than adding a third dimension to flat charts. The desired information about trace gas distributions and profiles can only be retrieved when the user has the option to interactively modify graphical attributes (colours, lines, etc.) and the 3D scene. Furthermore, the use of volume and surface elements is necessary to render the scene and all profiles must be able to be hidden or shown to identify adjacent profiles.

## 7. The WISA Software System

The management component allows clients to connect to the database server for the administration of users, groups, projects, and MIPAS data. The administrative and meta data of MIPAS is hosted in the database whereas the basic MIPAS data is located on a file system associated to a processing cluster. The processing of the trace gases is performed in a separate processing environment and the results (trace gas profiles) are stored in the WISA database to allow dedicated, fast and flexible access for the visualisation (figure 4). The visualisation component offers tools for searching, selecting and visualising the trace gases interactively. A data preparation takes place to map the profiles to common altitudes within the *DataSet3D* elements. The visualisation of *DataSet3D* elements can be performed for both, the 2D and 3D space. For every chart type, an own viewer component exists for 2D and 3D. It provides chart-specific functionalities and is added to a base viewer frame offering common manipulation tools for e.g. zooming, rotating of the elements or the whole scene, and animation. Additional tools allow the configuration of background world maps, a coordinate system, or using a 2D or 3D grid. Finally, it is possible to generate JPEG images of the visualisation scene.

WISA is mainly written in Java (plus Java3D, JDBC), several scripts (UNIX shell, Perl) exist for managing the start-up configuration and the separated start of Java VMs as sub processes for 3D Viewers to avoid storage problems with fixed Java VM sizes.

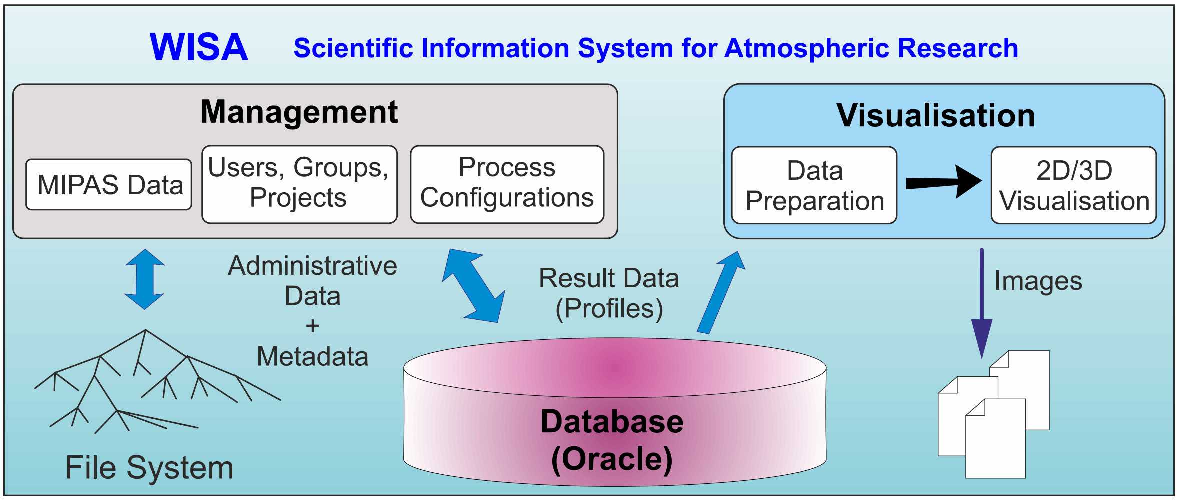


*Figure 4: The WISA software system*

## 8. The Visualisation Workflow

The first step is the selection of desired result profiles. The user can search for the results of whole cycles (all orbits within 36 days, see section 1), or one or several orbits or parts of them. Figure 5 shows the *Profile Retrieval Tool* with selected *DataSet3D* elements (red circles) of 2 chosen orbits.

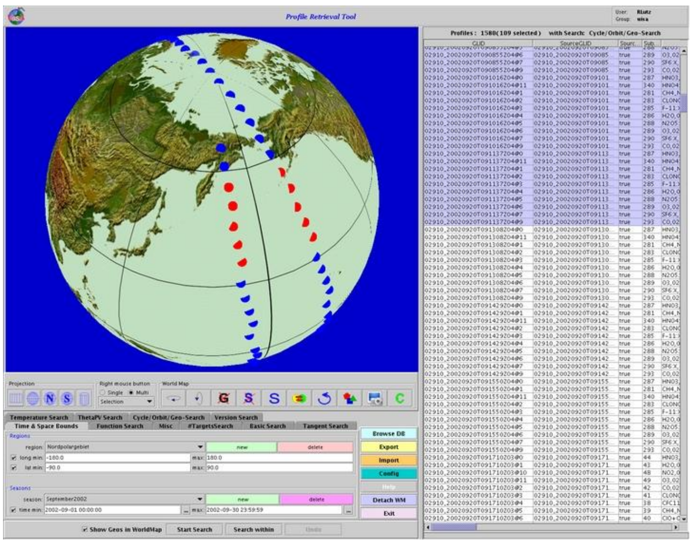

*Figure 5: The WISA Profile Retrieval Tool for the selection of trace gas profiles*

The selection can be visualised for all given chart types. In order to increase visualisation performance, the data can be reduced to the most interesting altitude range. The user can interactively switch between a flat world map and a spherical globe view.

## 9. Results

In order to compare the visualisation results of each viewer, one dedicated orbit was chosen which contains several trace gas profiles. Each representation of a trace gas profile can be faded out in order to improve the visibility of correlations between selected profiles.

### 9.1. Simple Diagram types – Bar Charts, Circle Diagrams, Line Graphs, Scatter Plots

Depending on the chart type, some optimisations had to be performed in order to get a fast and manageable software tool and a good visualisation result:

- **Bar Chart:** The first approach was the use of Java3D box primitive to represent the bars. It turned out that rendering of the box primitive is really slow. Hence, the cube primitives were replaced by Java3D surfaces with additional boundary lines for a better visibility (figure 6). Furthermore, profiles are often covered totally or partly by other profiles of the scene. To overcome this problem, the profiles can be ordered arbitrarily.
- **Line Graph:** The trace gas profiles were mapped to polylines and surface boundaries, which can be arranged in a circle, side by side (figure 6) or one above the other.

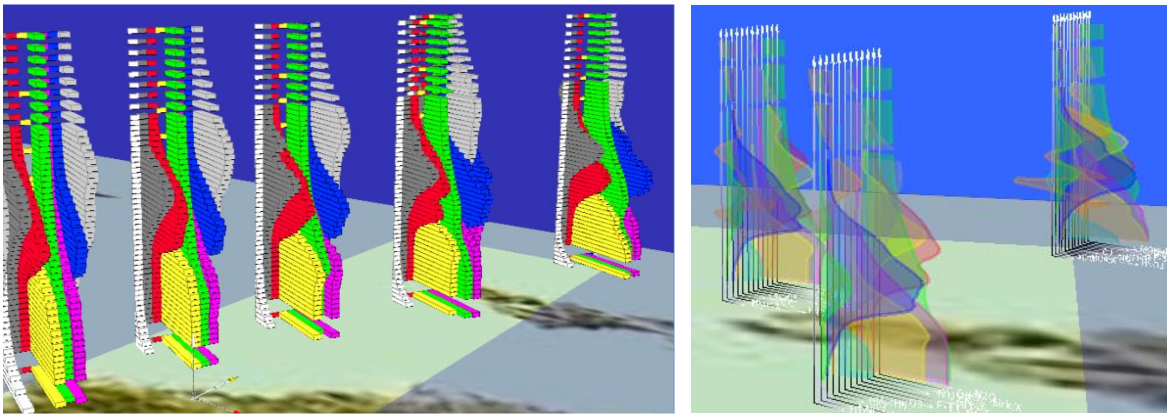

*Figure 6: visualization of a part orbit with bar charts (left side) and with line graphs ordered in parallel with surfaces (right side)*

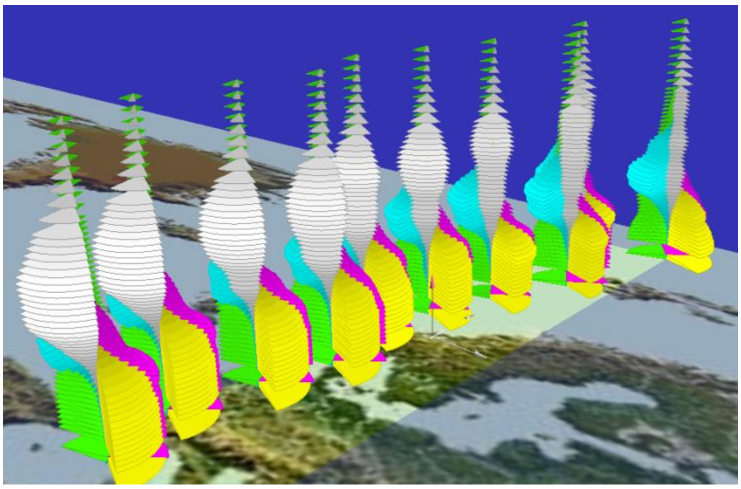

*Figure 7: visualization of a part orbit with circle diagrams (pie charts, flat form)*

- **Circle diagram:** Four alternatives are realised, which can be chosen at start-up. Either the upper and bottom surfaces are parallel like the segments of a pie chart or they have a flat end. Furthermore, either the sizes of the segments or their radiuses are proportional to the dimension of their trace gas values (figure 7).
- **Scatter plot:** Each altitude value of a profile is represented by a point, rather than creating a whole scatter plot on the given area. The simple Java3D sphere and box primitives were used to represent the points. Three trace gases can be visualised using the three geometric dimensions, i.e., the sphere will be deformed to an ellipsoid. A fourth trace gas profile can be shown when the resulting elements are superimposed with colours which are mapped to the trace gas values (figure 8).

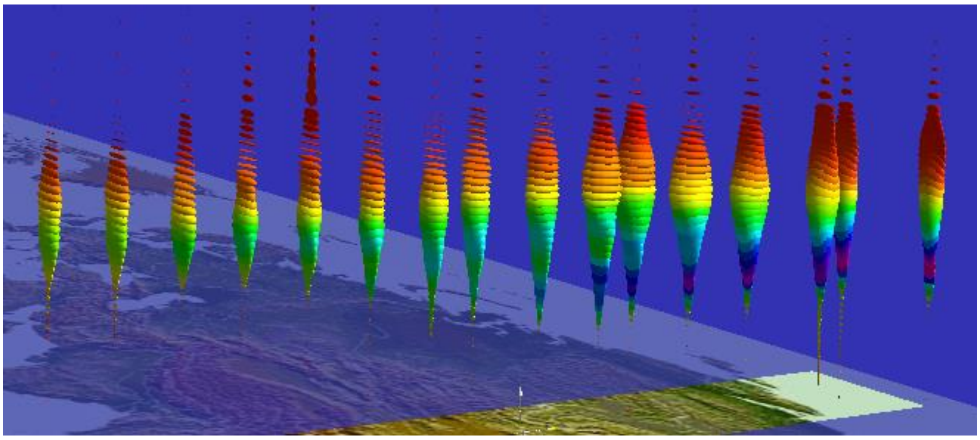

*Figure 8: a part orbit visualized with scatter plots*

Each diagram type can generally be used to visualise the trace gas profiles in order to show distributions along an orbit for a given area. Changes of profile gradients can be recognized easily. The tests showed that each diagram type has its advantages and disadvantages depending on the amount of profiles and *DataSet3D* elements which should be visualised.

The simplest and fastest element is offered by the scatter plot type. Since Java3D sphere elements can be rendered very fast, the scatter plot type can be used for a big data amount like data for a whole satellite cycle. Figure 9 shows the ozone distribution on the northern hemisphere for several orbits on the flat world map and on the globe. Approximately 40.000 spheres are used for this scene. At the North Pole, the low concentration of ozone can be recognised very well (ozone hole?).

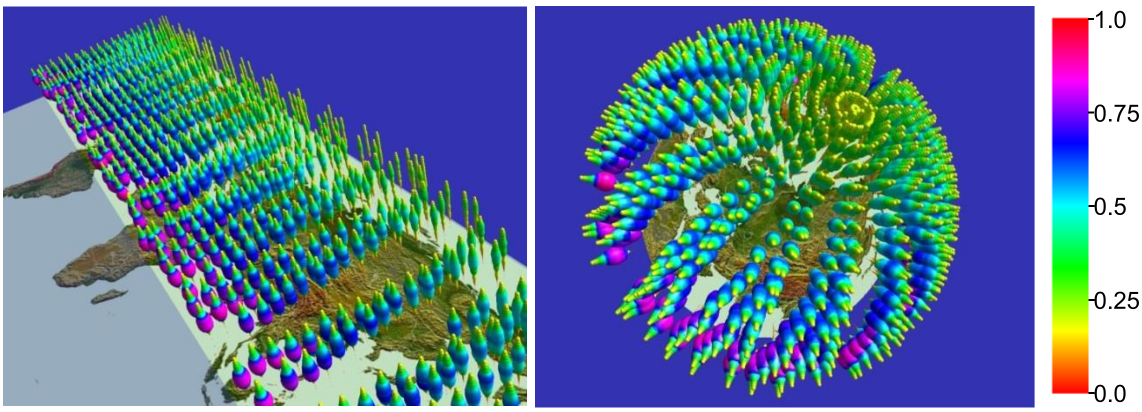


*Figure 9: the distribution of ozone in the northern hemisphere using the scatter plot type*

### 9.2. Stick Figures

Picket and Grinstein introduced this method already in 1988 to identify correlations between closely spaced data sets with five dimensions. They applied the stick figures while testing different figures manually to get a result [6]. The method aims at the creation of textured patterns which help to recognise structures. For WISA, the stick figures have been extended for a better maintenance.

Within WISA, stick figures are used in 2D and in 3D. The figure is built of two arms and legs connected to a body. The extremities are positioned with an angle relative to the body. The trace gas values can be mapped to the angle, the element colour, the length and thickness of the element. Considering all the attributes, 18 stick figure variants can be derived. They are all implemented in the software and the user can switch from one variant to another to determine the best visualisation.

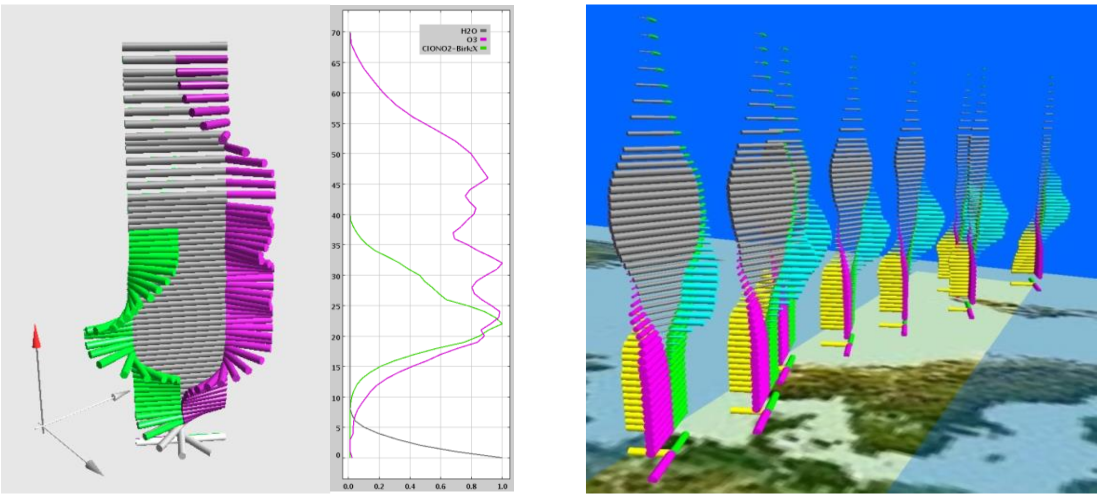

*Figure 10: Stick Figures; a) functionality, the corresponding line plot, and b), the 3D scene;*

Figure 10a) shows a *DataSet3D* element with three trace gas profiles represented by the stick figure type to show its functionality, and the corresponding line diagram. The body (grey) represents H2O, the left arm (magenta) ozone and the left leg chlorine nitrate (green). The values are only mapped to the angles between the extremities and between the body and the local coordinate system. Figure 10b) shows the stick figure scene with profile values mapped by length, thickness and extremity angles (fixed body angle). The tests showed that stick figures are a good way to identify correlations when the body is fixed and the same values are mapped on length and/or thickness and/or angles of one extremity. In so doing, 4 trace gas profiles can be compared easily.

### 9.3. Parallel Profiles

This concept, developed by [4], is based on visualisation effects which arise when equidistantly ordered profiles are resized and/or stretched. The standard approach is shown by figure 11: at first the profiles are ordered (a). Then they are moved and stretched (b, c) to the final arrangement (d). Note: for a clear identification of the behaviour of the profiles, the values are normalised.

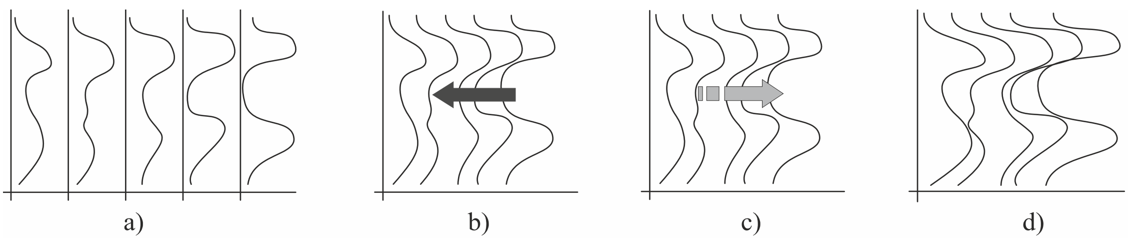


*Figure 11: Parallel Profiles; positioning, moving, stretching the profiles, and the final result*

Figure 12 shows a given orbit starting and ending at the equator and passing the North Pole. The left side shows the profiles for ozone overlaid with the colour map of ozone to emphasise the interesting areas (maximum ozone concentration at the equator, minimal concentration at the pole). The right figure shows the same profiles overlaid with the colour map for chlorine nitrate.

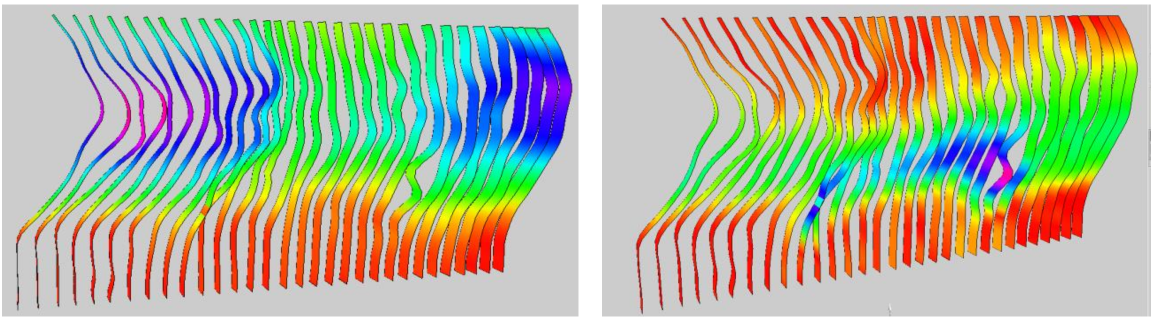

*Figure 12: Parallel Profiles; 3D scene with profiles for ozone with colour maps for ozone (left –hand side) and chlorine nitrate (right-hand side)*

## 10. Conclusions

The use of 2D charts is a reasonable option for the visualisation of structured 3D datasets. Although the presented approach is tailored towards the given Envisat/MIPAS data structure, it can be used for other arbitrary scenarios, too. The main advantages are the utilisation of 3D features like rotation, zooming, shading as well as a simple identification of the geographical locations. Furthermore, the functionality offered by the WISA tool, e.g. modifying all graphical attributes and the selection of each chart type, is a basic key for a good and successful visualisation.

Disadvantages may be the need for computer power and big main storage for the Java3D scenes and perhaps the unfamiliarity of many users with the interactive use of the viewers.

In order to improve the identification of temporal and spatial distribution changes for selected orbits or geographical areas, animation concepts must be applied to the given approaches in 2D and in 3D, which are already realised in the WISA system.

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# Planning of a water distribution network sensors location for a leakage isolation[1]

Marcin Stachura[2], Bartłomiej Fajdek[3]

## Abstract

The paper presents a method of water distribution system sensors placement. Location of sensors depends on the purpose of monitoring of a network. In this paper, this objective has been defined as the ability to detect network failures (leakages). Therefore, the location of monitoring points should be designed so as to maximize the effectiveness of the location method. The main objective of the algorithm deployment of sensors is to find a placement that minimizes the number of components for the largest collection of leakages (faults) with the same signature. The simplest way of determining the best sensors placement is to use an exhaustive search method. However, even a slight increase in the number of possible sensors locations makes exhaustive search very inefficient. Therefore, the selection of sensors placement was performed by optimization using evolutionary genetic algorithm. The computations were performed on the example of the water supply network in Glubczyce town in Poland.

## 1. Monitoring of the water supply network

Water losses in the distribution network is an important issue for the water companies. It should be reduced consistently and methodically. Techniques based on locating leaks by pressure monitoring devices are more effective and less costly than search in situ [5, 6]. Hence a placement of the monitoring devices is a crucial issue to the detection and isolation of the leakages.

When designing a monitoring system one should make the choice of placement of measurement points, which is guided by two criteria: the total cost of installation of these points and the amount of information, which can be gathered with it. It is the problem of multi-criteria optimization. The first criterion is subject to minimization and the second - to maximization.

## 2. Problem formulation

Leakage detection is commonly based on the measurement data analysis. This problem was, however not solved in terms of local and international jural acts and norms [9, 10]. In the current Polish legal requirements, there is no specific guidance on the location of the sensors in the water supply networks. When considering the possibility of assessing the pertinence of the location of sensors for hydraulic parameters measurement, including pressure, in water networks one should pay attention to the diversity of monitoring purposes [10, 12].

It can therefore be concluded that the location of measurement points depends on the purpose of monitoring of the water supply network. In this paper, this objective has been defined as the ability

[1]The paper presented has been realized in frame of the research project of the Polish National Centre for Research and Development (NCBiR) co-financed by the European Union from the European Regional Development Fund, Sub-measure 1.3.1. "Development Projects"; project title: “IT system supporting the optimization and planning of production and distribution of water intended for human consumption in the sub-region of the central and western province of Silesia”; project ref no POIG.01.03.01-14-034/12.

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to detect network failures (leakages). Therefore, the location of monitoring points should be designed so as to maximize the efficiency of the method used for network fault location [16].

## 3. Leakage detection

The applied methodology used to detect leaks is based on the classic theory of diagnosis based on a model, and implemented in the supply networks to damage detection [4, 7, 20] with a hydraulic model [2, 13, 14, 15, 17, 18, 19]. Diagnosis based on the model can be divided into two subtasks: detecting and isolation of damage [11]. Detection of damage is to observe the state of the object, and the location of damage is to identify the damaged component of the system [3, 8, 11]. Observation of the object is based on the determination of residuals $\boldsymbol{r}(k)$ determined from the measured input signal $\boldsymbol{u}(k)$ and output $\boldsymbol{y}(k)$ using the sensors installed in the monitoring system, using the following, generic, formula [8]:

$$\boldsymbol{r}(k) = \boldsymbol{\Psi}(\boldsymbol{y}(k), \boldsymbol{u}(k)) \tag{1}$$

where $\boldsymbol{\Psi}$ is a function of generating residuals, which depends on the type of the chosen strategy (the parity equation [8] or the observer [3]). At any moment of time $k$ residuals are compared with the threshold value (zero in the ideal case or close to zero in real applications). The threshold value is determined using statistical methods and methods based on fuzzy sets [11], taking into account the presence of both measurement and model inaccuracies. If the value of the residuum is larger than the threshold, occurrence of damage is concluded. Otherwise, it is considered that the system is working properly.

Hence, the main objective of the algorithm of sensors deployment is to find a placement that allows to maximize the number of leakage signatures – distinguishable faults. This means to minimize number of sections described by the same value of residual $\boldsymbol{r}(k)$.

In the diagnostics of complex technological installations, methods of designing faults–symptoms relation that utilize expert knowledge play the most important role. Deep knowledge about the process operation helps to define this relation in a relatively simple way. Additionally, the diagnostic system designer can utilize the knowledge of process engineers or operators. The binary diagnostic matrix [11] is most often used. An example of such a matrix is presented in Fig. 1.

| *S/F* | $f_1$ | $f_2$ | $f_3$ | $f_4$ | $f_5$ | $f_6$ |
|---|---|---|---|---|---|---|
| $s_1$ | 1 | 0 | 1 | 0 | 0 | 1 |
| $s_2$ | 0 | 1 | 0 | 1 | 1 | 0 |
| $s_3$ | 0 | 0 | 1 | 0 | 1 | 0 |
| $s_4$ | 0 | 1 | 0 | 0 | 1 | 1 |
| $s_4$ | 0 | 0 | 0 | 0 | 1 | 0 |
| $s_6$ | 1 | 0 | 1 | 1 | 0 | 1 |

*Figure. 1. An example of the binary diagnostic matrix.*

The matrix element in the *j*-th row and the *i*-th column has the value $v_j(f_k) = 1$ if the diagnostic signal $s_j$ detects fault $f_k$ and the value $v_j(f_k) = 0$ otherwise. In other words, the occurrence of fault $f_k$ brings the occurrence of the diagnostic signal $s_j = 1$, which is called a symptom. The relation $R^{FS}$ described by the binary diagnostic matrix can be defined by attributing to each diagnostic signal the subset of faults $F(s_j)$ that are detectable by this signal:

$$F(s_j) \equiv F(s_j = 1) = \{f_k \in F: v_j(f_k) = 1\} \tag{2}$$

It can be also defined by attributing to each fault $f_k \in F$ the subset of diagnostic signals $S(f_k)$ that detect the particular fault $f_k$:

$$S(f_k) = \{s_j \in S: v_j(f_k) = 1\}. \tag{3}$$

where, $S(f_k)$ determines the set of $k$-th fault symptoms. Each matrix row corresponds to the rule of the following type (4):

$$\text{if } (s_1 = 0) \wedge \dots \wedge (s_j = 1) \dots \wedge (s_J = 1) \text{ then } f_k \tag{4}$$

If the signatures are identical then the faults are indistinguishable.

## 4. Sensor placement algorithm

Pipe network model can be represented as a graph $G = (V, E)$ [17], where $E$ is the set of edges that represent pipes and $V$ is a set of vertices (nodes). Vertices may reflect sources such as reservoirs or tanks and demand nodes, which are the places where the water is consumed. Each pipe connects two vertices $v_i$and $v_j$which can be written as follows $(v_i, v_j)$.

The problem of sensors deployment, with the network representation in the form of a graph, can be formulated as an integer programming problem. Each decision variable $x_j$ associated with a network node $v_i$ can take a value of 1 or 0, where 1 means the sensor is installed, and 0 that is not installed in the $i$-th node [1].

Rows of the diagnostic matrix (Fig. 1) refer to the distribution of sensors, while columns refer to a leakage at a given node. This means that if the matrix element has a value of 1, the sensor installation on a node allows the detection of leakage associated with a given column (only in the case of a single leak).

Assumed methodology implies application of the hydraulic model of the system. First, a numerical simulation of the water supply system under standard operation is performed. For a given network load, nodal pressures are determined for all nodes, and flows in all sections of the network. Next, a set of simulations is performed for assumed network faults. This means that, in each node, in which leakage was introduced, the leakage flow is calculated using the following formula:

$$q = Cp^{\gamma} \tag{5}$$

where $q$ – leakage flow rate, $C$ – flow constant through the leak, for each node, this value was the same, $p$ – pressure at the node , $\gamma$ – pressure exponent ($\gamma$ = 0.5).

For a given sensor deployment the number of signatures is estimated. Next, the deployments are changed so as to achieve the maximal possible number of faults signatures (distinguishable faults).

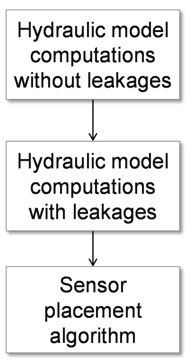


*Figure 2. Sensor placement algorithm.*

The main objective of the sensor placement algorithm is to minimize the number of leakages (faults), described by the same signature (the same set of symptoms). This function can be written as follows:

$$J = \min_{x_1,\dots,x_n} \max\{n_1, \dots, n_{nf}\} \tag{6}$$

where $x_1, \dots, x_n$ are decision variables which defines the specific arrangement of sensors and $n_i$ is the number of nodes in the indistinguishable group $i$ for a given leak $f_j$.

The simplest way of determining the best sensor deployment is to use an exhaustive search method. This method is simple to implement, but requires checking all the existing combinations of subsets of sensors positions to determine the subset giving the largest value of the signatures. Using this method a global solution can be obtained, but it is only effective for a set of data with a small number of network nodes. Even a slight increase in the number of possible monitoring points makes exhaustive search becomes very inefficient [21]. Therefore, in the selection of measurement points location a genetic algorithm was used.

## 5. Mathematical model of a water distribution system

The main task of a water supply system is to provide a sufficient amount of water at the appropriate pressure to all users of a system. Each water network consists of three main components: pumps, storage tanks and distribution network. Most systems require pumps that allow to raise the water to the desired height and to cover energy losses due to friction. The pipes can be fitted with devices to control the flow, such as return or relief valves.

Hydraulic model is described by linear and nonlinear algebraic equations, similar to the equations describing the balance of voltages and currents in electrical networks [23]. A mathematical description results from the first and second Kirchhoff's law known from electrical engineering. For the formulation of equations of a model, a structure of an investigated network has to be known. Basically, it consists of links (pipes), nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. Hydraulic model calculates the water flow in each pipe, the pressure at each node, the height of water in each tank. Flows in the water supply system are calculated in accordance with the principle of conservation of mass and energy. The mass conservation law shows that the entire mass stored in the system is equal to the difference between inlet and outlet flows to the system. In the pressurized water distribution network, it is not possible to store water in pipes, although the levels in the tanks may change over time.

Assume we have a pipe network with $N$ junction nodes and $NF$ fixed grade nodes (tanks and reservoirs). Let the flow-headloss relation in a pipe between nodes $i$ and $j$ be given as:

$$H_i - H_j = h_{ij} = rQ_{ij}^n + mQ_{ij}^2 \tag{7}$$

where $H$ is nodal head, $h$ is headloss, $r$ is resistance coefficient, $Q$ is flow rate, $n$ is flow exponent, and $m$ is minor loss coefficient.

The value of the resistance coefficient will depend on which friction headloss formula is being used (see below). For pumps, the headloss (negative of the head gain) can be represented by a power law of the form:

$$h_{ij} = -\omega^2 \cdot \left(h_0 - r \cdot \left(\frac{Q_{ij}}{\omega}\right)^n\right) \tag{8}$$

where $h_0$ is the shutoff head for the pump, $\omega$ is a relative speed setting, and $r$ and $n$ are the pump curve coefficients. The second set of equations that must be satisfied is flow continuity in all nodes:

$$\sum_j Q_{ij} - D_i = 0 \quad \text{for} \quad i = 1, \ldots, N \tag{9}$$

where $D_i$ is the flow demand at node $i$ and by convention, flow into a node is positive. For a set of known heads at the fixed grade nodes, one seeks a solution for all heads $H_i$ and flows $Q_{ij}$ that satisfy equations (7) and (9).

## 6. Considered water distribution system

Glubczyce is a town in the Opole province, Poland, in the district of Głubczyce situated on the river Psina is inhabited with 23 778 people. The water supply network within Glubczyce provides water to 13 286 inhabitants (data from 2011). Water production in 2011 was estimated at 2.782 $m^3$/day. In the city there is one pressure zone, in which pressure varies from $P_{min}$ = 0.2 MPa to $P_{max}$ = 0.42 MPa.

## 7. Results

The presented method has been used to estimate the suboptimal location of pressure sensors deployment. The selection of sensors placement was a task of choosing the most cost-effective sensors configuration satisfying certain criteria (possibly a small group of indistinguishable nodes). This task was realized with use of numerical simulations. During the necessary computations, the simulation time was selected as 24 hours, with the time discretization step of one hour.

The series of computations was performed so as to determine position of the individual sensors. In each of the numerical experiments a different number of installed sensors was assumed (from 2 up to 12 sensors). It should be noted that the used methodology does not take into account the investment costs associated with device installation. The overall investment consist of the cost of metering equipment, which is a pressure gauge, the cost of construction of the necessary wells and necessary electronic devices (i.e. containing energy source and a data transmission unit). Moreover, in the case of pipes of different diameters, the mounting cost of a single sensor might differ. On a pipe having a large diameter it may be greater than the cost of assembling two measuring points on the small diameter pipes.

The results of the comparison of the performed computations are presented in the table (Table 1). The numerical computations have shown that in some cases a relatively large group of nodes will have the same signature (failure on any of the sections will be indistinguishable at the level of the individual group).

*Figure 3 Example of a solution in which a large group of nodes (marked in red) is defined by the same signature.*

*Table 1. The results of the numerical computations,* $J = min_{x_1,\ldots,x_n} max\{n_1, \ldots, n_{nf}\}$ *– number of elements (nodes) with the same signature.*

| Number of sensors | $J = \min_{x_1,\ldots,x_n} \max\{n_1, \ldots, n_{nf}\}$ |
|---|---|
| **2** | 98 |
| **4** | 38 |
| **6** | 32 |
| **8** | 21 |
| **10** | 19 |
| **12** | 14 |

Applying the prescribed diagnostic system is a separate topic of fault detection, usually conducted under the assumption of single faults. After defining a set of available faults, the diagnostic signals should be reduced by these signals, which are susceptible to failure detected. Their values are in fact determined by the existence of recognized fault. The exemplary diagnostic matrix was presented in fig. 4:

f

s

*Figure 4. Example of a designated binary diagnostic matrix for 12 sensors, s - symptoms, f - failure. Black color indicates a value of 1.*

As the number of sensors is increased the state of the network can be more precisely defined and the leakage can be more accurately detected. One can, however, note that the appropriate choice of a relatively small number of sensors may be equivalent, in terms of quality, of the knowledge about the network, than a large number of sensors located in less sensitive network areas. On the other hand the cost of the system and its operation is increased.

Number of sensors:2, number of signatures: 2

Number of sensors:4, number of signatures: 8

Number of sensors:6, number of signatures: 16

Number of sensors:8, number of signatures: 42

*Figure 5. Examples of results of sensors location (marked as circles) for different numbers of devices.*

## 8. Summary

The presented method for determining pressure sensor placement is designed to maximize the possibility of fault location. Normally, in the diagnosis of complex technological systems the most important factor is an expert knowledge that described the relationship between damage and symptoms [11]. Designer of a diagnostic system can additionally use the engineers', process operators' and maintenance staff's knowledge. The article presents a method for determining the diagnostic matrix using numerical computations of a hydraulic model. The results show that using the this method the suboptimal binary diagnostic matrices can be estimated.

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# Flickering Events in Wind and Solar Power

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## Abstract

This paper reports stochastic properties of renewable wind and solar energy resources by studying their conditional probability distribution functions (cpdf) in different time lags. The empirical results are obtained for data of global horizontal irradiance measured by a single sensor and the power output of a single wind turbine, as well as for an averaged solar sensor field and an aggregated wind farm. Moreover, the dependency of the time series' spread on the solar elevation angle, and the wind speed, respectively, is investigated in order to assess the risk of flickering in relation to these variables. The results show that the conditional distribution functions deviate strongly from Gaussian statistics and possess positive skewness, while the risk of flickering events in wind power and solar irradiance generally increases with wind speed and solar elevation, respectively, for single point measurements. Spatial averaging leads to flickering risk reduction.

## 1. Introduction

In the course of the decided exit from nuclear and fossil-fuel energy, German power grids face increasing challenges regarding the integration and management of wind and solar energy. As the shares of both renewable sources are on the rise, the guaranteed meeting of power demand and the maintenance of stability in voltage and frequency, amongst others, are expected to become more and more difficult due to the stochastic nature of wind speed and solar irradiance. Both resources are strongly intermittent in general and possess clusters of large amplitude fluctuations on short time scales [3, 6].

Wind turbulence is thereby responsible for the intermittency in wind power time series on short time scales, and the non-linear relation of wind speed $u$ and wind power $P$ (i.e. $P(t) \propto u^3(t)$) results in the power output of wind turbines being even more intermittent than wind speed itself. As for solar power in general and photovoltaics (PV) in particular, the dynamics of clouds and their size distributions are the origins of the intermittent characteristics of the respective time series. The on/off pattern of the rapid succession of direct sunlight exposure and cloud shadow coverage of a fixed location thereby leads to many extreme events of large amplitude ramps and jumps in solar irradiance [e.g. 9].

In [7] it is shown that the computed power spectrums from high frequency time series of global horizontal irradiance and wind power reveal a power-law behavior with an exponent $\sim -5/3$ (Kolmogorov exponent) in the frequency domain 0.001 Hz < f < 0.5 Hz. This means that the power grid is essentially receiving input from turbulent-like sources. Although the spatial averaging acts as a filter [e.g. 1], strong deviations from Gaussian distributions remain the norm in the increment statistics of wind power and solar irradiance time series [6].

The uncontrollable fluctuations of these renewable sources in time are a major problem for keeping up the stability of power grids with high shares of wind and solar energy feed-in, especially regarding the high connection densities of photovoltaics in the distribution low-voltage grid [4, 8]. Therefore it is imperative to understand the nature of such fluctuations in order to successfully

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manage decentralized power production, which is a main component in the exit from nuclear and fossil-fuel energy. Thus we investigate the non-Gaussian characteristics of solar and wind power time series in the following. We also study the occurrence and risk of flickering events with respect to different wind speeds and solar elevation angles for single point measurements and spatially averaged data.

## 2. Material and Methods

The results presented in this study are derived from data measured on operating wind turbines and continuous solar irradiance measurements with a sample rate of 1 Hz in Germany and Hawaii, respectively. The analyzed time series are the dimensionless wind turbines' scaled power output $P(t) = P_o(t)/ P_r$, which is the quotient of the turbines' power output $P_o(t)$ and the turbines' rated power $P_r$, along with global horizontal irradiance $I(t)$ in units of $Wm^{-2}$. Figure 1 provides two typical subsets of the available data, illustrating the variations in time and the spatial smoothing effect of both the wind farm in relation to a single turbine (figure 1a), and the averaged global horizontal irradiance in a field in relation to a single sensor (figure 1b). The area containing the wind farm is about 4 x 4 km², while the solar field measures approximately 1 x 1 km².

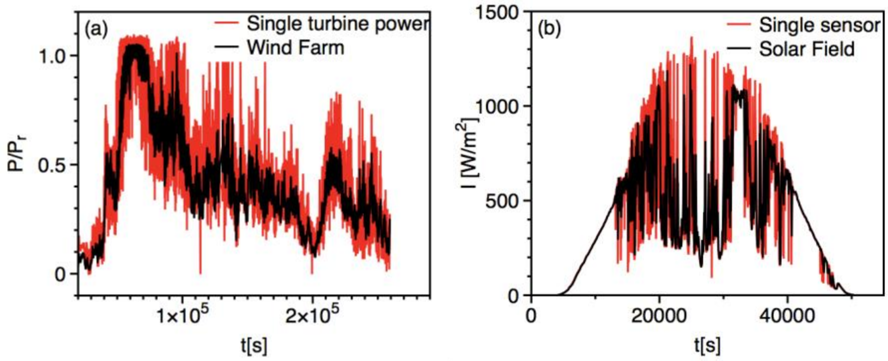


*Figure 1: (a) Time series of normalized power output of a single wind turbine and the aggregated sum of a wind farm consisting of 12 turbines in an area of about 4 x 4 km². (b) Variations of the global horizontal irradiance measured by a single sensor and the averaged radiant flux density of 17 sensors in a solar field with an area of about 1 km².*

Due to the different geographical origins of the used datasets, any comparison of the two must accept their respective meteorological conditions. While Hawaii is subject to tropical climate and trade winds, Germany is located in the temperate latitudes under the influence of prevailing westerlies. Both wind and solar energy resources are affected by the resultant differences to some extent, so it is important to keep in mind the different origins of the data.

As we aim to characterize the fluctuations in the aforementioned time series of wind power and solar irradiance, we compare their short time intermittency and extreme events using the estimation of their conditional probability distribution functions (cpdf) with short time lags in this study. We use the analysis of cpdfs in connection with a two dimensional contour plot. Stronger correlations between subsequent states in the time series thereby result in a more diagonal configuration in the two dimensional representation that facilitates the classification of cpdfs into their context.

Furthermore, we investigate the dependency of the time series' spread on certain conditions. In the case of wind power, the standard deviation

$$\sigma_u = \sqrt{< \left(P - \bar{P}(u)\right)^2 | u >}$$

of the scaled wind power $P$ associated with different wind speeds $u$ serves as an estimate of the stochasticity of wind power that is expected for different given wind speeds. Similarly, the standard deviation $\sigma_\alpha$ of the global horizontal irradiance $I$ measured at different solar elevation angles $\alpha$

$$\sigma_\alpha = \sqrt{< \left(I - \bar{I}(\alpha)\right)^2 | \alpha >}$$

expresses the influence of the apparent movement of the sun relative to Earth on the spread and the fluctuations in irradiance time series.

## 3. Results

When comparing the contour plot of wind power and solar irradiance, as well as some conditional pdfs for different values of power $\mathrm{P(t-\tau)}$, with $\tau = 5$ s, and irradiance $\mathrm{I(t-\tau)}$, with $\tau = 1\ s$, fluctuations in the short time intervals $\tau$ and non-Gaussian characteristics of the associated cpdfs are evident for both renewable energy sources (see figure 2). The left panels of figure 2 thereby provide an overview of the short term correlations in wind power and irradiance time series by means of the contour plots of $P(t)$ vs $P(t-\tau)$ in the upper panel, and $I(t)$ vs $\mathrm{I}(t-\tau)$ in the lower panel, respectively. For three certain transects $\alpha_1, \alpha_2, \alpha_3$ of $P(t-\tau)$ and $I(t-\tau)$, respectively, the corresponding conditional pdfs are plotted in the right panels. Gaussian distributions are also provided for comparison.

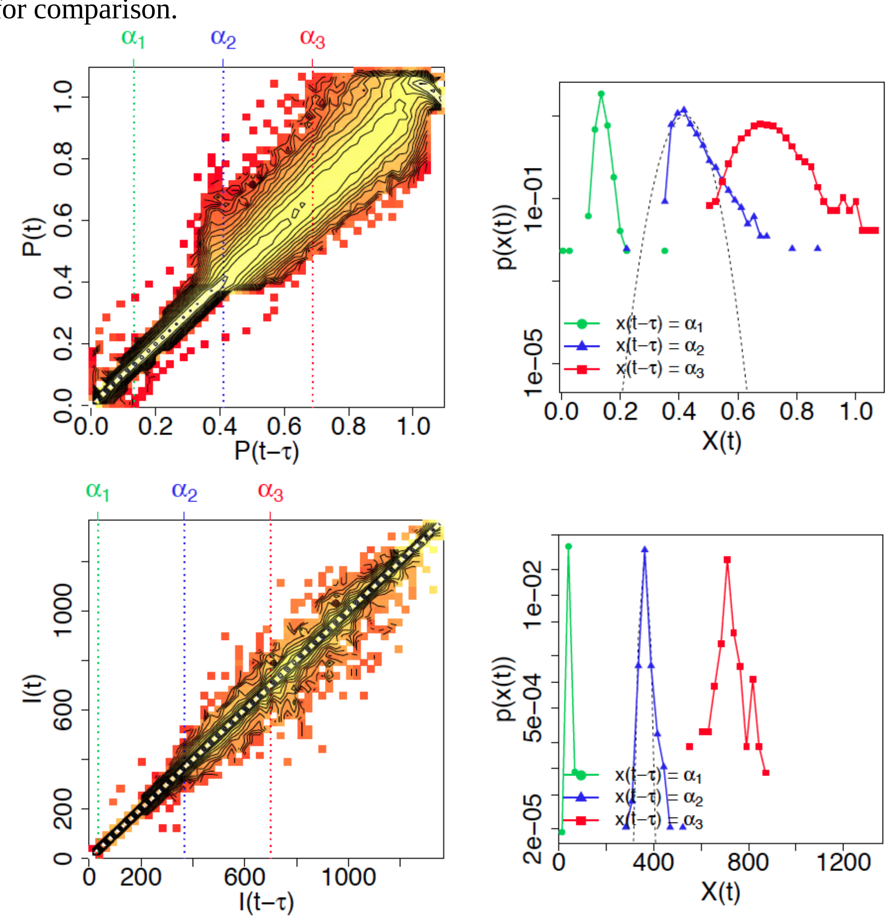


*Figure 2: The panels show the contour plots (left) and conditional pdfs (right) of wind power for a single turbine with a time lag of $\tau = 5\ s$ (top), and of global horizontal irradiance for a single sensor with a time lag of $\tau = 1\ s$ (bottom).*

As for the wind power analysis in the top panels of figure 2, lower magnitude subsets of the time series $P(t-\tau) < 0.4$ are mostly correlated strongly with their subsequent $P(t)$, which is demonstrated by a low spread and close adherence to the diagonal line ($y = x$) in the contour plot, as well as a very narrow conditional pdf of the transect at $\alpha_1$. In contrast, the contour plot of wind power begins to exhibit weaker correlations of subsequent states at $P(t-\tau) \approx 0.4$, and continues to prove weakly correlated characteristics for all higher magnitudes of wind power $P(t-\tau) > 0.4$. The positive skewness of the conditional pdfs at $\alpha_2$ and $\alpha_3$ show that higher values of $P(t)$ are more likely to follow $P(t-\tau)$ than lower ones. The fat-tailed structures of the cpdfs indicate the possibilities of large magnitude fluctuations of power in short time scales, which is considered flickering in the time series.

The analysis of the bottom panels of figure 2 reveals similar general characteristics for global horizontal irradiance as previously identified for wind power, while some differences are also present. Both low and high magnitude subsets of the time series $\mathrm{I}(t-\tau) < 200\,Wm^{-2}$ and $\mathrm{I}(t-\tau) > 1200\,Wm^{-2}$ are shown to be mostly correlated strongly with their following $I(t)$, as there is a low spread and a close adherence to the diagonal line $(y = x)$ in the contour plot. Consequently, the conditional pdf of the transect at $\alpha_1$ is very narrow. In between the two aforementioned values, the time series is only weakly correlated to its previous state, with most flickering events occurring around $\mathrm{I}(t-\tau) \approx 850\,Wm^{-2}$, as illustrated by the spread of the contour plot. Both positive skewness and fat tails of the conditional pdfs at $\alpha_2$ and $\alpha_3$ are less pronounced compared to wind power, but still evident.

The dependency of flickering in wind power and solar irradiance on wind speed and solar elevation angle, respectively, may be analyzed by means of figure 3. The standard deviation $\sigma_u$ of wind power associated with certain wind speeds is visualized for a single turbine and the aggregated sum of the wind farm in figure 3a, while the standard deviation $\sigma_\alpha$ of global horizontal irradiance associated with certain solar elevation angles is displayed in figure 3b.

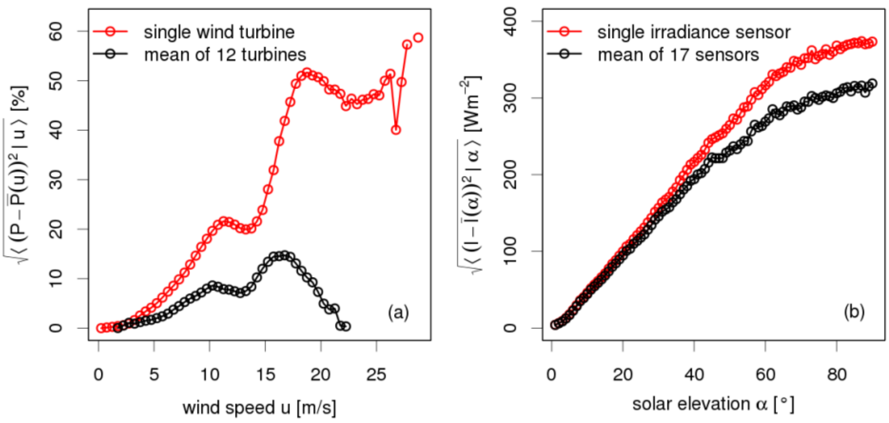


*Figure 3: (a) The standard deviation of the normalized wind power output, conditioned to the wind speed, and (b) the standard deviation of global horizontal irradiance, conditioned to the solar elevation angle*

In case of the wind power, both single turbine and wind farm exhibit increasing values of standard deviation $\sigma_u$ of conditioned wind power time series with increasing wind speeds until a local maximum around $u \approx 11\,ms^{-1}$, and $u \approx 10\,ms^{-1}$, respectively. A significant increase of $\sigma_u$ is further evident for the single turbine, while $\sigma_u$ of the wind farm output increases at a much smaller rate until it reaches a global maximum around $u \approx 16\,ms^{-1}$, after which it decreases sharply. The single wind turbine power spread exhibits a similar maximum around $u \approx 18\,ms^{-1}$, but there are both higher and lower $\sigma_u$ present for even higher wind speeds $u > 18\,ms^{-1}$. Spatial smoothing obviously has a big impact on the difference of the two curves and suggest much more flickering in the output of a single wind turbine compared to the output of a wind farm. Please note that there are no wind farm power outputs associated with high wind speeds $u > 22\,ms^{-1}$, because wind turbulence is also affected by spatial averaging, of course, and the highest wind speed values measured at a single turbine never occur in the entire wind farm simultaneously.

The characteristics of the standard deviation $\sigma_\alpha$ of solar irradiance conditioned to solar elevation angle $\alpha$ are different, as $\sigma_\alpha$ keeps increasing rather smoothly with increasing $\alpha$ for both a single sensor and the mean of the solar field. However, spatial smoothing effects are also evident to a lesser extent, and for solar elevation angles above $\alpha > 30°$.

## 4. Discussion

The results presented in the previous section confirm the flickering attributes of wind and solar power by showing the weak correlation of subsequent states in the analyzed time series and the non-Gaussian characteristics of corresponding conditional pdfs.

In this regard, it is especially interesting to note the strongly positive skewness of the cpdf $\alpha_2$ in the upper panels of figure 2. For the order of wind power $P(t-\tau) \approx 0.4$, it shows that the subsequent power value $P(t)$ is very likely to be much higher than its predecessor but comparatively unlikely to be lower. We relate this phenomenon to the effect of inertia in a rotating wind turbine: when a wind gust hits the blades, the power is immediately increased by the exercised torque, while the power will not drop within the same timeframe if the wind speed decreases for a moment, because the inertia of the rotating generator. This argumentation also qualitatively explains the positive skewness of cpdf $\alpha_2$ in the upper panels of figure 2. The decrease in magnitude of this effect from cpdf $\alpha_2$ to cpdf $\alpha_3$ may be connected with some specifications of the wind turbine and possibly results from internal control mechanisms or some other turbine properties that exhibit different effects at different levels of power output.

The fact that both positive skewness and fat tails of the conditional pdfs are less pronounced in the case of solar irradiance (bottom panels of figure 2) compared to wind power (top panels of figure 2), may be attributed to the different values of $\tau = 5\ s$ for wind power and $\tau = 1\ s$ for solar power. We confidently expect the non-Gaussian characteristics of global horizontal irradiance to be more pronounced for increasing $\tau$, as reported by [6].

As for the positive skewness of conditional pdfs for solar irradiance, we refer to the typical diurnal variation of global horizontal irradiance in Hawaii: after sunrise, the skies are usually clear and global horizontal irradiance increases with the solar elevation angle until sometime in the morning, when strong convection leads to the formation of cumulus-type clouds that cause measured irradiance to flicker strongly due to the cloud shadows passing rapidly over the ground. More often than not, this cloud behavior dominates during the rest of the day, so that there are more afternoons with flickering events than mornings. This asymmetry in the diurnal variation of solar irradiance in Hawaii may be related to the slight positive skewness of the cpdfs as observed in figure 2.

The well pronounced dependency of the standard deviation $\sigma_\alpha$ of solar irradiance on the solar elevation angle, and the more pronounced spatial smoothing of wind power variability illustrated in figure 3 give rise to the following remarks. Essentially, the former relationship illustrates the simple fact that the maximum possible radiant flux density of solar irradiance is higher for large solar elevation angles than for low ones. The fluctuations in irradiance reflected in the standard deviation of the time series are thus bound in magnitude to the maximum possible irradiance. This means that similar cloud dynamics will, of course, result in different irradiance fluctuations, depending on the solar elevation angle. In terms of wind power standard deviation $\sigma_u$ and wind speed, there is a profoundly different relationship in the spatial smoothing on small scales: while there is no spatial variability in the solar elevation angle, wind speeds are highly variable. Thus, the different wind turbines are subject to different wind speeds at the same time, but the different solar sensors are always exposed to the same solar elevation angle simultaneously.

## 5. Conclusion

In this contribution we study flickering events in wind power and solar irradiance time series and show that their conditional pdfs exhibit fat-tailed non-Gaussian characteristics with positive skewness. Moreover, we find that the risk of flickering in wind power increases with the wind speed for a single turbine, while the effect of spatial smoothing leads to a significant flickering risk reduction for high wind speeds in a wind farm. Similarly, the risk of high magnitude flickering in solar irradiance steadily increases with the solar elevation angle, because the higher the solar elevation, the more radiant flux density is available in global horizontal irradiance.

To continue our work, the next steps will include the development and evaluation of possible methods to suppress the flickering events based on power electronics and their control strategies, as well as the consideration of possible PV-related system characteristics that may affect the conversion of flickering in irradiance to flickering in PV system power output, like reported by [2]. Furthermore, we strive to acquire high resolution wind and solar measurements from the same location in order to analyze possible correlations in their respective fluctuation characteristics.

Finally classifying wind and solar power resources in terms of their stochastic properties will contribute to operating micro grids and virtual power plants reliably with high shares of renewables, as the quality of their respective control strategies and products are strongly influenced by flickering in power input. Generally, conditions of low flickering probabilities will allow more flexible network designs in both micro grids and virtual power plants, while conditions of high flickering call for larger aggregations of networks to balance the expected fluctuations.

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# Electricity Associations as Marked-based Steering Mechanism and Alternative to Fixed Feed-in Tariffs

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## Abstract

This paper describes a business model for local electricity supply and demand steering using flexible electricity prices. Therefore it evaluates first the composition of the electricity price. Secondly it estimates the future renewable electricity generation cost. Therefore future renewable electricity generation prime cost are calculated with a combination of historically derived learning rates and global market growth estimations, both derived from literature. Thirdly it evaluates the tax burden on local traded electricity. As result a business model and legal construct which reduces the tax and levy burden on electricity is identified as crucial factor for flexible electricity prices. With electricity associations this paper identifies such a judicial construct. Finally centralised demand steering with smart flexible agents like electric vehicles, dishwasher and washer-dryer is described. This steering allows to synchronize renewable electricity generation from photovoltaic power plants, wind turbines and combined heat and power and the local electricity demand.

## 1. Introduction

Due to significant technology learning progress reached with subsidized feed-in tariffs on renewable energy generation the contribution of renewable electricity on overall electricity supply reached 23.9%, including 9.3% from wind turbines and 4.7% from photovoltaic. Especially daytime and seasonal peaks of photovoltaic, but also wind turbines have reached challenging levels. Therefore the volatile regenerative energy production makes an expansion of the energy grid necessary.

In the current situation a fixed feed-in tariff is as well criticised as the partial self-supply with electricity from photovoltaic. The president of the “Federal Grid Agency” J. Homan describes the renewable energy generation which is independent of the actual demand and only focused on feed-in tariffs as “produce and forget” philosophy. He claims that the current EEG is lacking a demand steering and leads to non-controllable costs. Furthermore a regulation where additional capacities are installed would be necessary. In general the debate should focus more on the economic viability. Furthermore a new electricity market design should take economic efficiency and the availability of enough assured power into account. [1]

This paper suggests as alternative to grid expansion and high fossil backup capacities regional electricity associations with smart load scheduling. They are expected to result in a better fit between volatile renewable electricity generation and demand. The association construct allows not only temporal but also local price signals. This model is not only environmental but also grid friendly. As indirect subsidies existing options for reduced fees and levies are used. As building blocks of the business model future renewable electricity prices are estimated.

### 1.1. Future Electricity Generation Cost

The crucial parts of a business models based on renewable electricity are taxes, levies and prime costs. In this part future electricity prices are calculated using experience curves. Therefore a

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literature review of statistical derived progress ratios were conducted for each technology. Those results were combined with long term world market scenarios.

As estimation method for future technology prices two main options exist. One option are expert estimations based on possible technology innovations and implementations and changes in input factor prices, the second option are learning or experience curves.

While expert estimations need concrete innovations in mind and include success or failure predictions, learning curves are statically derived. In this analysis only experience curves are used, because their use is robust for long time technology predictions and their usage is widely spread in policy scenarios. [2] The literature cited later in this section shows, that they are derived for nearly all renewable technologies, and its more often discussed how they are done best, and which parameters should be used, then if they have a predictive value at all.

Learning curves origin from Wrights observation the price of aircraft manufacturing dropped with a constant percentage for every doubling of production. Using a double logarithmic scale the learning curve is linear. A learning curve can be calculated as following : [3]

$$C_t = C_0 (\frac{Q_t}{Q_o})^{\frac{Ln(PR)}{Ln(2)}} \tag{1}$$

*$C_t$ is the unit cost of a given cumulative production at time t.*
*$C_0$ is the unit cost at t = 0.*
*$Q_t$ is the cumulative production at a time t*
*$Q_0$ is the cumulative production at t = 0*

The Progress Ratio (PR) can be expressed as:

$$PR = 2^b \tag{2}$$

*With b as the rate of innovation or learning parameter. It is statically derived from data.*

The function describes, that the price of a unit depends directly on the number of units ever produced.

In general learning rates should be cleared by inflation. Therefore this paper is written in constant prices of 2013. Otherwise a rising inflation rate would underestimate learning rates, a decreasing inflation rate would overestimate future prices. With a constant inflation rate the learning is perceived lower but if the result is deflated it would lead to consistent results.

For photovoltaic the assumed market size is the baseline scenario from the IEA. [4] As progress ratio a value between 77% [5] and 82% [6] is suggested in literature. This paper uses the literature value of 80%. [7] In this paper the suggestion of C. Candelise et al. is used who estimate a PR of 80%. The price for PV-modules in 201 per kWp installed and ready to where in Germany 1900€ [8]. As estimation in Hanover, (lower Saxony)  a yield of 930 kWh p. a. and kWp is used.[9]

In the calculation of future actual cost of electricity generated by wind turbines the predicted growth rates are adopted from Literature the GWEC. [10] As initial price of onshore wind energy projects the average price estimation of 0.073€ is used. [11]  A review of PR from Å. Lindman and P. Söderholm offers a wide spectrum of global learning rates. This paper uses their recommended PR of 89%. [12]

For the battery sector the McKinsey estimation of 457€ in 2015 is adopted. The same study assumes that the current market growth rate of 26% continues until 2020. Due to a limited overall market, for later than 2020 a continued market size growth of 10% is assumed and a PR 86% is estimated.[13] Other studies estimate a learning rate of 83%. [14] Furthermore a battery lifetime of

5000 fullcycles is assumed. Due to a positive market dynamic mainly driven e.g. by the company Tesla a stronger battery market growth driven by the automotive sector is possible. Therefore a faster reaching of lower price levels on the experience curve is possible.

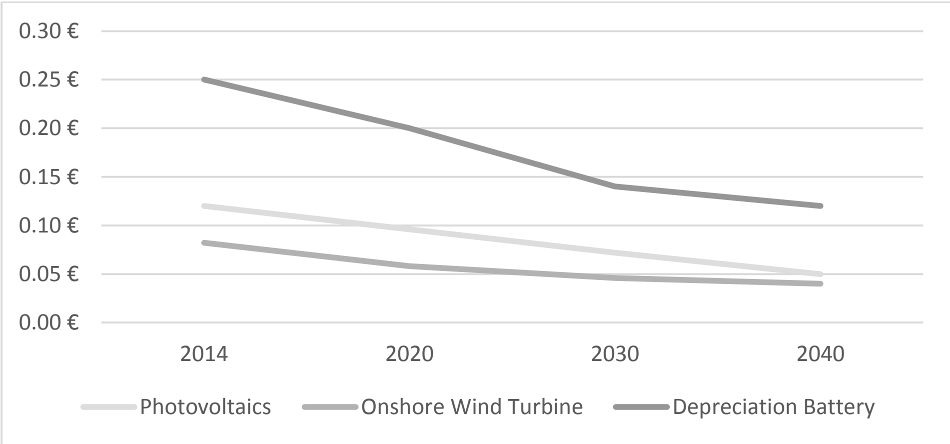



*Figure 1: Actual cost of renewable electricity generation.*

### 1.2. Tax and duty burden

Figure 1 illustrates, that from the actual costs perspective a business model based on local renewable electricity production is feasible and a spread compared with private consumer prices exists. A more significant influence factor is though the tax and levy burden included in electricity prices. They add up to 0.21€. Most important factors are the EEG-apportion (0.0624 €) and the grid fee (dependent on area with an average of about 0.07 €). Connected to the grid usage are also the concession levy, which differs dependent on the city size, increasing for larger cities (average 0.0179 €). The energy tax is dependent on extracting electricity from the public grid and the sales tax is an addition of 19% of the electricity price including and is also raised on the taxes included in the electricity prices. With such a high tax burden the consumer price of 0.21 € only for retrieving taxes is too high for flexible electricity tariffs. Therefore the business model needs an essential step to reduce the tax burden. Due to the nature of the different taxes the grid fee can be saved if no public grid is used. If a public grid is used, only the actual usage has to be paid. Therefore the usage of only one low voltage grid, saves the grid fees for high voltage usage.

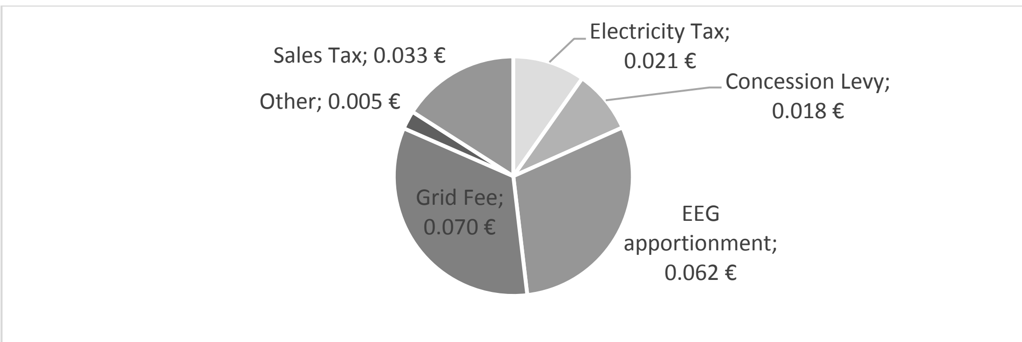



*Figure 2: Tax and levy burden on private electrcity consumption per kwh.*

The EEG apportionment can be saved if electricity from renewable sources is used by its propietary and the maximum power is below 10 kWp. If the maximum power is above 10 kWp 40% of the EEG apportionment has to be paid. [15] Furthermore the power generation units have to be in the same low voltage grid. The concession fee is dependent on the usage of a low voltage grid, therefore it has to be paid if electricity is transported from one household to another. The assessment basis of the electricity tax is the usage of power from the public grid, which also cannot be avoided. The sales tax can only be reduced if other taxes and levies are reduced.

### 1.3. Association Model

As option for shifting electricity from one prosumer to another consumer Gleiss et al. [16] describes a juridical construct, which allows different natural persons to be one juridical person.

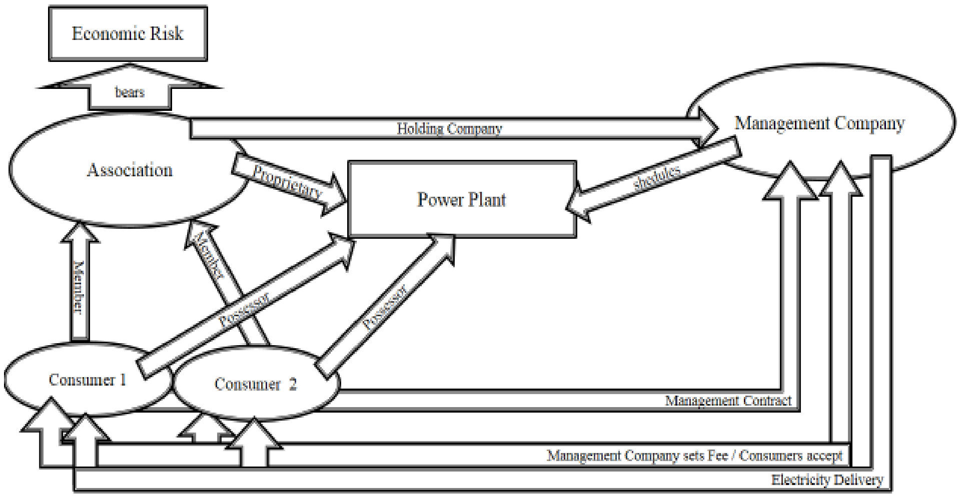
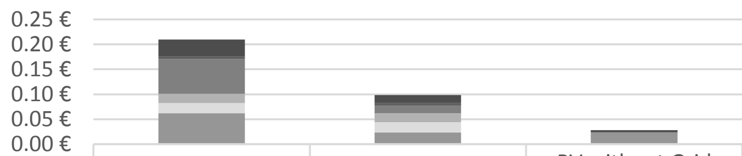



*Figure 3: The energy association model. Own figure according to Gleiss et al. [16]*

The power plants are run by a management company, which is a sub company of the electricity association. The consumers are possessors of the power plants and the association is proprietary of the power plant. All consumers are members of the energy association. Between consumer and management company exists a management contract, which allows the management company to influence the behavior of power plants and batteries.

The management company charges every consumer the same variable price for electricity. This offer accepts the consumer (automatically) for each 15 minute time period. This construct allows that no energy delivering contract exists.




| | Privat Consumer | Association Modell | PV without Grid usage |
|---|---|---|---|
| Sales Tax | 0.033 € | 0.016 € | 0.005 € |
| Other | 0.005 € | 0.005 € | 0.000 € |
| Grid Fee | 0.070 € | 0.015 € | 0.000 € |
| Concession Levy | 0.018 € | 0.018 € | 0.000 € |
| Electricity Tax | 0.021 € | 0.021 € | 0.000 € |
| EEG apportionment | 0.062 € | 0.024 € | 0.024 € |

*Figure 4 Comparison of different tax and levy burdens.*

As result from this model the fixed fees and levies decrease from 0.21 € in the initial situation to about 0.10 € in case the association model is used. As additional option the electricity which is not transferred through the public grid e.g. in case of a multi-family buildings is only charged the reduced EEG apportionment and the sales tax. With this business model consumption within one building remains the most attractive option, but an overall supply and demand management is established. This allows to give not own consumer the chance to benefit from overproduction of photovoltaic power plants via flexible electricity prices.

This lower electricity prices make investments e.g. in comparable large flexible consumer as electric vehicles more viable.

## 2. Demand steering

Due to the reasons explained in chapter 2 regional markets are under the current law and levity conditions an option, to enable flexible electricity prices and therefore make price based demand steering possible. As positive side effect a better demand steering not only allows grid friendly consumer behaviour but also the higher the amount of local produced electricity is, the lesser electricity transport is necessary. Also the usage of the reduced levity and tax burden for the participating consumer increases, the more electricity from within the association is used. In the following the technical implementation is described.

Existing studies committed field tests, and evaluated the demand shift potential of different technologies. They identified the largest demand shifting potential in smart, automatic steerable white goods. Smart electricity consuming goods not only achieved the best results, but were also able to avoid the problem a fading consumer motivation and resulting reduced reaction on price incentives. Overall a price elasticity of 11% could be observed.[17]

Based on this results, this papers concept is based on automated demand shift, done by smart electricity consuming devices. The demand shifting potential could be enforced if consumer also change their usage behaviour of none smart devices e.g. by usage of price signals from their smart meter or a smartphone application.

In this papers concept the demand side of this regional market consists of perfectly price inelastic agents (e.g. TV, illumination) and price elastic, smart agents (e.g. electric vehicle, wash-dryer, heat generation and battery). As well the supply side consists out of perfectly inelastic agents (e.g. photovoltaic systems and wind turbines) and elastic agents (e.g. cogeneration units, batteries).

Aiming to minimize the communication and hardware demand the smart consumer only communicate if it is filled, and the by consumer demanded finishing time. A centralised agent aggregates those demands and schedules the demand fitting to the expected power generation from renewable power plants. Expected supply lacks are then filled by cogeneration power plants. As last option residual supply or demand is traded with other grid areas.

The electricity price can either follow strictly prime costs. In this case a high base fee is needed for financing the IT-infrastructure and the initial investments in renewable power plants and batteries. This is compensated with only taxation and levitation charged electricity in hours where photovoltaic or wind power is used. The alternative is charging a price which mainly is cost competitive with existing electricity charges aiming to finance fixed cost with an additional margin on the marginal cost.

## 3. Conclusion and further research

This paper shows that with the association model a constructs exist, which allow indirect electricity trading between its members without losing most of the tax and levy advantages. This allows flexible electricity prices, which at last allows price based demand steering. As research in progress some questions are left open. First this paper offers two options for financing the associations overhead cost like IT infrastructure, but the question can only be answered if further simulations are conducted.

Other studies mention the even larger demand shifting potential in the industrial sector. [17] Due to tax exemptions and already flexible EEX based electricity prices for large electricity consumer, the business model cannot be expanded on large industrial electricity consumer. Due to only slightly reduced, inflexible electricity prices which small and middle sized electricity consumer need to pay, they can generally be included in the business model. In this papers concept they were excluded because a specific understanding of their workloads is necessary for selecting suiting shift able loads.

For increasing economic efficiency it is possible to use fossil based electricity in those hours with very small renewable electricity supply. This is charged normal tax and levy rates. This is an option to reach an overall efficient solution which uses for a transformation time also existing fossil power plant capacities.

The described areas with flexible regional tariffs have the potential to be innovation drivers. Time periods with low priced electricity increase the economic viability of green technologies as e-mobility or electricity based heat generation (heat pumps).

In further research the described simulation needs to proof, that regional markets including reserve capacities and supply and demand steering are economic efficient and able to deliver the expected results regarding grid services.

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# Aligning IT Architecture Analysis and Security Standards for Smart Grids

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## Abstract

In this paper, an approach using the European Smart Grid Architecture Model (SGAM), in the context of the NISTIR 7628, is presented. Research has shown that both models and methodologies have particular impact, but have not yet been put into mutual context. The combination of these models makes it possible for US smart grid experts to re-use the SGAM model and its benefits, and vice versa European stakeholders are encouraged to use the security analysis framework from NIST. Within this paper, we briefly introduce the methodologies including their strengths and fallbacks. We outline the necessity to make them interoperable and aligning them. Finally, the logical interface framework from NISTIR 7628 is mapped onto the SGAM and its planes, domains and zones, bridging the previous gap.


## 1. Introduction

One particular important aspect of a future smart grid, being a system-of-a-system, is the growing need for using ICT for communication between the various components, involved in the processes. Particular goals, to be achieved by the smart grid, may be related to aspects like the optimization and coordination of the various elements and their operation in the transmission as well as the distribution grid [1].

The importance of the aspect of (system) availability and uptime for the electric power distribution system is high. Furthermore, the dependability of the infrastructure, as well as of its basic components, is the focus of system and interfaces at design-time. Additionally, interoperability and interchangeability have to be taken into account to ensure a meaningful analysis of both, technical and non-technical requirements [2]. To achieve this goal, one particular way is to standardize technical solutions like data models, interfaces, processes and communication protocols at both international and national level. [3].

After the first standardization, initiatives were raised by both IEC and NIST, the very idea, that standards without being applied as best-practice in real-world applications are not the solution per se, became very apparent [4]. The NIST framework and roadmap for interoperability, as well as the European initiatives derived from the M/490 Smart Grid mandate [5], focuses on properly using, expanding and adopting so called IEC core standards as well as various related ones. To realize this, in 2012 the *Smart Grid Coordination Group* (SG-CG) initiated four different groups, that should develop a report for their corresponding topic, which are *"Sustainable processes"*, *"(First) Set of Consistent Standards"*, *"Reference Architecture"* and *"Smart Grid Information Security"* [6].

## 2. Security Architecture Development in the Smart Grid

Within this section, we highlight the existing work, which is relevant to the ideas, and preliminary work presented in this paper. First, the scope of the M/490 mandate motivates the need for a common architectural viewpoint in order to foster better component and system interoperability. This section concludes with a short overview on the NISTIR 7628 document series and a

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motivation why the various models should be combined for a better security-by-design methodology.

### 2.1. The SGAM

In the context of the European Commission’s Standardization Mandate M/490 [7], [8], a holistic viewpoint of an overall smart grid infrastructure named Smart Grid Architecture Model (SGAM) is developed. This work is based on existing previous approaches and subsumes the different perspectives and methodologies of the smart grid concepts. Figure 1 depicts the SGAM structure with its layers; the subclasses of the domains and zones are also outlined in Figure 1.

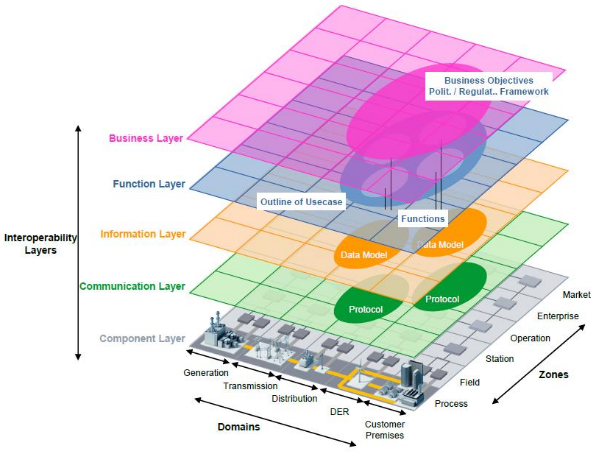


*Figure 1: The SGAM cube*

The SGAM comprises five so-called core viewpoint layers which support energy architecture design of different domain experts. Additional, the domains and zones support a holistic view on an architecture, including the business processes, which usually are out of scope for standardization. These layers were adopted from the Gridwise Alliance Architecture Council (GWAC) stack and context-setting framework [9].

### 2.2. Security Standards for Smart grids

Information security is not just relevant for the operation of the smart grid as a critical infrastructure, it is also very important for user acceptance and general operations. This particularly affects technologies like smart metering, especially in the part of privacy issues. Many different standards exist in the IEC TC57 portfolio, among them there are standards especially designed for end-to-end security; see e.g. [10] – one of particular interest is the NISTIR 7628 series [1]. Following the executive summary, the first volume of this internal report describes the overall approach, including the so-called risk assessment process, used by the CSWG to identify so called high-level security requirements. It also represents a high-level architecture, followed by a sample logical interface reference model with a composite view of 46 actors, distributed among the seven energy domains (transmission, bulk generation, marketing, operations, service provider, distribution and customer). This model is used to identify and define 22 logical interface (LI) categories within and across the domains. For these LI categories, so called high-level security requirements are described.

### 2.3. Linking Architecture and Security

As stated beforehand, combining the two state-of-the-art models from Europe and the US should lead to a better security analysis possibility for the current SGAM cube methodology. Later, this should lead to a better dependability analysis for SGAM models as well as a proper linking of logical interfaces (LI) from the NISTIR 7628 to a domain and zonal oriented viewpoint. Additionally, there is potential to crosscheck the NISTIR 7628 with the latest IEC Smart Grid Mapping Tool and, thus, enhancing the possibility to properly assess security standards for Smart Grids to the logical interfaces from NIST. Round-tripping between the various methodologies, tools and models will become possible. The Smart Grid Information Security (SGIS) group from the M/490 mandate currently focuses on privacy and data protection issues, therefore only complements the work done by NIST. Part of this work was a mapping of the logical interfaces and their systems from the NISTIR 7628 onto the SGAM functional plane. This implies that with the logical reference model, mapped onto the SGAM, even the logical interface categories with its *Smart Grid Cyber Security Requirements* (SG-CySecReq) can be transferred onto the SGAM model. The example, shown in this paper, will cover a part of this work. To properly use this model, the authors suggest a canonical model using five individual steps to integrate the methodology into the development to use it as security assessment, which can be seen in Section 3 of this paper. Normally, the use case itself typically covers 10-15 pages in the IEC PAS 62559 template, with an additional ten pages for the SGAM and NISTIR 7628 security analysis, so the description is limited to the very necessary aspects.

## 3. Example Use Case “Control of DER”

We assume a very simple scenario for this example that can be seen in **Fehler! Verweisquelle konnte nicht gefunden werden.**. Within a so called virtual power plant, different, mostly small *distributed energy resources (DER)* are combined to achieve a critical mass of generating capacity and, thus, to act as if they were a bigger single unit. Trading of energy at markets or providing various ancillary services is one focus of this virtual power plant (e.g. frequency control, voltage control, grid recovery or contingency planning). Based on their individual generation forecasts, *virtual power plant (VPP) operators* contract with market participants and create schedules to operate their individual units for a so-called combined product. To realize such a plan at operational level, generation and load has to be adapted to the needs of the market bid. Typically, this is done by direct control of the individual plants (*control unit for DER*) or by providing incentives to the owners to behave appropriately. In Figure 2, the communication and data exchange of the actors in this use case is displayed in a so-called UML sequence diagram that is explained in the following paragraphs.

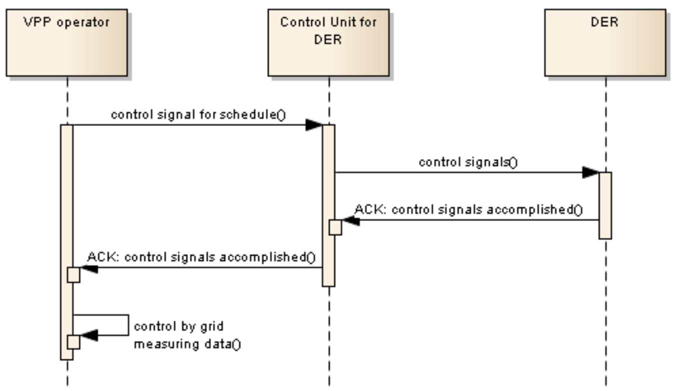


*Figure 2: Example use case sequence diagram*

Applying the aforementioned methodology, the following five steps have to be taken to assess security requirements from NISTIR 7628 to this use case.

**(1) Identifying and (formally) specifying the use case in PAS 62559 templates**

We start using the IEC PAS 62559 template and specify the use case of the former paragraph. Because of the limitation of pages in this paper the definition of the use case is here reduced to the identified actors and sequence diagram. The identified actors are: *DER*, *VPP operator* and *Control Unit for DER*. The sequence diagram of Figure 2 is useful to get an overview about the communication between the actors and to identify interfaces.

**(2) Identification and mapping of LI, communication links and interface categories**

The identified actors and communication links have to be mapped on the NISTIR 7628 descriptions. Figure 3 shows the scenario as a so-called high-level diagram from NISTIR 7628. The DER is a Customer DER (CDER). It is controlled via the Customer EMS and the VPP Operator gets involved in the control process via the LMS/DRMS system. The communication links, U106 and U45 from the NISTIR 7628 annex, and their corresponding interface categories, 10 and 15, are identified using the generic blueprint from the authors.

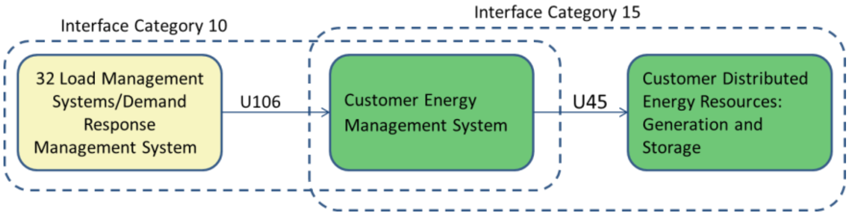


*Figure 3: Interface categories and systems*

The colours, used in Figure 3, reflect the domains of the LI diagrams. The system with number 32 LMS/DRMS (= yellow, domain operations) sends two different signals to the system number 5 Customer EMS (CEMS) (green = domain customer). After an appropriate ramp-up time the two signals, of tariffs and schedules, are submitted. If the time of the schedule is reached, real-time measurements are used to check the fulfilment. If the schedule is not satisfied, direct control, using a control signal for the Customer DER, is initialized. Once the signals are sent to the CEMS, the CEMS decides how to react, based on pre-defined and engineered rule sets, and sends control signals to the CDER. After accomplishing the tasks, first, the CDER acknowledges to the CEMS and the CEMS acknowledges to the LMS/DRMS, as can be seen in Figure 2.

**(3) Integration of the LI onto the SGAM Functional Layer**

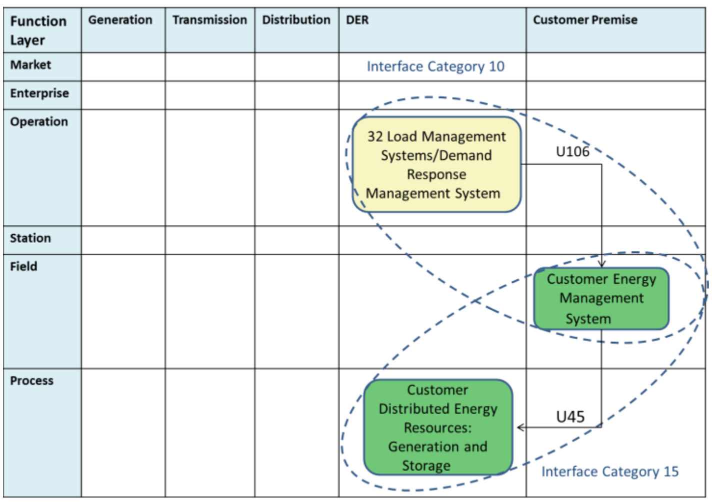


*Figure 4: Mapped actors and interfaces*

Within this step of the methodology, the mapping onto the SGAM layers is conducted. For this example, it is done in the Function Layer. Figure 4provides an overview of the mapped actors as well as the corresponding communication links. Utilizing this kind of graphical representation makes it easier to check which domains are covered by which actors as well as to recognize the hierarchical zone they reside in.

### (4) Using the SG-CySecReq annex from NISTIR 7628

In the NISTIR 7628 the interfaces are categorized and for the different categories protection goals, like CIA analyses and high-level security requirements, are determined. Based on the previous identified interfaces and categories, Table 1 shows the corresponding SG-CySecReq and the resulting sum of these to obtain requirements for the communication from the LMS/DRMS to the CDER. In addition, security requirements from other standards can be used from the annex lookup tables of the NISTIR 7628 report, volume 1 and 3.

| **Logical Interface Category:** | **10** | **15** | **Result:** |
|---|---|---|---|
| **Confidentiality:** | Low | Low | **Low** |
| **Integrity:** | High | Medium | **High** |
| **Availability:** | Medium | Medium | **Medium** |
| **Smart Grid Cyber Security Requirements:** | AC-14 (Permitted Actions without Identification or Authentication) | AC-14 | **AC-14** |
| | IA-04 (User Identification and Authentication) | IA-04 | **IA-04** |
| | SC-05 (Denial-of-Service Protection) | SC-05 | **SC-05** |
| | SC-06 (Resource Priority) | SC-06 | **SC-06** |
| | SC-07 (Boundary Protection) | SC-07 | **SC-07** |
| | SC-08 (Communication Integrity) | SC-08 | **SC-08** |
| | SC-26 (Confidentiality of Information at Rest) | SC-26 | **SC-26** |
| | SI-07 (Software and Information Integrity) | SI-07 | **SI-07** |
| | | SC-03 (Security Function Isolation) | **SC-03** |
| | | SC-09 (Communication Confidentiality) | **SC-09** |

*Table 1: CIA and SG-CySecReq analysis for the example*

### (5) Mapping additional SGAM layers

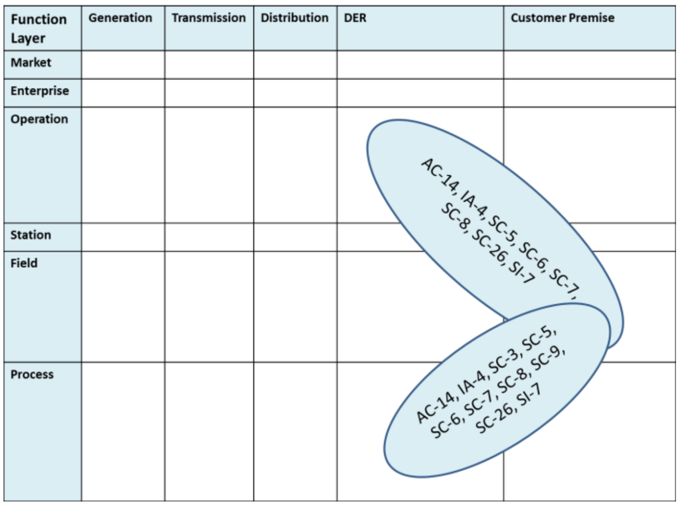


*Figure 5: NIST 7628 requirements*

In this step, the identified SG-CySecReq and their actors and communication links are mapped onto the individual further SGAM planes. Figure 5 shows where the high-level requirements are placed on the Business Layer. Figure 6 shows the corresponding SG-CySecReq, from the SG-

CySecReq classes. Additional aspects can be identified and assessed to the responsible architects for the individual layer.

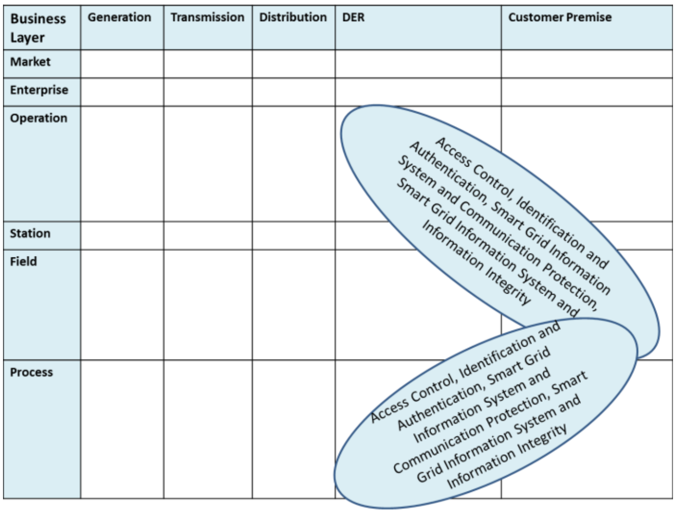


*Figure 6: high-level security requirements*

## 4. Conclusion and future work

Because of the very need of integrating security into the development process of smart grid architectures from the very beginning, the preliminary work, presented in this paper, shows a combined European and American approach, whereby the advantages of both facilitate a secure architecture development in the smart grid domain.

In the future, additional standards should be mapped to the SGAM to obtain a comprehensive model for the development of smart grid architectures.

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# A Risk Management for Agent-based Control of Ancillary Service Provision from Distributed Energy Resources in Smart Grids

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## Abstract

With increasing shares of renewable power generation, conventional power generation from large-scale and highly predictable fossil power plants decreases. Reliably substituting these plants depends on distributed energy resources (DER) being able to provide ancillary services such as frequency and voltage control that are necessary for a reliable and stable power supply. In this paper, we present first concepts regarding an agent-based approach for a stable and reliable control of ancillary service provision from DER, and we outline research challenges regarding the management of the economical risk an operator faces when trading active power and ancillary services from DER at energy markets.

## 1. Introduction

In order to reliably substitute conventional power plants, distributed energy resources (DER) have to participate both in active power trading and in the provision of ancillary services that are needed to safely operate the grid. This implies new challenges both for the control of the underlying system and the management of economical risks, as one has to cope with many individually configured, distributed, small generation units (photovoltaic (PV) systems, combined heat and power plants (CHP), wind energy converters etc.) as well as with the fluctuation in their feed-in especially depending on meteorological conditions. Regarding the technical implementation of stable, reliable and scalable control methods, self-organizing agents that represent generators, loads and (electrical) storage systems have been proposed for several years by the Smart Grid community [9], [13], [11].

Within the Smart Nord research project, an agent-based, self-organizing method for clustering DER into so called coalitions is being developed.[2] The agents representing single DER units – thus called unit agents – are not only capable of matching power products at energy markets such as the European Energy Exchange (EEX), but also allow for the provision of ancillary services in order to stabilize the power grid when necessary. For instance, frequency response reserve must be provided as an automatic reaction to a loss in supply or demand in order to stabilize the frequency. This is typically provided by large power plants through a controller yielding a small boost or drop in generation to balance demand and supply, respectively, thus stabilizing the frequency. As these reserves are necessary for a stable power supply, the provision of an ancillary service must be guaranteed and has to fulfil specific reliability constraints.

In this paper we present first concepts regarding an agent-based approach for a stable and reliable control of ancillary service provision from DER. In addition to a discussion of the technical properties of the developed system, we also outline research challenges regarding the management

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of the inherent economical risk an operator faces when trading active power and ancillary services from DER.

## 2. Related Work

### 2.1. Virtual Power Plants and Agent-Based Control of Smart Grids

Static virtual power plants (VPP) have initially been designed to overcome market barriers on active power markets [1]. Although several operators of VPPs are currently active participants on energy markets, the underlying concept has several flaws especially regarding its scalability. First, the VPPs are static regarding the pool of aggregated units – changes within the pool creates substantial and costly engineering overhead. Second, the control architecture is centralized, i.e. a single VPP control centre typically supervises and controls each single unit based on centrally optimized schedules – with the obvious shortcomings regarding scalability and complexity in the reflection of local constraints. Third, these VPPs were not designed to take system stability into account. VPPs of this kind only optimize economic integration of distributed energy resources (being a very important issue nonetheless).

As a consequence, a new aggregation type was defined in the project FENIX to overcome some of these shortcomings. Using a technical VPP concept, operational feasibility aspects are integrated into the market mechanism for commercial VPPs [6]. However, the proposed aggregation methods are still prone to flexibility and scalability issues. With the PowerMatcher approach, a more dynamic and agent-based concept was proposed, which was initially dedicated to matching supply and demand locally [7]. DER in the distribution grid trade their schedules locally and try to reduce the necessity of electricity transport from or to other voltage levels. Source [14] propose a similar concept, but focus on real-time requirements. In contrast to the concept presented in this paper, both systems work fully reactive without taking the energy market into account.

### 2.2. Risk Management

Nowadays, risk management is being applied in the context of conventional power plants. In [4] risk management is described as an economical task to combine the economical view on and the acceptance of risk. Thus, the main tasks of risk management are:

1) defining and implementing risk management,
2) limiting economical risks, and
3) implementing change management and improving planning security.

In the following example, a plant operator’s view on risk management is being used to illustrate these tasks: The operator of a coal power plant applies risk management in order to identify and monitor economical risks. This has to be done at every process level of the business (including management, projects and operative processes). As an economically feasible operation of coal power plants depends on external factors such as long-term prices for fossil fuels (coal), the plant operator has to avoid price risks. For the comprehensive integration of risk management into the business processes it is recommendable to integrate further functions of risk management (like change management or the improvement of planning security) into the operation of the power plant. Those functions might help to detect risks like an imminent breakdown that may lead to (possibly preventable) downtimes of the power plant.

A more detailed discussion on risk management will be given in section 4.

# 3. Agent-based Control of Ancillary Service Provision in Smart Grids

## 3.1. Reliability-dependent Agent Coalitions of DER

In Smart Nord, ancillary services are provided by base coalitions and corresponding core coalitions [8]. The purpose of a base coalition is to aggregate and to represent a group of agents at an energy market. This way, agents gain access to the market and may take part in placing bids on the product by collaboratively providing the required amount of power for the entire delivery period of a given ancillary service product. Core coalitions are subsets of base coalitions. Their purpose is to provide the service over a period of time that is typically shorter than the original delivery period of the service. As forecasts are typically more precise with shorter forecasting horizons, the contribution of individual units of a given core coalition might be larger over this shorter period of time than initially anticipated within the base coalition's delivery period. Thus, a more efficient utilization of units within a base coalition can be obtained through more precise short-term forecasts. With an increase of forecasting errors over time, a coalition's reliability decreases respectively (cf. section 3.2). Figure 1 visualizes the decrease of a coalition's reliability over time and the respective restructuring of the coalition, i.e. the contribution of its members for different time intervals. Here, $C_{Core}$ denotes a core coalition within a base coalition $C$ consisting of 13 units $U_i$ with $i \in \{1,2,\dots,13\}$.

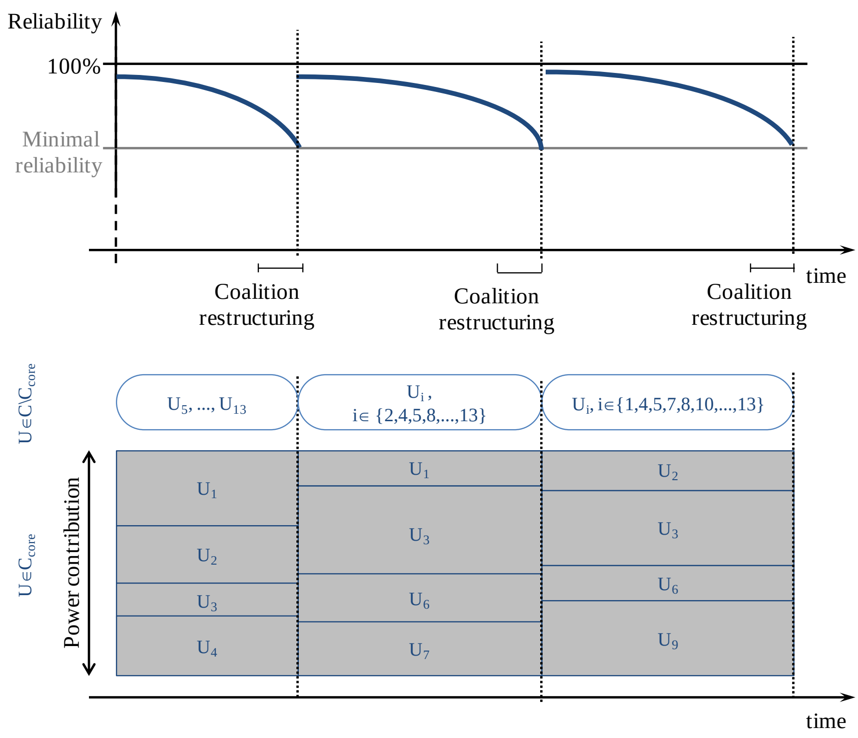


*Figure 1: On-line restructuring of core coalitions in regard to decreasing reliability.*

In summary, units being in the core coalition are actively responsible for ancillary service provision while the remaining units play a passive role until a minimal reliability threshold is reached and a restructuring yielding a new core coalition becomes necessary. Thus, the provision of ancillary services from agent-controlled DER is guaranteed with at least the minimum acceptable reliability across several core coalitions and ultimately for the whole product delivery period.

### 3.2. Modelling DER-Reliability for Ancillary Service Provision

Units participating in the provision of ancillary services must guarantee their ability to do so. However, especially renewable energy sources (RES) are subject to fluctuating, hard to predict weather conditions. In order to take the resulting uncertainties into account, a new model for reliability was introduced in [2] that reflects the availability of a unit to provide ancillary services. The reliability of a coalition is thus defined as the probability with which this service is available within a time horizon under normal conditions (i.e. for instance without the existence of vicious agents or extreme weather conditions).

The reliability of an agent coalition depends on the reliability of each of its member units, and the reliability of a single unit is influenced by several factors categorized as *influenceable* and *non-influenceable* factors. Whereas an agent has no control on the non-influenceable factors, it can manipulate the influenceable factors in order to fulfil its objective or fit into a coalition. Those factors are: considered time horizon (directly influencing the quality of a forecast), provided amount of power (smaller quantities may be provided with higher reliability), and acceptable level of reliability.

## 4. Risk Management for Energy Markets and Ancillary Service Provision

This section deals with the strategic and market-oriented behaviour of agents in ancillary service coalitions. In the context of risk management, “risk” is defined as a financial or an entrepreneurial uncertainty within a business context. The historical definition of risk management comes from an economic context and describes the financial uncertainty that a company is willing to accept, and non-acceptable uncertainties that in consequence have to be eliminated [10]. An undetected and not eliminated potential of risk may influence the business venture of a company in a negative way [5]. Thus, risk management is important to identify potential risks and to rate them in terms of *acceptable* and *non-acceptable*.

The main task of risk management is to avoid risks and to create strategies for handling existing risks. Those risks can be separated into two categories: those who have a critical influence on the current business and those who are acceptable. These categories are described by [10] as *main risks* and *secondary risks*.

| *Main risks* | *Secondary risks* |
|---|---|
| Risks of the energy market price | Liquidity risk and credit-worthiness of a new co-contractor |
| fuel price risk | sales fluctuation (especially regarding day-ahead power trading) |
| risk of investment | risks of new business areas (e.g. ancillary service provision) |
| risk of prediction error | risks of change management, unbundling and reorganization |

The main category already focuses on energy-related risks. The category of the secondary risks is closer to the economical consideration than the first one. For a domain-specific approach, it is necessary to adapt it to an energy-economical context.

In an energy-economical context, risk management has to be discussed regarding two distinct, yet closely related aspects: active power trading markets and ancillary service provision. In the context of active power markets, risk management is differentiated regarding short-term and long-term trading. In both trading activities, risk management is important and sometimes already used in companies. In Europe, energy is traded both short-term and long-term at a central market, the European Energy Exchange (EEX). The main risks listed before, the most important risks are the price risk and the risk of not being able to produce the sold energy to a contract partner. In the past, the risk in long-term energy trading was low because conventional power plants typically generated constant power outputs over a long period of time that could be traded comfortably via future contracts. Nowadays, the share of renewable energies sources (RES) is immensely increasing. The installed capacity of RES has risen up from 11.573 MW in 2000 to 82.356 MW in 2014, which is an increase of 711 percent [12]. The renewable energy law of Germany (EEG) which was created at 2000 and revised in 2008 and 2012 [3] describes the preferential feed-in of RES into the power grid and the guaranteed feed-in compensation. Thus, there is currently no financial incentive for RES to participate in power trading. However, the currently discussed revision of the EEG aims at a more active market participation of RES and DER units. In this case, the owners / operators of RES units face a financial and possible a production risk when selling their power on energy markets. In case a unit (or, more probable, a cluster of units) doesn't generate enough energy, it is possible to buy power 'last-minute' at the intraday energy market in order to maintain a power balance. This may, however, influence the profit of the unit or the cluster in a negative way.

Another aspect of risk management is concerned with ancillary service provision (ASP). Ancillary services such as frequency and voltage control are necessary for a reliable and stable power supply. Regarding for example primary control reserve, a DER unit or a cluster of DER units can sell a constant power reserve to the operating reserve market, realising a variable price that orientates itself on the bid of the unit owner. This power reserve will be activated when the frequency is higher or lower than 50 Hz. The uncertainty of surplus or deficit power production yields the risk of a retribution payment to the operating reserve market.

Both active power trading and ancillary service provision comprise technical and financial risks and therefore require a structured risk management. The research focus for our future work is on financial and production-related risk management for DER, as these units can be active on both active power and ancillary services markets at the same time and are prone to uncertainty and inherent unreliability. A suitable risk management should be able to rate every unit of the cluster in a risk scale describing the level of risk as a function unit reliability. This approach is closely correlated to the reliability modelling as discussed in section 3.2.

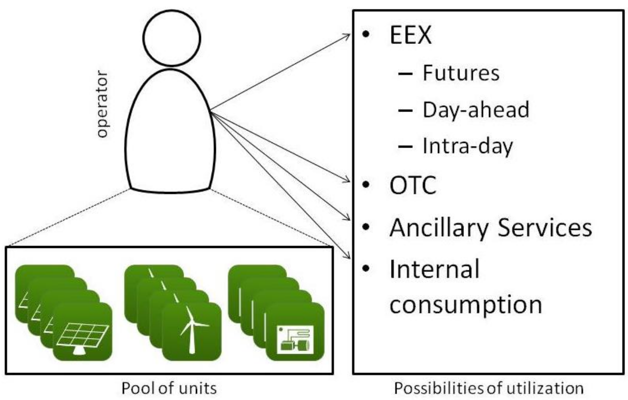


*Figure 2: Different power trading points of an unit operator*

The investigated setup consists of an owner or operator of RES who has different types of units in his RES pool. The pool consists of a fixed set of units that can be of different types (fig. 2). The operator has different possibilities to market or utilize the energy produced by its units, e.g. at the EEX, OTC, as ancillary service or as internal consumption. However, in the first step the focus lays on the calculation of the risk management of combined heat and power plants, trading on the EEX as a future contract. There are multiple financial and economical risks within the future power trading. If an operator is not able to produce the contracted energy, he has to buy expensive power at the EEX on the Intraday market. This additional expense has to be paid by the operator and can pose a huge financial risk. To avoid those risks, an approach is needed, which is based on forecasts (e.g. like weather-, price- and feeding) and has a connection to the reliability. The reliability model, which is described in chapter 3.2, provides a method to estimate the reliability for an ancillary service product provided by distributed units. This may be used or adapted for the risk management concept since it takes into account uncertainties of energy supply. The risk management approach can create instructions to avoid risks while, e.g. trading power on future contracts in advance. We will report on our progress in related and upcoming publications.

## Acknowledgment

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# Model-based Energy Consumption Prediction for Mobile Applications

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## Abstract

Investigating the energy consumption of mobile applications (apps) is becoming a growing software engineering challenge due to the limited battery lifetime of mobile devices. Energy consumption is defined as the power demand integrated over time. Profiling the power demand of an app is a time consuming activity and the results are only valid for the target hardware used during the measurements. The energy consumption is influenced by the resource demands of an app, the hardware on which the app is running, and its workload. This work adapts resource profiles for enterprise applications to predict the energy consumption of mobile apps without the need to own a physical device. Resource profiles are models that represent all aspects influencing the energy consumption of an app. They can be used to predict the energy consumption for different hardware devices and evaluate the overall efficiency of an app. Moreover, the workload can be changed so that the impact of different usage patterns can be investigated. These capabilities lay the foundation for a platform-independent way of quantifying the energy consumption of mobile apps.


## 1. Introduction

The capacity of batteries dictates the uptime of smartphones and tablets. The battery usage limits the daily device availability and decreases the long term battery quality. Reducing the energy consumption of these devices decreases the number of loading cycles, improves user satisfaction, reduces total operational cost, and eases the carbon footprint of mobile technology [1, 2]. Recent developments in battery technology are mostly defined by larger or brighter displays, faster central processing units (CPU), or an increasing number of sensors [3]. Optimizations on the operating system (OS) level cannot compensate for that increasing power demand [4]. An underestimated optimization potential can be found in applications (apps) [5-7]. Capra, Formenti et al. [8] showed that, under the same workload, different Enterprise Applications (EA) with similar functionality have significantly different levels of energy consumption [8]. Comparable effects can be discovered in apps on mobile devices [9].

Reducing the power demand of apps can be achieved by exchanging algorithms or resources and limiting the usage of sensors or network traffic [1, 3]. The most common methodology to enable developers to detect energy bugs is energy profiling [10]. Profiling technologies differ per device and per platform, in formats and accessibility [3]. Profiling results can diverge per target device, even if it is running on similar platforms [6]. A common requirement of these profiling methods is that they require the hardware: the device under test (DUT) [2]. Existing research focuses on profiling and lacks models and simulations. In this work we propose an abstraction of the hardware characteristics in terms of resource profiles [11]. These profiles as input for a simulation engine can predict energy consumption and battery life for apps without the need for a DUT.

The proposed approach allows developers to compare multiple devices, which are running the same app by exchanging only parts of a resource profile. This leads to a more automated evaluation and

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less labor intensive analysis compared to using real DUTs. The effects of using an app for hours can be simulated and those simulations are typically faster than real time. Furthermore, this approach allows the comparison of multiple versions of the app according to its energy consumption in different usage scenarios (e.g. power user, medium interaction). As this approach is completely software-based it can be distributed and scaled for remote evaluations.

## 2. Predicting Energy Consumption

### 2.1. Resource Profiles for Mobile Applications

Predicting energy consumption requires three different inputs: the workload, resource-demanding aspects of an app, and the hardware environment. Each of those inputs can be depicted independently from each other. The hardware and the workload define the environment in which the app is running. The energy consumption is predicted by a simulation engine as shown in Figure 1 - Simulation Process.

The hardware environment represents the power demands of different power consumers of a device. These power demands may vary depending on their state and usage. For example, the power demand of a CPU is dependent on whether it is running on a full clock signal or in power saving mode. It is furthermore dependent on the utilization of a hardware resource. The hardware environment captures these dependencies. It contains CPU, Wi-Fi, cellular transmitters, the display and sensors like the Global Positioning System (GPS) sensor. The power demand necessary to run the OS and keep the device alive is also represented in the hardware environment. Battery life prediction relies on the capacity of the used battery; the battery capacity is also specified in the hardware environment.

The prediction of the energy consumption of an app requires the specification of its resource-demanding aspects. These specifications define which hardware resources (e.g. CPU, sensors, and display) are used by an app and how much demand is placed on them for different control flows. The power demands of these components can then be calculated using the simulated utilization of the hardware. The battery life prediction is then calculated from the energy consumption and the battery capacity.

Different usage scenarios can result in different energy consumption calculations. The third and last component of the resource profiles describes the user's behavior. This part is called the workload. The workload describes how a user utilizes the publicly available interfaces of the app. In a typical app, this public interface is the user interface; therefore the workload describes how the user interacts with the app.

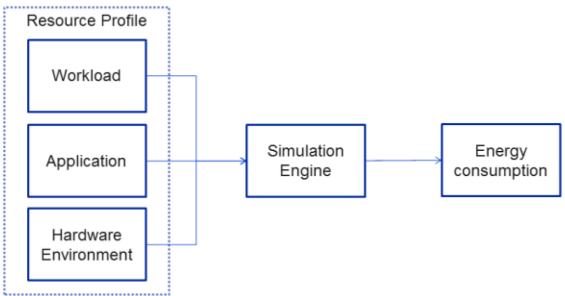


Figure 1 - Simulation Process

### 2.2. Use Cases

Resource profiles allow developers to predict energy consumption without the actual device. Each hardware environment contains the necessary information to simulate the energy consumption of a device. The battery lifetime of these devices can vary due to the fact that some components are more efficient in one device, some devices have larger displays that consume more power, and the capacity of the batteries itself varies among different devices. In short, the power demand of a component depends on the platform it is running on [6]. The same app can therefore have different effects on the battery life when deployed on multiple devices. Resource profiles can be used to predict those effects by simulating the same workload and app inputs with different hardware environments. The approach can also be used to compare multiple versions of an app, to detect changes in the power behavior of the app and its components.

Prediction results simplify comparing of the energy consumption of apps. Apps with similar functionality can be compared according to their energy consumption by exchanging the app input and keeping the workload and hardware environment stable. The simulation results show the differences according to the energy efficiency of those apps. These differences allow developers to rate which of the simulated apps uses the least battery capacity. Comparing two apps with similar functionality can lead to a recommendation for using one app over another.

Investigating different workloads nowadays requires different profiling experiments. Comparing the results requires developers to re-run exactly those experiments with different hardware or different versions of an app. Using resource profiles for this purpose allows developers to change the workload input before executing a simulation. Comparing simulation results with different workloads leads to different energy consumption predictions.

### 2.3. Realization

To realize the resource profile concept outlined in section 2.1 and the corresponding use cases explained in section 2.2, we are using the Palladio Component Model (PCM) meta-model to represent resource profiles [11]. PCM allows the modeling of resource-demanding aspects of an app, workloads, and hardware environments independently of each other. PCM consists of several model layers [12]. One of the main models within the PCM meta-model is the repository model. The repository model contains the components of apps, their operation behavior, and resource demands as well as their relationships. These repository model components are combined into a system model. The available devices and their capacities (i.e. CPU cores) are specified in a resource environment model representing the hardware environment. An allocation model specifies how the system model elements are mapped to these devices. The workload on the system is represented by the usage model. The default simulation engine of PCM is called SimuCom [13]. It uses the five PCM model layers to predict performance metrics such as response time or CPU utilization of a software system. The PCM meta-model is represented using the Eclipse Modeling Framework[3] (EMF).

PCM models cannot be used to predict energy consumption without further extensions. The work of Brunnert et al. [11], therefore, contributed power consumption models to PCM to predict the energy consumption of EAs. These power consumption models specify a linear formula to calculate the power consumption of a hardware device in the resource environment model. The formula takes the utilization of different hardware resources into account. At the end of a simulation run, their extension automatically integrates the resulting power demand values over time to calculate the energy consumption of a device.

Mobile apps and devices require further extensions to the PCM meta-model, as the structure of their hardware resources and power consumers is different compared to EAs. Energy consumption predictions for EAs do not need to consider displays, Wi-Fi transmitters, or other sensors (e.g.

[3] http://www.eclipse.org/modeling/emf/

GPS, Accelerometer, etc.). This work extends the existing power consumption models for PCM to take smartphone and tablet energy characteristics into account. For this purpose, models that represent hardware environments (i.e. resource environment) and resource-demanding aspects of an app (i.e. repository model) need to be extended to represent GPS and similar sensors and an app's use of these sensors. Additional extensions are required to specify the battery capacity of a mobile device to analyze how long this capacity will last for a specific usage scenario.

PCM simulations aim to predict the load for different components with various workloads. The power consumption models calculate the power demand of a hardware device based on the load on the resources utilized by an app. Hardware devices are represented as so called resource container in the resource environment model. As part of these containers the power demand of different hardware components is specified. Furthermore, the power consumption model of such a container includes the power demand necessary to run the system in an idle state. In contrast to EA systems, mobile OS power consumption depends on the environment of the device. An example of these variances is the power consumption of the cellular connection, as it varies based on the quality of the connection to the next cellular base station. Therefore, the power consumption models are extended by adding an approximation of the base power consumption of the mobile device. This approximation includes the varying power consumption of the OS and the device in an idle state.

As in the work of Brunnert et al. [11], the power demand of resources like CPUs is calculated based on their utilization. The power demand based on the utilization is described by a linear function. Several authors such as Fan et al. [14] and Rivoire et al. [15], showed that such linear models are sufficiently accurate for representing these kind of resources [14, 15]. Increasing the CPU utilization will thus increase the power demand proportionally. The linear function calculates the current power demand based on the utilization of the CPU calculated by PCM.

The standard PCM resource environment model contains linking resources. These resources represent network components like a Wi-Fi or a cellular data transmitter. For mobile devices, the data transmission, especially over cellular, can be a significant power consumer. Therefore, this work extends the PCM meta-model with power consumption models for linking resources in order to simulate the power consumed by transferring data to and from the device. This extension of the linking resources provides developers with the ability to model several transmission units for the hardware environment with different levels of power demand. This allows the simulation of varying power demand of Wi-Fi compared to cellular data.

The display is considered a resource similar to a semaphore, as usually only one or no app can use the display at the same time. To represent this behavior, we use the active resource PCM meta-model element type that is also used to represent resources such as CPUs or HDDs. However, we modify the scheduling behavior for this component in a way that prevents other processes from accessing this component while in use. This ensures that the display can only be used by one consumer at a time. To simulate different brightness or color intensities that affect the power demand of a display, we use a distribution function that assumes a certain display behavior.

Sensors like GPS can be accessed by multiple processes at the same time. The constraint applied for displays is not valid here. The power consumption model therefore only takes into account whether such resources are used or not. The power demand of such a resource is therefore considered for the calculation of the device's power demand when at least one process accesses the sensor. The power demand of such sensors also varies depending on the required sensor accuracy. The required sensor accuracy is therefore also taken into account as a variable in the power consumption model.

### 2.4. Creating Resource Environment Models

The creation of the resource environment model is based on a calibration app. This app reads and parses manufacturer hardware profiles as a baseline, if present. The profile is then adjusted with measurements of the current battery drain. This approach can only measure the complete power consumption at a specific time [16]. In order to determine the power consumption of a specific component, we measure the electric current before, during, and after the activation of this component and calculate the difference between using and not using the component. This process is repeated several times to approximate a sufficiently accurate mean value or function. This mean value, multiplied with the battery voltage, results in the power demand of a component in our model. After the complete calibration we calculate a function over the base current drain on the battery and consider this as the OS power consumption for our device.

## 3. Related Work

Resource profiles are already being used in the area of EAs [11]. These profiles are based on architecture-level performance models and provide a common description of the performance-relevant aspects of an EA architecture including its resource-demands. The separation of the app descriptions from the hardware environment and the workload provides the ability for dynamic assemblies and individual evaluations. Such evaluations are performed by using resource profiles as input for a simulation engine. Therefore, the same resource profile can be used to evaluate the energy consumption and performance of an app on multiple hardware environments without deployment or the physical presence of the specified hardware. This work adapts resource profiles for mobile apps in order to create a hardware and platform independent energy evaluation and prediction engine.

Hönig et al. [6] suggest a model-based approach to provide developers information about the power demand of their code. This approach is based on hardware models provided by Android[4] manufactures. We reuse these models as calibration baseline for our resource environment models and refine them by calibrating the power demand of the hardware components of the device.

Josefiok et al. [3] outline that power measurements on Android devices differ between manufactures and OS versions. The multitude of application programming interfaces and variances in granulartiy complicate comparisons between different measurements. The work suggests a common energy abstraction layer as a profiling baseline technology [3]. We add a representation of the results in terms of a hardware environment model to this approach.

## 4. Conclusion and Future Work

This work proposed to adapt EA resource profiles for predicting the energy consumption of mobile apps. Simulations of the energy consumption of mobile apps are realized by extending PCM with power consumption models. We focus on a platform independent representation of the hardware characteristics and the simulation of the utilization of sensors, CPU, display and data transmitters. Using these extended models as input for a simulation engine allows predicting battery life of a device running a mobile app. The model extensions help developers to understand the varying power demands of different devices, to predict diverging battery life, and to optimize mobile apps in order to save battery power and reduce profiling effort.

The resource-demanding aspects of an app (i.e. repository model) are nowadays created manually. Brunnert et al. [17] described a way to create such models automatically using dynamic analysis for Java Enterprise Edition (EE) applications. An adapted approach for mobile apps could be used to

[4] http://www.android.com/

create repository models automatically. This could decrease the effort required to simulate mobile apps energy consumption.

PCM usage models represent the behavior of a user while working with a mobile app. Observing user behaviors automatically and detecting common usage patterns could create better usage models for the simulation. Tools like Google Analytics[5] already allow detailed user tracking for web and native apps for desktop and mobile. The most common interaction paths can be extracted from such tools as well as the probability distribution across all interaction paths. Analyzing this data for capturing more accurate workloads would reduce the effort for the model creation and improve the simulation results.

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# CONTEXTO: Leveraging Energy Awareness in the Development of Context-Aware Applications

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## Abstract

We introduce a new context classification and recognition framework for the development and deployment of mobile, context-aware applications. The framework is complemented with an energy calculator that specifically assists mobile developers in estimating the energy footprint of context-aware applications during the development process with the framework. The framework abstracts from the raw context information gathering, allows for sensor fusion, enables the prediction of custom and higher-level contexts, and provides for context sharing.

## 1. Introduction and Motivation

The evolution of mobile devices and the general availability of information sources that describe the situation and environment (i.e., the context) of mobile users offer new opportunities for innovative applications [1]. By constantly monitoring the contexts in which mobile users are situated, applications obtain a potential to adapt their behaviour to current contexts more intelligently and without user intervention. However, such mobile context awareness comes at a price: Novel challenges of the mobile environment and specific constraints of mobile devices and their use (e.g., limited battery life, a comparably small screen size, dependence on network infrastructure) can severely impact the acceptance of mobile context-based approaches. In addition, adequate developer support for the realisation of context-aware applications is currently lacking. Consequently, most application developers are on their own when realising the sensing and interpreting of context information, or the sharing of context. With the increasing interest in, and a growing market for, context-aware applications, developers are more and more in charge of carefully designing context-aware applications and they need to be able to competently address issues such as privacy [2], availability, precision of context recognition, or energy requirements.

In this contribution, we address the energy-related implications of developers' choices of sensing components, processing algorithms, and granularity or temporal frequency of sensing. We specifically aim at developer energy awareness and present CONTEXTO, an energy-aware framework for offline context classification and recognition on mobile devices. The framework provides a layered, component-based architecture that can easily be extended, modified, or customised. It follows established software engineering patterns to provide high learnability and a low threshold for beginners. Within the framework, the energy requirements for all used components on a specific device are always made transparent, and information about energy requirements can be used early in the design process with the help of the framework's energy calculator, and at runtime.

The following section will introduce the main concept and energy model of CONTEXTO. Section 3 will address the software architecture and implementation details. Section 4 will give an overview of related work. Section 5 will provide an outlook on future work.

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## 2. Energy Model

CONTEXTO aims at providing energy awareness for developers of context-aware applications. We hope that insights into the specific energy footprints of alternative implementations of context recognition will lead to more energy-efficient applications that, in turn, will be more widely accepted by its users. At its core, the framework employs an energy model for a number of smartphone devices. The model provides information on the individual power consumption and required energy for all of a device's sensors in relation to a chosen sampling interval [3]. We conducted extensive measurement experiments with a software-based remaining capacity approach to build energy models for the Apple iPhone 4, 4S, and 5. A detailed description of the measurement setup would go beyond the scope of this paper, in essence we read the remaining battery capacity in mAh, as provided by the *IOPowerSources* part of the *IOKit* framework (please see [4] for further details). Information about the energy demand of the current selection of sensors is made available to developers at runtime, directly within the framework.

In contrast to most of the classic context platforms and toolkits that rely on a distributed or client/server-based architecture, CONTEXTO is completely self-contained and provides true offline context classification and recognition. All steps of the processing pipeline (data acquisition, pre-processing, context classification, context prediction) happen directly on the mobile device, and there is no external service or context platform required. Our tests of the framework have shown that recent smartphone models provide the required resources (e.g., CPU speed and RAM size) for all processing steps. We think that the offline approach is superior to online approaches because it allows for higher levels of privacy (all gathered data remain on the device), reduces the amount of energy required for the context recognition (UMTS and WiFi hardware requires most of the energy on a smartphone [5]), and does not rely on any kind of network infrastructure.

| Component | Energy demand (J, 10 minutes) | | |
|---|---|---|---|
| | iPhone 4 | iPhone 4s | iPhone 5 |
| **Sensors** | | | |
| Accelerometer | 29.15 | 25.13 | 20.42 |
| Camera | 217.02 | 317.00 | 293.89 |
| GPS | 143.29 | 143.56 | 180.44 |
| Gyroscope | 61.67 | 49.53 | 34.26 |
| Heading (Compass) | 69.23 | 70.34 | 37.41 |
| **Features (measurement / computed)** | | | |
| Camera+GPS | 543.31 / 549.63 | 662.45 / 657.00 | 638.49 / 646.16 |
| Accelerometer+Orientation | 237.68 / 240.86 | 247.28 / 241.93 | 202.97 / 205.79 |
| **Framework (local / remote)** | | | |
| Baseline | 211.86 / 268.18 | 245.12 / 318.92 | 181.89 / 249.30 |
| Battery+Carrier+Contacts+Date+Reminder | 302.45 / 380.18 | 358.31 / 486.87 | 307.44 / 399.47 |
| Camera+GPS+Heading+NetworkInfo | 671.80 / 750.35 | 846.49 / 977.99 | 694.60 / 808.45 |

*Table 1: Device-specific energy demand overview of hardware sensors*

We conducted an extensive series of experiments on all three devices. On each device, the energy demand of about 20 hardware and software sensors (the exact number varies, depending on the device capabilities and available sensors) and 10 features was measured with a sampling frequency of 1 Hz over the course of 10 minutes. For every sensor/feature, we repeated each trial three times on every device. We also evaluated if our initial argument for local (offline) processing and classification directly on the device had a positive energy impact, compared to a remote solution where gathered sensor data was sent to a server using WiFi. Table 1 gives a short overview of some of the most interesting findings. In the table, we compare the energy demand (expressed in Joule for a 10-minute trial, all values are averages across three trials) of selected sensors and features across our tested devices. Furthermore, we used the measured energy demand of individual sensors to approximate the energy demand of our features. Finally, we evaluated the difference between keeping all data local vs. sending data to a remote server for processing.

Our gathered data indicates that most of the sensors in the iPhone 5 (the most recent device among our test devices) show a lower energy demand than the older sensor components in the iPhone 4 and iPhone 4S. There is an exception with the GPS sensor of the iPhone 5. Since that sensor's performance has drastically improved since the iPhone 4S, we suppose that, for the iPhone 5, Apple opted for high accuracy and low latency over low energy demand.

We were also able to show that the sum of the individual energy demands of sensors very well approximates the energy demand of features using these sensors. In most cases, the computed energy demand overshoots the measured energy demand; this is probably due to internal optimisations of the underlying iOS sensor APIs.

Finally, our evaluation clearly shows that sending sensor data over a WiFi connection requires a considerable amount of energy; and that this overhead cannot be compensated with energy saved by outsourcing the processing and classification algorithms. We are still looking into this issue, since we assume that very complex processing algorithms and classifiers running on the smartphone may change this circumstance.

## 3. Implementation

The CONTEXTO framework follows a layered architecture, based on the proposed architectures in [6, 7]. As shown in Figure 1, it separates context usage from context detection. In the *Context Detection* layers, we set a *Managing* layer that contains context models and persistence functionality on top of classifiers and features of the *Thinking* layer. The basic *Sensing* layer contains all sensors that are used as data sources.

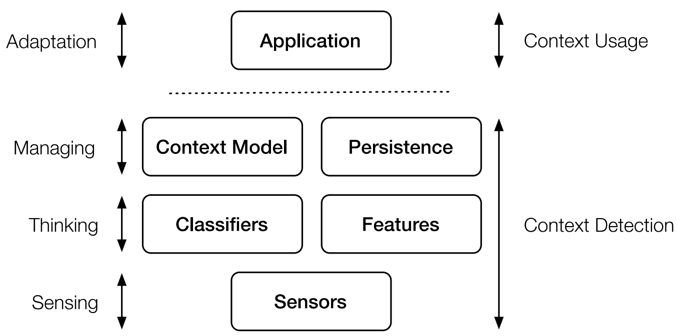


*Figure 1: Layer architecture of CONTEXTO*

Our prototype implementation is currently available as an iOS framework, but the concept can be adapted to other smartphone operating systems with little effort. The sandbox design of iOS currently prohibits a service architecture for providing context data to other applications, but this could easily be overcome on other platforms. The framework implementation was tailored to support easy extensibility, learnability, customisability, and maintainability by paying particular attention to accepted design principles (Separation of Concerns, Single Responsibility, Interface

Segregation, Dependency Inversion). This means in particular that developers familiar with common iOS frameworks should have a fast learning experience and quickly make efficient use of CONTEXTO. All components can easily be extended or replaced. In our prototype implementation, we currently provide a naïve Bayes classifier; additional classifiers can be added by overriding our well-documented *JPClassifier* class. All key components follow this pattern of extensibility.

## 4. CONTEXTO Energy Demand Calculator

The *Energy Demand Calculator* (see Figure 2) is a tool for developers to estimate additional energy demands of selected information sources (sensors and features) for context acquisition. The tool gives developers the ability to determine an approximated energy demand early in the development process of a context-aware application. The calculator allows developers to try out different combinations of information sources, and visualises their impact on the energy demand of the application. Such information allows optimising an application's energy footprint and increases the awareness for major energy consumers.

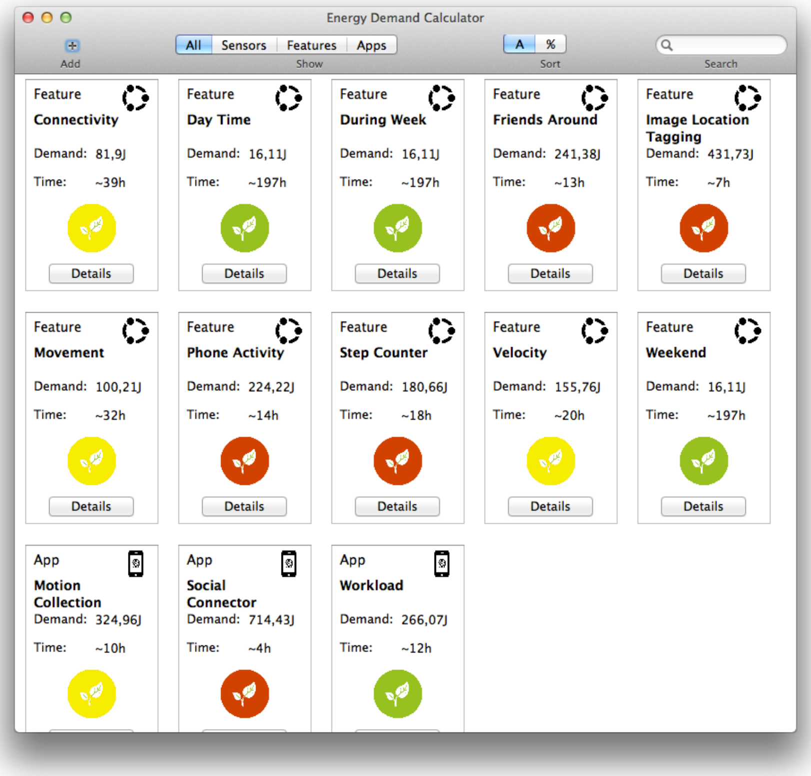


*Figure 2: Graphical user interface of the CONTEXTO Energy Demand Calculator*

The previously introduced energy model serves as the basis for all estimations. In order to compute the energy demand of an application, the calculator searches recursively for related sensors, generates a unique sensor pool by removing duplicates. The construction kit of the calculator provides a *Sensor*, *Feature*, and *Application* component to interact with. This allows developers to rebuild their context-aware application and simulate possible configurations. The *Application* component represents the real-world application that is yet to be developed by holding a set of assigned feature components. A *feature* component is composed of necessary *Sensor* and *Feature* components, just as is the case in the framework. As lowest-level component, *Sensors* provide information about their average and device-specific energy demand. Based on this information, *Feature* and *Application* components accumulate their own energy demand, show the overall energy demand of their sources, and provide a breakdown of the energy demand of sensors they depend on. Figure 3 shows a detail views of all three component types. In addition, the calculator roughly estimates the time the component would need to completely drain a charged battery. This estimate helps developers to get a better sense of the actual impact of their application.

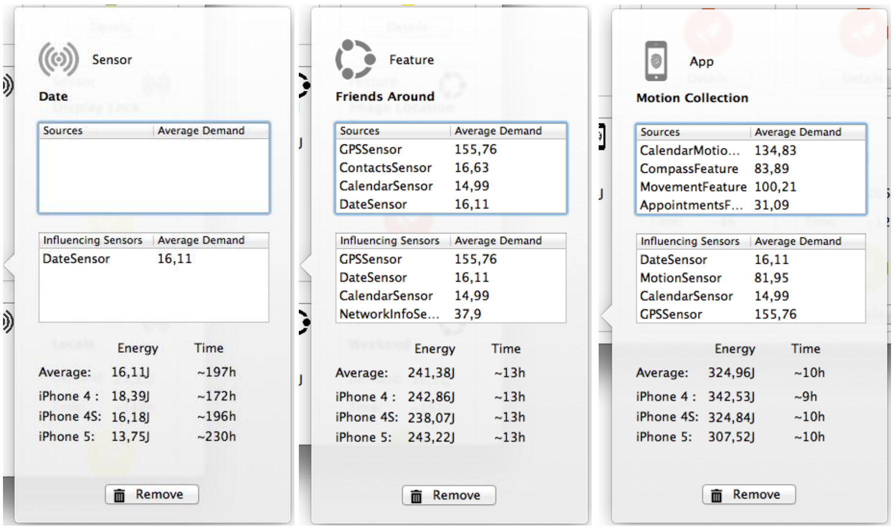


*Figure 3: Detail view in the CONTEXTO Energy Demand Calculator*

For a still better orientation, the calculator introduces three general energy demand classes: *Low*, *Mid*, and *High*. Class membership is defined in terms of varying energy thresholds for sensors, features, and applications. Sensors belonging to the *low* energy class require barely more energy than an idle application. Sensors in the *mid* class have a noticeable impact, but are still far from the high energy demand class. The average energy demand of all sensors is approximately 40 J in 10 minutes. The classification uses this as a reference value and assigns sensors with an above-average energy demand into the *high* energy demand class. The remaining range is divided into two identical parts. Sensors belonging to the *low* energy demand class do not exceed an energy demand of 19 J. The *mid* class ranges from 20 J to 39 J. Table 2 provides an excerpt of the framework's sensor classification.

| Low | Mid | High |
|---|---|---|
| BatterySensor | AccelerometerSensor | CameraSensor |
| CalendarSensor | AudioInSensor | GPSSensor |
| ContactsSensor | MuteSwitchSensor | GyroscopeSensor |

*Table 2: Energy demand classes for sensors (excerpt)*

## 5. Related Work

The research presented here is embedded in a broad range of mobile, pervasive, and ubiquitous computing activities. Within these communities, there has been active research on context models, context recognition, and context-aware applications and devices. Concept and implementation of CONTEXTO highly benefit from this previous research. Various frameworks for context classification and recognition exist: *Context Toolkit* [8] supports developers in rapid prototyping of context-aware applications. The framework relies on a distributed architecture and provides sensor fusion. The *Hydrogen Context-Framework* [9] is based on a centralised architecture comprising adaptor, management, and application layers. The centralised design makes it more robust against network failures, and permits context use by multiple applications. *ContextDroid* [10] is an expression-based context framework that is implemented as an Android platform service. The framework utilises *context entities* that abstract from sensors. CONTEXTO is also related to research in the field of energy-aware software engineering and development: [11] presents the concept of energy labels for Android applications, a simple mechanism that easily allows end-users to assess the energy demand of their apps. *PowerTutor* [12] was one of the first energy models that were used for a mobile application. Numerous ongoing research regarding the measurement of energy demand on smartphones also exists (e.g., [3], [13]).

## 6. Future Work

CONTEXTO aims to provide energy awareness to developers of context-aware applications. In the future, we would like to make the framework itself aware of energy requirements. Using an energy budget system, developers will then specify a desired energy footprint, and the framework will make sure that the allocated budget is respected. This raises questions of the relation between energy demand and user requirements such as accuracy, precision, availability, or actuality of sensor data and context recognition. These parameters greatly influence the user acceptance of context-aware applications, which we will investigate further with the help of the framework. On a closer time horizon, we will conduct a user study with developers, to see if our design goals regarding the ease of use of the framework have been met.

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# On the Impact of User Feedback on Energy Consumption

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## Abstract

The energy consumption of mobile devices is of increasing importance for users, developers and vendors. Frequent recharging cycles have an impact onto the mobility of a device and thus, on user experience. While hardware and software are known to have an impact on energy consumption, user behaviour (when and how a device is used) is often not in the focus of attention. Research in on “smart-metering” has shown that user behaviour is a non-negligible impact factor. This paper reports about the results of an ongoing study on the impact of user feedback onto the energy consumption of mobile devices (i.e. Smartphones). The hypothesis being, that the frequent provision of energy-related feedback on user actions will significantly reduce energy utilization. First results support this hypothesis and indicate that feedback frequency and feedback clearly linked to specific user activities are key in this regard.

## 1. Introduction

Energy is one of the most limiting factors for the growth of information and communication technologies, especially when it comes to mobile devices. Usually such devices are battery powered and thus, have limited energy resources. Beneath hardware, the software running on a device utilizes the device hardware and therefore has an impact onto energy consumption too [6]. An often neglected, but nonetheless important, third impact factor is user behaviour or more precisely the actual usage of a device. The user decides on which application or service to start, or which sensors and communication means are going to be used. Changing this behaviour might therefore reduce energy needs. Unfortunately, user behaviour often deviates from a standard rational choice model. From a user perspective comfort and performance are regarded higher than energy consumption. Single or isolated energy saving instructions are often without effect.

This paper presents a study that examines the effects of frequent, action- and energy related user feedback onto the energy consumption of mobile devices. This is achieved by comparing the energy needs of different Smartphone user-groups: Users that are frequently informed about the energy costs of their actions and users who are not. It is assumed that members of the first group will, in the long run, use significantly less energy than users of the other group. The hypothesis being that frequent and prompt feedback will positively alter user behaviour. It is important to note that the results presented in this paper are preliminary and that the actual study is ongoing. Thus, the examination of long-run learning effects is not within the scope of this paper.

The remainder of the paper is structured as follows: Section two discusses related work. Section three provides details about the underlying research hypothesis, study design and study execution. Section four presents and analyses collected data and discusses possible threats to validity. Finally, section five concludes the paper and provides an outlook on future research.

## 2. Related Work

Several research projects have been conducted regarding the energy consumption/needs of mobile systems. Often these address hardware or software related approaches [7]. Research that belongs to

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the hardware category, usually attempts to optimize the energy consumption by optimizing hardware usage, such as [3], or by introducing energy-efficient hardware devices and techniques, such as[12], [13]. Research in the second category attempts to understand how software and its development affects energy consumption. Research in this category can be further classified according to factors such as networking/communication, application nature, memory management, and algorithms. Concerning networking and communication projects such as [4] provide new routing techniques that are aware of energy consumption. Other efforts of this category focus on providing energy-aware protocols for transmitting data in wireless networks [11] and ad-hoc networks [5]. Memory consumption is another important factor concerning a system’s energy consumption. In this regard work such as [8] provides energy-aware memory management techniques. In battery powered systems, it is not sufficient to analyze algorithms based only on time and space complexity. Energy-aware algorithms such as [7] supporting randomness, or [9] focusing on cryptographic networks were published.

Beneath technical approaches towards optimizing energy needs, users and their behaviour are additionally identified as an important factor. [16] defines microbenchmarks for emailing and web browsing, and evaluates applications from these domains. [15] proposes an approach for profiling the power consumption of mobile applications and thus a means for comparing the consumption of similar services (Energy Labeling). [2] compares the energy consumption characteristics of mobile networking technologies and how this influences user interaction. [14] presents a framework that that automatically recognizes user daily activities and energy needs in real time using sensors on an smart phone. Still missing are (empirical) studies that actually monitor user behaviour over a longer period of time to better understand the relationship of behaviour and energy consumption.

## 3. Study Design

### 3.1. Subjects

The experimental subjects used in the study are students (bachelor and master) across all departments and cohorts of the University of Applied Sciences Stralsund. Volunteers owning a suitable device were asked for participation and were informed about the nature of the study. Subjects were motivated by making it clear that they would gain valuable experience from participating and that their data will help in improving battery life of future devices. As a result, 30 subjects volunteered to take part. The subjects knew that data would be, anonymously, collected and that an analysis would be performed on the data, but were unaware of the experimental hypotheses that were being tested. While the call was open to all students the majority of subjects are studying computer science. Before attending, subjects were asked to answer a small questionnaire on their background, used devices, typical usage scenarios, and expectations/experience regarding the energy consumption of mobile (smart-) phones. It appeared that most subjects (>90%) use high-end devices and (~75%) had the subjective impression that the energy consumption of their device is too high. Interestingly only a minority (10%) of them were aware that their behaviour might have an impact while the majority believed in in-efficient hardware (40%), energy mismanagement (OS) (29%), or badly programmed apps (18%).

### 3.2. Hypotheses

The relationship between user behaviour and energy consumption is in the focus of this study. The assumption being that keeping user informed about the implications of their actions will significantly improve the energy consumption of the devices they are using. More precisely the null hypothesis can be stated as: The energy consumption of devices whose users are frequently informed about the energy related effects of their activities does not significantly differ from the energy consumption of devices whose users are not actively informed.

### 3.3 Experimental Design

In order to test our hypothesis subjects we selected a between subject design and randomly assigned subjects to one of three groups (10 subjects per group). The dependent variable being the information frequency and the independent variable being energy consumption. When performing experiments regarding the behaviour of humans, the Hawthorne effect, i.e. subjects change their behaviour in response to the fact of being observed, bears the danger of falsifying results. While this effect cannot be fully excluded it also correlates with the experience of a user. Experienced subjects know which factors do have a significant impact onto energy consumption. Behavioural changes might therefore result in larger effects. To control this random group assignment was performed. As the number of subjects was known before running the experiment, it was a simple to create groups of equivalent size, which is important to prevent the independent variables from becoming non-orthogonal. Subjects within the two treatment groups receive real-time feedback regarding the impact of their activities on energy usage. The difference between both groups is the frequency of feedback. Subjects within the control group are not provided with such feedback.

### 3.4 Infrastructure

The hypothesis of this study requires users to be informed in real-time about the impact of their activities onto the energy consumption of the device. This requires energy measurement at the level of user activities. Energy consumption could either be measured by using onboard software tools or by measuring voltage drops at battery level. Following [6] this study uses onboard which are sufficient for trend analysis. We developed an app that runs as a system service using the AIDL-Interface. The service measures app-usage in terms of time and energy [1]. Data is stored locally and is send daily to a central server. Additional sensor data (e.g. GPS) is not monitored, although correlations between energy usage and Geo-position might be an interesting future topic.

The service also creates system notifications to inform users about their energy related behaviour (treatment group). Such notifications provide information about the app being used, the time of usage and energy related information. The latter is not provided as a Joule value but in form of a “traffic light” symbol. Joules are provided on user request only. In addition, a summary report is created on (user definable) times. These reports inform users about the actual trend. On the server side incoming data is stored with a timestamp and provided as a CSV-file for further analysis.

### 3.5 Procedure

The week before the experiment started, subjects were asked to fill a questionnaire in order to learn about their background, experience, etc. Then subjects were given an overview of the study and its procedure. Subjects were assisted for preparing their devices and informed the type and nature of collected data, data security, etc. Subjects were told that there is no external access to their device, that personal data will not leave the device, and that data will be anonymized prior to sending. Finally, groups were formed and the study was started. Subjects of the treatment groups were asked to pay attention towards the energy related feedback, while subjects of the control group were not told anything in this regard but were free to use system energy information. Subjects of the first treatment group received feedback on a time basis by pushing a system notification every 5-10 minutes. The second treatment group was notified based on their actions (switching apps, making phone calls, etc.).

## 4. Results

Once the study was started, data was collected by the background service running on subject devices. Since the study is ongoing no final statistical analysis has taken place yet. Unfortunately, the dataflow of the first treatment group was sparse. During a feedback session it appeared that subjects quickly got annoyed by the high frequent feedback (5-10 minutes) that was not directly correlated with their actions. As a result, subjects soon stopped data collection. Thus, valid data is only available for the second treatment as well as the control group.

Figure 1 visualizes the accumulated energy consumption (KWh) of both groups (Control and Treatment) over a period of eighty days. As time advances, the gap between both groups continuously grows. This supports the assumption that real-time feedback enables continuous energy savings. At a more detailed level it can be concluded that the treatment group adapted their behaviour (energy wise) within the first days) while the control group did not.

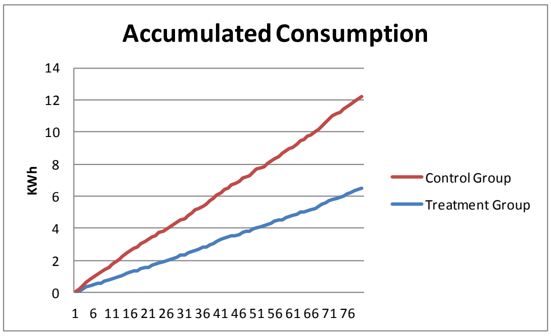


*Figure 1: Accumulated Energy Consumption of both groups*

This is supported by Figure 2, which compares the energy consumption of both groups at an early stage of the project (day 3) with those later in the experiment (day 40). While the behaviour of the control group has not significantly changed over time (from 0.0079 KWh to 0.0081 KWh) the treatment group does show a change (from 0.0079 KWh to 0.0059 KWh). Although a saving of 0.002 KWh per day is not a dramatic change, data supports the hypothesis that behaviour and thus energy consumption can be changed by keeping the user informed.

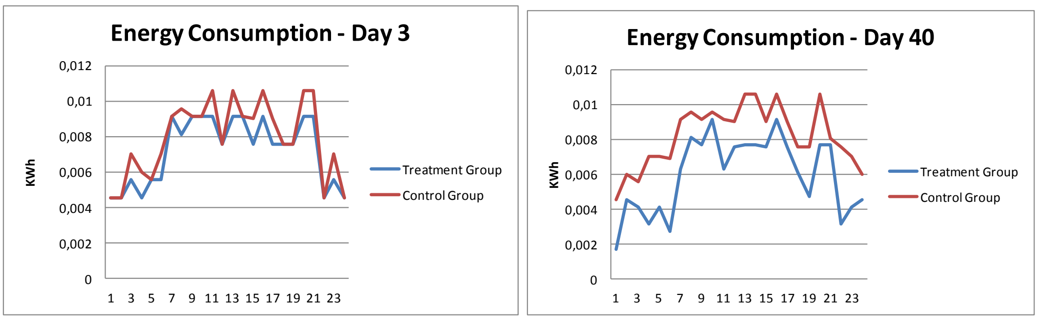


*Figure 2: Energy Consumption – Day View*

Another interesting fact is that energy consumption data reveals the daily activity (level) of users. It appears that it is possible to identify the currently executed app just by viewing at its energy profile. It can be clearly identified if a user is making phone calls, surfing the web or playing games. This confirms findings in the smart metering domain that energy profiling allows user identification [10] or even the movie currently playing. In this study we guaranteed anonymous data collection and therefore deleted all information that would allow data backtracing.

Although the study is ongoing we performed a first statistical analysis in order to test our hypotheses. Checking the data for normality revealed that it is substantially non-normal and that, thus, a non-parametric test has to be used. Due to the early stage of the study we preliminary set the level of significance (i.e., α-level) to $\alpha = 0.05$. To test the hypothesis we decided to use the Kruskal-Wallis test since it is known to be robust against variations in group size. Results show that there is a significant difference between both groups (p-value $< 0.03$) and thus the null hypothesis can be rejected. Unfortunately, the test does not identify where the differences occur or how many differences actually occur. Thus, additional analysis is needed.

## 5. Threats to Validity

There are a number of threats to validity that can affect the dependent variables. While these threats limit generalization of this research, they do not prevent the results from being used in further studies.

### 5.1. Construct Validity

Construct validity is the degree to which the independent and dependent variables accurately measure the concepts they purport to measure. The energy consumption of a mobile device is a difficult concept to measure. Granularity, preciseness and timeliness are key in this regard. In the context of this study it is argued that using the onboard measurement facilities of Android are sufficient regarding the goals of the study. However, additional studies are required to investigate if other measurement approaches lead to different results.

### 5.2. Internal Validity

Internal validity is the degree to which conclusions can be drawn about the causal effect of independent variables on the dependent variable. The following possible threat was identified: • A maturation effect is caused by subjects learning as the experiment proceeds. Due to the long execution time information about the goals of the study and the expected results might reach subjects and alter their behaviour. However, since subjects were randomly assigned to their group, we assume that learning effects are equal to all groups and can therefore be neglected.

### 5.3. External Validity

External validity is the degree to which the results of the research can be generalized to the population under study and other research settings. The following possible threats were identified:

• The subjects were students and are therefore unlikely to be representative of Smartphone users in general. We assume that students are using their devices more intensively than the majority of users and thus, that only effect size will differ between students and other user groups.

• Using volunteers as subjects may affect validity (i.e., selection bias). Volunteers are almost certainly different from those subjects who do not volunteer. They are, by definition, motivated to participate and presumably expect to receive some benefit. These differences limit the ability to generalize the results of this study beyond the research sample and require future studies.

## 6. Summary and Conclusions

Energy resources are a limiting factor for most mobile devices and especially for smart-phones. The consumption of this resource is driven by the devices' hardware, running software, and the user. This paper reports about an (empirical) study that investigates the relationship between user behaviour and energy consumption. More specifically the study examines if keeping users informed about the energy "costs" of their activities lowers energy needs and thus, increases device uptime. Although the study is ongoing, data analysis supports our hypothesis that keeping users informed has indeed a significant impact (p-value below 0.03). Feedback related to concrete user actions seems to be key in this regard. Time-triggered feedback seems to have a contrary effect as demonstrated by the drop-out of a complete group of subjects. However, there are a number of threats to validity that hinder generalization. Future studies have to address these threats and, more importantly, examine the effects of different forms of user feedback. Another study will investigate if subjects of the treatment group have permanently altered their behavior (learning effect).

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# Certifying Energy Efficiency of Android Applications

Johannes Meier[1], Marie-Christin Ostendorp[1], Jan Jelschen[1], Andreas Winter[1]

## Abstract

While smartphone and tablet functionality is increasing, battery runtime goes down. Both users and software developers are not always aware of the energy consumed by applications. Without this information, users cannot choose energy-efficient apps to prevent battery drain. Awareness of energy consumption would also entice app developers to implement more energy-efficient apps to remain competitive. This paper presents a certification process and corresponding Android tool support for comparing apps regarding energy efficiency. It is demonstrated using notepad apps.

## 1. Motivation

Application possibilities of mobile devices (e.g. smartphones, tablets) keep increasing, yet average battery runtimes stagnate at about one day [7]. Reasons for low battery runtimes are not only slow progress in battery research, but also increasing energy consumption of apps. Even though power-wasting apps are known and discussed by users, e.g. at Google's Play Store [8], there is little information about the energy efficiency of apps [1]. This concerns both users and developers: On one hand, users need selection aid for energy-efficient apps. On other hand, developers need data about their apps' energy consumption to guide energy efficiency improvements, and for comparison with competitors. This paper's objective is to create certificates (example in Fig. 1), allowing to compare applications wrt. their energy efficiency, akin to EU energy labels for electrical devices [2]. Thereby, awareness for energy-efficient apps, and in the long run, energy efficiency itself rises.

A certification process has to be supported by a toolchain, allowing certifiers to create such certificates. This paper's core idea is to measure energy consumption for typical user actions on apps. There are challenges to overcome when specifying such a certification process and its tool support:

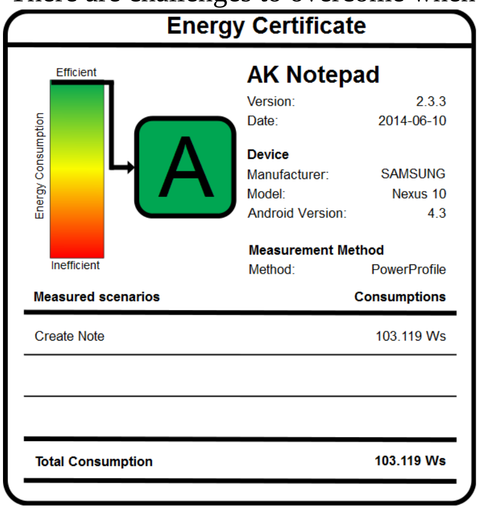


*Figure 1: Example Certificate*

**1) Modeling user actions**: Typical user actions have to be taken into account, to find comparable apps and get comparable values while measuring.

**2) Certifying without computer science knowledge**: Certifiers do not necessarily have programming skills, and must be enabled to easily perform certifications without it, using appropriate tooling (cf. Sec 4).

**3) Measuring energy consumption**: Application's energy consumption has to be measured during user actions on actual mobile devices.

**4) Using devices minimally invasive**: Devices for measurements shall be used minimally invasive, to prevent damage or voiding warranties, and allow reuse for further projects. Particularly, this prohibits rooting devices.

**5) Automating user actions**: For comparability of energy measurements of the same user actions for different apps, human inaccuracy while operating devices (e.g. different delays) has to be reduced. To this end, "test cases" are used to automate user actions. This provides repeatability, and

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comparability of different test case runs, and ensures uninfluenced measurements. To create such test cases without computer science knowledge (Challenge 2), tool support is required.

**6) Preparing results**: Measurements have to be evaluated and visualized (cf. Fig. 1) differently, e.g. for users (energy efficiency as buying criteria) and developers (details for app optimization).

After discussing related work in Section 2, this paper presents a certification process coping with these challenges in Section 3. Its tool support, generating energy efficiency certificates for Android apps, is demonstrated in Section 4. For certification and toolchain validation, Section 5 applies the certification process and tooling to notepad apps. The paper concludes with Section 6.

## 2. Related Work

A similar approach for application certification was presented by Wilke [8], which can be seen as the first relevant work in this field. Apps with similar functionality are compared by measuring energy consumption while running typical user actions. Measurements are used to compare and certify apps, which are visualized with energy labels A through F. The challenges introduced in Section 1 will be used in the following to delimit Wilke's approach from this paper's approach.

For *modeling user actions* (1), both approaches group apps with similar functionality into categories: Apps in the same category support similar user actions called "scenarios". Scenarios of apps represent their main functionalities – e.g. "create note" is a scenario for notepad apps. To define user actions, Wilke uses finite state machines, which model app states like the current window as states, and user actions as state transitions between app states, enabling dynamic consumption calculation for different user actions. In contrast, this paper defines typical user actions as *text-based* scenarios, so certifiers need no state machine modelling skills to use the tool support (Challenge 2).

Moreover, the tool support presented in this paper is more comprehensive, because certifiers are supported in administration and controlling the whole certification process via a GUI to allow *certifying without computer science knowledge* (2). Furthermore, certifiers and users have access to different visualizations presenting results of a certification in detail via a GUI (Challenge 6).

Wilke provides several methods for *measuring energy consumption* (3) and focuses on hardware-based measurements. This paper uses only software-based measurement methods, to allow measuring energy consumption without external hardware and without breaking devices to access non-removable batteries (Challenge 4). However, Wilke's approach yields higher precision results.

While Wilke offers no tool support for the creation of test cases for *automating user actions* (5) on a device, due to his different focus, this paper introduces a *recorder* to log user actions, and a *generator* to generate test cases out of recorded data. This technique is self-implemented, because existing tools for non-rooted devices have restrictions or runtime errors. Approaches for rooted devices, e.g. RERAN [3], conflict with non-invasiveness (Challenge 4).

## 3. Certification Process

The steps of the certification process (as shown in Figure 2) are described in detail using an example coming from the domain of notepad applications. These steps address the challenges of Section 1, and are set in italics with their number in brackets.

At the beginning of the certification process the apps to certify will be categorized after their main functionality (steps 1 and 3). The scenarios define user actions (step 2). For automating these scenarios for each app and scenario a test case has to be developed (step 4) which is executed during the measurement of energy consumption on devices (step 5). After measuring all scenarios for each app of the category, the measuring results are evaluated (step 6). The results of measurements and evaluations are visualized in different forms for users and app developers (step 7).

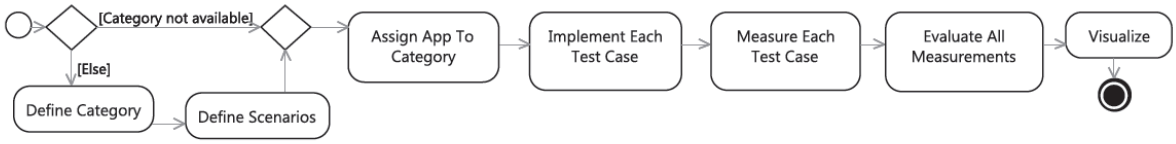


*Figure 2: Certification Process*

**1) Define Category**: For comparability of similar apps, the application to be certified (called *app*) has to be assigned to a specific *category* as first step. A category is a classification of apps providing the same set of similar user actions. In the following, typical user actions are called *scenarios* for *modeling user actions* (1). E.g., if a specific app for managing notes like "AK Notepad" should be certified, it can be assigned to a category called "notepad apps". Another possible category is, for instance, "email apps", containing apps for managing emails.

**2) Define Scenarios**: For each typical user action of the category, a scenario has to be specified for *modeling user actions* (1). To get comparable certifications for different apps of one category, scenarios have to be precise. Two possible scenarios of "notepad apps" would be "create note" and "delete note". "Create note" is further detailed: "create new note, add text "Hello", and save note".

**3) Assign App to Category**: To find proper categories, the functionality of apps to certify has to be compared with scenarios of existing categories. If there is no match, a new category with scenarios has to be created (see above). E.g., "AK Notepad" is an app to manage notes and allows creating new notes. The latter functionality fits the scenario "create note" of the category "notepad apps". Thus, "AK Notepad" belongs to "notepad apps", not "email apps", as it does not show emails.

**4) Implement Each Test Case**: For each scenario of the category, and each app in it, a test case has to be implemented. A *test case* is an app for *automating user actions* (5) of one scenario for exactly one app. Such test cases are necessary to replay user actions on different apps, and to reduce human inaccuracy during measurements. This ensures the comparability of apps, and reproducible results. E.g., for „AK Notepad", a test case for the scenario „create note" has to be implemented, which presses the icon to create a new note, adds text into the new note, and saves the new note by going back to the main window. For test case implementation, certifiers can record user actions and automatically generate test cases, or they can implement test cases by hand.

**5) Measure Each Test Case**: Each test case is executed on a device for *measuring energy consumption* (3) while the test case is running.

**6) Evaluate All Measurements**: After measuring all test cases, the results are evaluated for each category (using all its scenarios), and each device, which is necessary for *preparing results* (6), because this step calculates the energy efficiency of apps to certify. The evaluation is done for each device, because the same app can behave differently on different devices, and various hardware, for instance different screen sizes cause different energy consumption. Measurement data of apps relating to the same scenario is used for energy efficiency rating: The best app (lowest consumption) gets an A rating, defining bounds for the other energy classes, which are (for example) 10% higher than the boundary before. Wilke [8] proposed different boundaries for different categories.

**7) Visualize**: After the evaluation, results are visualized in five forms to fulfill the challenge *preparing results* (6) for different stakeholders: *Labels* present evaluation results as single colored letter, the simplest visualization of the energy efficiency classes for users and app developers. *Certificates* (cf. Fig. 1) are more detailed, containing data such as background information about the app, the device used for measuring, and the energy consumption of different scenarios for users and app developers. *Reports* show all certified apps of one category for comparison, for users who want to buy the most energy-efficient app. *App reports* represent one app, and show further details about the measurements for app developers, to compare different energy consumptions per scenario or device component. *Measurement data visualizations* are the most detailed descriptions of all data collected during the measurement of one app. This is interesting for app developers, to view all measured data, particularly with regard to the point in time of the energy consumption. For each device, all visualizations are available. Labels are also available for mean values over all devices.

## 4. Tool Support

The toolchain supporting the certification process (Section 3) is shown in Figure 3. The tool architecture follows a three-layer-architecture with data management on the *server*, web views allowing the actors to interact (*PC*), and energy measurements on *Android devices*.

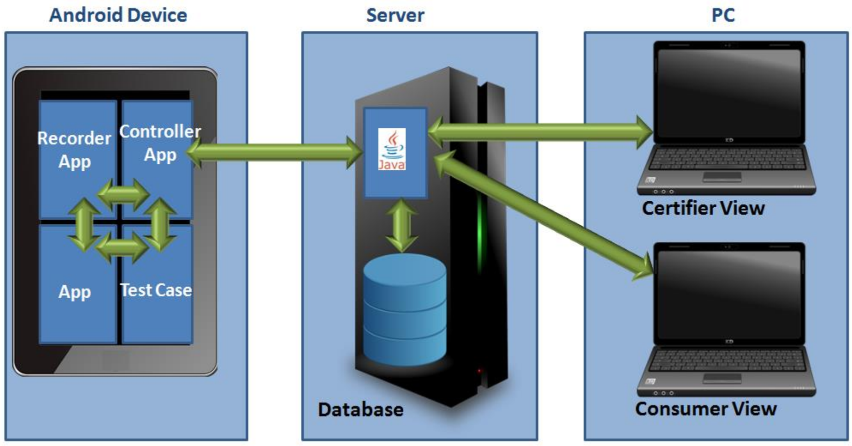


*Figure 3: Architecture Overview*

The steps *Define Category, Define Scenario,* and *Assign App to Category* of the certification process (Section 3) are technically supported by a web view called *certifier view*. The certifier view allows the certifier to manage the toolchain. Separate from the certifier view, the *consumer view* allows users and app developers to see certified apps with their visualizations (step *Visualize*). Therefore, all certification results are placed at one central place. Certifier and consumer view are communicating with the *server*, which manages data persistence with an external *database*.

Android devices used by the toolchain use four relevant apps: The *ControllerApp* manages *server* communication and measurements, *test cases* execute scenarios on *apps* to certify, and the *RecorderApp* simplifies creating *test cases*.

The **ControllerApp** runs on each Android device used for measuring. The ControllerApp takes the communication tasks, manages the installation of possibly missing apps and test cases, and execution of apps and test cases, and runs measurements. For that, the ControllerApp secures the installation of required apps, starts measurements, and runs test cases. After the test case finished, the measurement will be stopped, the collected measurement data will be sent to the server, and saved in the database (step *Measure Each Test Case*).

***Apps*** are Android applications whose energy consumption should be certified, and have to be installed on the measuring device. In the example, “AK Notepad” is an *app*.

From the technical perspective, **Test Cases** are Android apps which control the apps to certify, automatically executing user actions of scenarios at measuring time (steps *Implement Each Test Case* and *Measure Each Test Case*). Test case implementations use the Robotium framework [6], which is a test framework for Android to control GUIs of other apps. The toolchain supports uploading test cases via the certifier view, or recording test cases using the RecorderApp.

The **RecorderApp** allows creating test cases via executing the scenarios on the app to certify, instead of writing Robotium code. The certifier executes the user actions of scenarios on the app. The RecorderApp listens for those user events, and sends the events to the server. The server generates Java code using the Robotium framework from the recorded data to replay the user actions, and creates automatically test cases through compiling the Java code as Android app (step *Implement Each Test Case*). This allows creating test cases without programming skills (Challenge 2).

As measurement method for Android, the *Power Profile* method is implemented in the ControllerApp, reusing the work of Josefiok, Schröder, Winter [4]. The Power Profile method is based on power profiles available on devices. In a power profile, the average energy consumption per time unit of specific hardware components such as screen, CPU, Bluetooth etc. is listed. Measuring the time each component has been active during test case execution allows calculating the total energy consumption. Side effects at measuring time will be reduced by the certifier through stopping other apps, and running the test cases multiple times (step *Measure Each Test Case*).

On the server, the measured data will be evaluated to determine the energy efficiency of apps using the evaluation idea of step *Evaluate All Measurements*. In the toolchain, there are five visualizations, automatically generated using ELVIZ [5], a framework for model-driven visualization. All visualizations are provided through the *consumer view* (step *Visualize*).

## 5. Application

This section shows how to use the presented certification process and the supporting toolchain. As the result of the following practical example with three notepad apps, Figure 4a shows the view for consumers with certified notepad apps.

To certify notepad apps "AK Notepad", "ColorNote", and "Fast Notepad", the certifier has to create a category "Notepad Apps" for apps whose main functionality is managing notes (step *Define Category*). To concretize this functionality, scenarios have to be created representing typical user actions with notepad apps. Examples for notepad scenarios are "create note", "delete note", "read note", and "search for a note" (step *Define Scenarios* (2)). Here, the "create note" scenario is considered. After that, the three apps have to be uploaded and assigned to the notepad category (step *Assign App to Category* (3)). All these steps are managed via the certifier view (see Figure 3).

The consumer gets results and visualizations as shown in Fig. 4. The certified "notepad" apps will be shown as list with their names and labels, showing the final certification result (A, B, C) in the consumer view (Fig. 4a). The visualizations of the measurement data ("Measurement Data") and the app report ("App Report") are accessible via the links. The detailed certificates are accessible by clicking on the app's label graphic. The category report (accessible via "Category Report") includes as an example Fig. 4b, which shows different energy consumptions of the three apps.

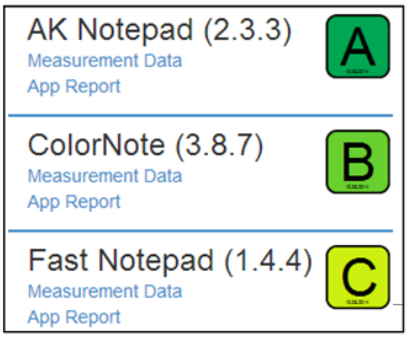


*Figure 4a: Consumer view*

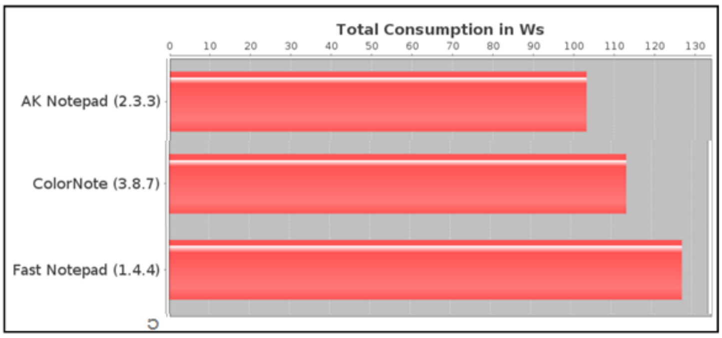


*Figure 4b: Consumptions of apps in category report*

With the list of certified apps, the user can choose an energy-efficient app and can use the energy efficiency as criterion at his buying decision. An app developer can use this overview for a first fast evaluation of his apps and the apps of competitors. More detailed information is accessible via the list of different scenarios (in certificate and app report) of the category showing differences having regard to scenarios. Further information for the app developer consists of the measurement data and app report of the app. Here, the Power Profile measurement method allows the analysis of energy consumption per device component showing, as example, different CPU usage.

Realized experiments with the tool support show that the duration of a test case has a significant effect on the energy consumption, because the measured energy is as tendency proportional to the time in which a test case is running. As consequence of that, app functions which need many user actions (for example menus with much nesting levels) need more energy because the app runs longer. That is the reason why “Fast Notepad” consumes more energy than “AK Notepad”.

## 6. Conclusion

This paper presented a way for certifying the energy efficiency of applications. A certification process which allows comparability of energy consumption of different applications has been demonstrated. Furthermore, tool support for this certification process for Android apps has been provided allowing certifiers to generate certificates – including administration, measurement of energy consumption, evaluation, and visualization – automatically, without having specific knowledge in computer science. Thereby, a selection aid for users is available with visualizations like labels, certifications, and reports. But not only users benefit from this new information: App developers now have detailed information about the energy consumption of their applications and are thereby able to improve the energy efficiency of their implementations. As future trend, the awareness for energy efficiency can increase and app developers will be able to reduce the energy consumption of their apps. Thus, in the long term apps can be more energy-efficient.

As outlook, the tool support can be used to evaluate the energy efficiency of apps for other research questions. Further experiments with much more certified apps will help to validate and fine-tune the certification process. Furthermore, the working certification process can be transferred to other domains like iOS apps and desktop software.

## Acknowledgment

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# Usability-Quiz: Die Begriffswelt der Usability durch ein Lernspiel vermitteln

Felix Hemke[1], Herbert A. Meyer[2], Knut Hühne[1], Maximilian Schneider[1], Volker Wohlgemuth[1]

## Abstract

Mit dem Glossar zur Basiszertifizierung CPUX-F (Certified Professional for Usability and User Experience – Foundation Level) des UXQB steht eine Sammlung von Definitionen zu grundlegenden Begriffen und Konzepten aus dem Fachgebiet Usability und User Experience zur Verfügung. Zur Erleichterung der Auseinandersetzung mit dieser Begriffswelt wurde ein webbasiertes Hypertextsystem erzeugt, das wahlweise über Smartphone, Tablet oder PC benutzt werden kann. Um den Lernanreiz zu erhöhen, wurde zusätzlich ein Frage-und-Antwort-Spiel mit einer Highscore-Liste entwickelt. Dieses so genannte „Usability-Quiz" wird im Rahmen dieses Beitrags vorgestellt.

## 1. Einleitung: Usability-Quiz

Betriebliche Umweltinformationssysteme (BUIS) bieten nach wie vor ein großes Potential für eine benutzerfreundliche Gestaltung [1]. Der Erfolg von Anwendungen in diesem Kontext hing bisher hauptsächlich von deren Funktionalität ab und weniger davon, diese Funktionalität möglichst einfach ausschöpfen zu können. Neueinsteigern fiel es deshalb teilweise schwer, sich in die Nutzung der Systeme einzufinden. Inzwischen steigt die Nachfrage nach Anwendungen, bei denen ein intuitiver Einstieg möglich ist und die so gestaltet sind, dass der volle Funktionsumfang leicht nutzbar ist [1]. An der HTW Berlin werden verschiedene Methoden der Usability angewandt, um BUIS hinsichtlich dieser neuen Anforderungen zu optimieren. Dazu gehören Usability- und Eyetracking-Studien sowie die Aus- und Weiterbildung von kleinen und mittelständischen Unternehmen (KMU) aus der Umweltinformatik-Branche. Zu diesem Zweck wurde eine Lernplattform für den Bereich Usability entwickelt, die das Erlernen von grundlegendem Wissen ermöglicht.

Das Glossar CPUX-F [2] kann als Meilenstein der Professionalisierung von Usability-Experten betrachtet werden. Erstmals werden Definitionen von zentralen Begriffen und Konzepten aus dem Fachgebiet Usability und User Experience zwischen Fachleuten vereinbart und vom Berufsverband der deutschen Usability und User Experience Professionals (German UPA) anerkannt. Die in dem Glossar aufgeführten Begriffsbestimmungen wurden in Anlehnung an die ISO-9241-Reihe entwickelt und stellen die Wissensbasis für die CPUX-F-Zertifizierung dar, die zum grundlegenden Kompetenznachweis in den Bereichen Usability und User Experience (UX) werden soll. Sie richten sich auch an Interessensvertreter, die mit Usability Professionals zusammenarbeiten [3].

Die Begriffsdefinitionen sollen im Rahmen des Projekts „KOMET" [4] als eine von mehreren Maßnahmen eingesetzt werden, um das in der ISO-9241-Serie dokumentierte Qualitätsmodell von Usability bei KMU bekannt zu machen. Die Unternehmen sollen auf die Vorteile hingewiesen

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werden, Usability und UX bereits zu Beginn der Entwicklung von Software zu etablieren und nachhaltig zu konsolidieren. Das Forschungsvorhaben ist Bestandteil des Qualifizierungsprojektes "Hochschulbasierte Weiterbildung für Betriebe an der HTW Berlin" und wird durch die Berliner Senatsverwaltung für Wirtschaft, Technologie und Forschung aus dem Europäischen Sozialfonds gefördert.

Für das webbasierte Hypertextsystem wurde zunächst ein funktionsfähiger HTML-Prototyp entwickelt. Dieser steht mit Beginn der Konferenz online zur Verfügung und kann live ausprobiert werden (siehe http://komet.f2.htw-berlin.de/lernspiel). Die 138 Begriffe mit ihren Definitionen wurden zunächst in eine hypertextbasierte Form gebracht und Funktionalitäten zur Navigation und zur Überprüfung des Lernfortschritts sowie ein ansprechendes Screendesign umgesetzt.

Die Anwendung basiert auf Twitter Bootstrap, einem CSS Framework zur Oberflächengestaltung von „Mobile first"-Anwendungen [5]. Benutzer können entweder mittels Paging durch die Begriffe in alphabetischer Reihenfolge navigieren, oder die Inhaltsübersicht mit Filterfunktion nutzen, um einzelne Begriffe gezielt nachzuschlagen. Die Entwicklungsarbeiten für die Releaseversion wurden bereits abgeschlossen. Abbildung 1 zeigt den aktuellen Stand des „Mobile first"-Entwurfs für die Begriffsseite und für die Hypertextnavigation.

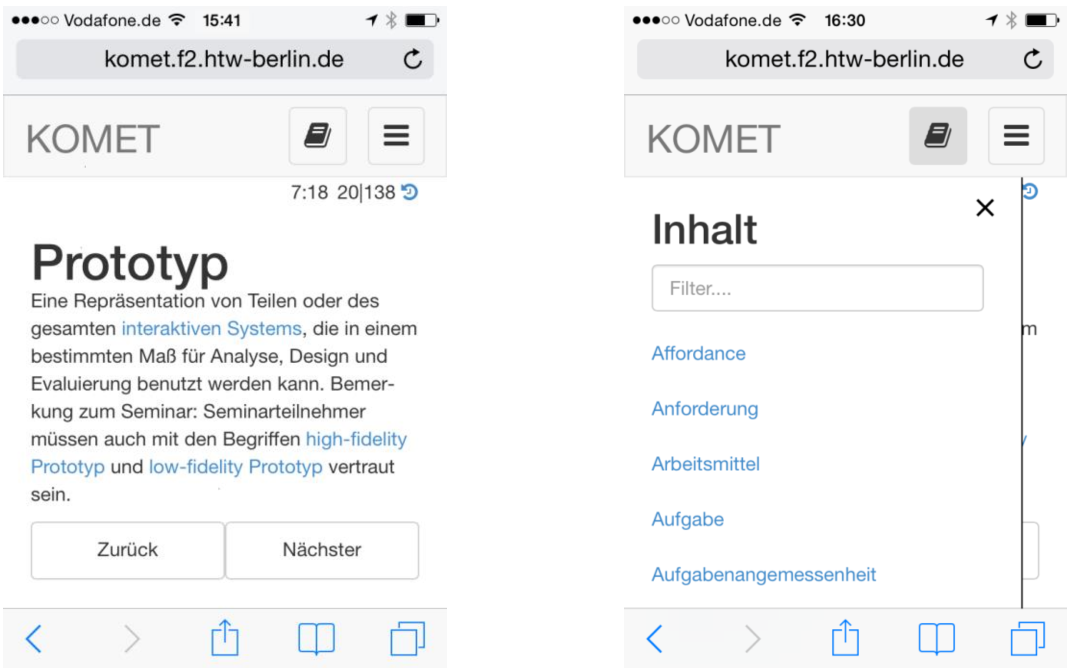


*Abb. 1: Ansicht einer Begriffsdefinition (links) und der Inhaltsübersicht (rechts) beim Prototyp des Hypertextsystems zum Erlernen der Grundbegriffe (Safari, iOS 7)*

Um den Lernanreiz bei der Aneignung des begrifflichen Inventars zu erhöhen, wurde auf Basis des Hypertextsystems zusätzlich ein Frage-und-Antwort-Spiel entwickelt. Bei diesem so genannten Usability-Quiz wird eine Begriffsdefinition zusammen mit vier verwandten Begriffen dargestellt. Nur einer der Begriffe ist für die Definition zutreffend und muss ausgewählt werden. Wird der gesuchte Begriff (oder eine Abwandlung des Begriffs) in der Definition selber genannt, erscheint an dieser Stelle ein Platzhalter („XXX"), um die Antwort nicht mit der Frage vorwegzunehmen. Auch für das Quiz wurde bereits eine Releaseversion entwickelt, die aktuell 114 Fragen enthält und zukünftig erweitert und optimiert wird (siehe Ausblick).

Die Begriffe wurden in sieben Kategorien eingeteilt (Prinzipien, Anforderungen, Rollen, Evaluierung, Planung, Gestaltung und Test). Die angezeigten Antwortmöglichkeiten zu einer Frage stammen immer aus derselben Kategorie. So werden zum Beispiel zu der Definition einer Rolle nur andere Begriffe der Kategorie Rolle als Antworten angeboten. Dadurch wird gewährleistet, dass die vier Antwortmöglichkeiten bezogen auf die gestellten Definitionen plausibel sind. Der richtige Begriff zu einer Definition soll nicht dadurch offensichtlich sein, dass die Alternativen nicht zur Definition passen. Wählt man einen zutreffenden Begriff aus, dann wird der „Hit" farblich in grün dargestellt und führt zur nächsten Frage-und-Antwort-Seite (siehe Abbildung 2).

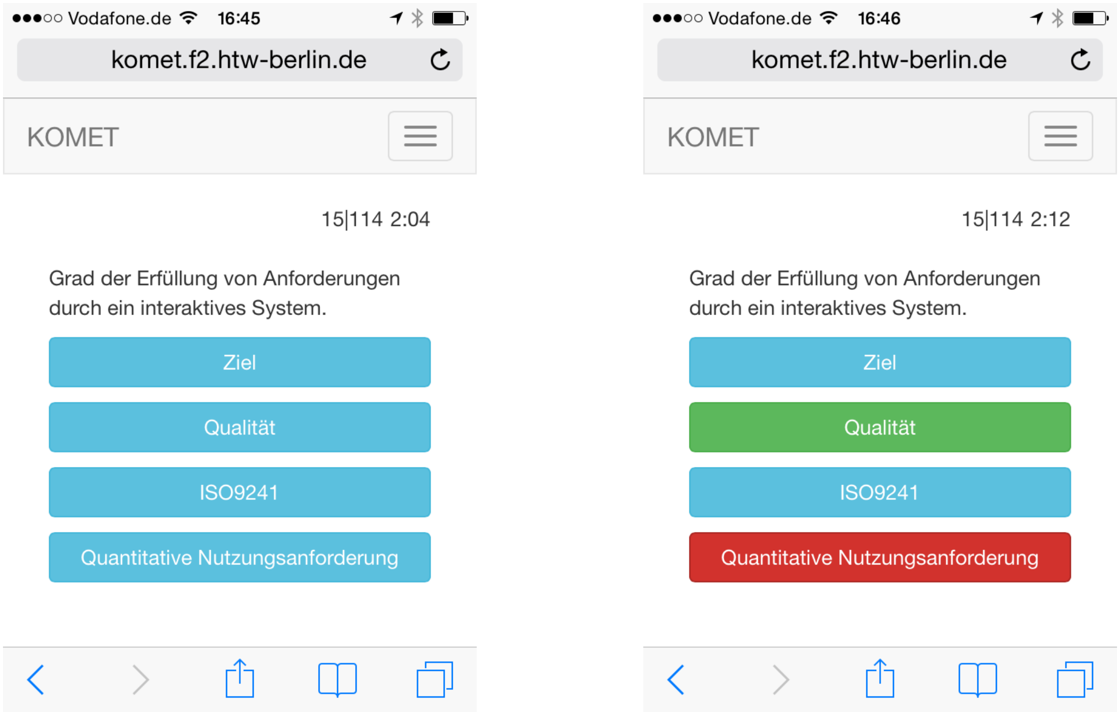


*Abb. 2: Ansicht einer Frage mit vier potentiellen Antworten (links) und Markierung der falschen (rot) und richtigen (grün) Antwort nach Beantwortung der Frage (rechts) (Safari, iOS 7)*

Der Score ergibt sich aus der Anzahl aufeinanderfolgend richtig gewählter Begriffe und wird unter der Sitzungsdauer angezeigt. Wird ein nicht zutreffender Begriff ausgewählt, wird die falsche Antwort rot markiert und die richtige Antwort zugleich grün markiert, um den Lerneffekt zu befördern. Die Sitzung wird in einem solchen Fall neu gestartet und der Score verfällt. Ein Eintrag in der Highscore-Liste („Hall of Fame") wird erlaubt, wenn die Anzahl richtiger Antworten innerhalb der monatlichen „Top 10" liegt (siehe Abbildung 3). Bei der Bearbeitung der Fragen wird die Zeit gestoppt, um einen weiteren Steigerungsanreiz zu geben. Usability-Experten, die alle Fragen beantworten können, haben somit die Möglichkeit, aufgestellte Bestzeiten zu unterbieten. Bei Punktgleichstand innerhalb der Highscore-Liste wird als zweites Kriterium die gemessene Sitzungsdauer berücksichtigt.

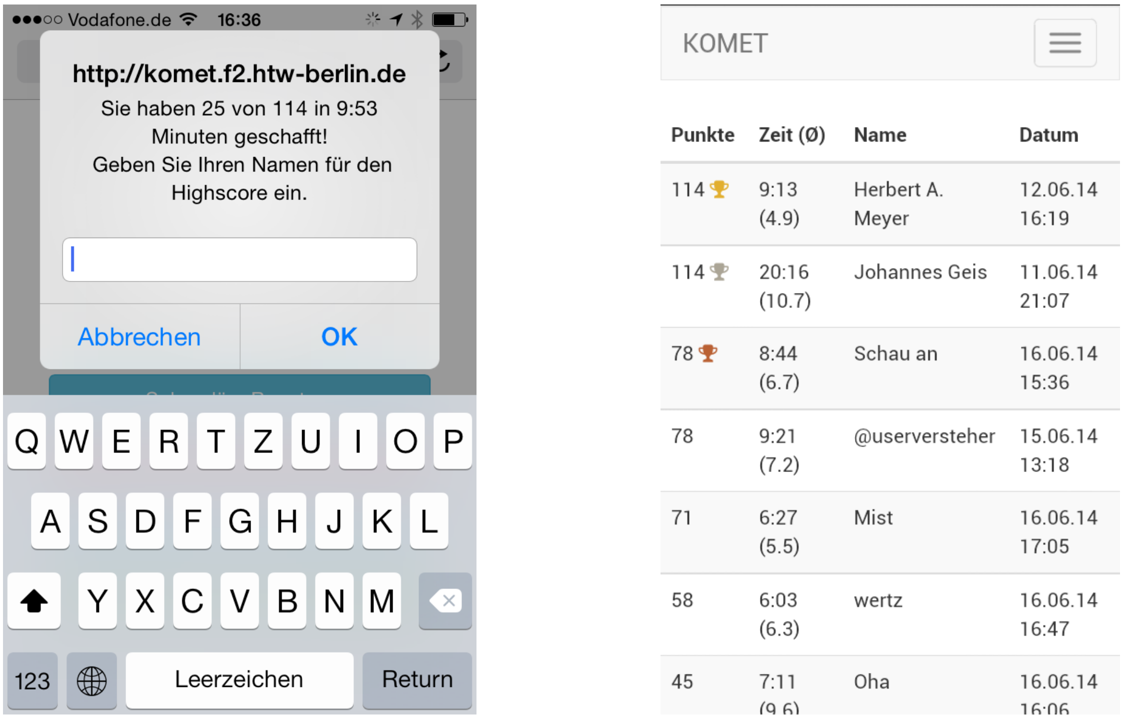


*Abb. 3: Ansicht der Eingabeaufforderung zum Eintrag in die Highscore-Liste (links) und die Highscore-Liste beim Prototyp des Usability-Quiz' (Safari, iOS 7)*

## 2. Portabilität des Konzeptes

Das vorliegende Konzept der Darstellung von kategorisierten Begriffen mit Synonymen und Beschreibungen innerhalb des Hypertextsystems und des Frage-Antwort-Spiels lässt sich auf beliebige Bereiche adaptieren, in denen zu Begriffen entsprechende Definitionen vorliegen. Im Bereich Usability ist zu erwarten, dass zukünftig weitere Inhalte, die mit dem vorliegenden Quiz-Konzept erlernt werden können, entstehen. Zur ersten CPUX-F-Zertifizierung sollen im Laufe des Jahres 2014 weitere Aufbaustufen hinzukommen, wie zum Beispiel für Usability-Testing, Requirements Engineering und User Interface Designing [3]. Die dafür entwickelten Begriffsdefinitionen sollen anschließend in das Usability-Quiz integriert werden.

Das Hypertextsystem beruht auf einer Begriffssammlung, die innerhalb einer JSON[3]-Object-Hierarchie strukturiert wird. Damit wurde ein kompaktes und lesbares Datenformat genutzt, das als der Standard für den Austausch von Daten gilt.

```
{
 "Kategorie X": {
  "Begriff Y": {
    "synonyms": [
      "Synonym Z"
    ],
    "description": "Beschreibung von Begriff Y"
  }, ...
 }
}
```

*Abb. 3: Aufbau der JSON-Object-Hierarchie für Begriffe*

[3] JSON steht für JavaScript Object Notation.

Für die vorliegenden Begriffe wurde zusammen mit Synonymen und Definitionen JSON-Objects erzeugt, die in der in Abbildung 3 dargestellten Weise aufgebaut sind. Zu einem Begriff gehören jeweils die übergeordnete Kategorie, Synonyme (optional) und die Beschreibung. In der Beschreibung sind zudem HTML-Links eingebettet, falls eine Definition weitere bekannte Begriffe enthält. Im Hypertextsystem kann dadurch auch über die Verlinkungen zwischen in Beziehung stehenden Begriffen navigiert werden.

Für die Darstellung der Inhalte als Quiz-Fragen wird auf dieselben JSON-Objects zugegriffen. Die Übertragung des Konzeptes auf weitere Kompetenzfelder von Usability Professionals (oder auch anderer Begriffswelten) erfordert lediglich die Anpassung der jeweiligen Begriffe mit Definitionen an diese Objektstruktur. Die Datenbasis der Begriffsdefinitionen und des Frage-Antwort-Spiels ist somit flexibel austauschbar.

Das Konzept kann damit für die Begriffswelt der Umweltinformatik eingesetzt werden, um Interessierten in ähnlicher Weise die Aneignung der Begriffe zu ermöglichen. In Deutschland werden von sieben Hochschulen Studiengänge im Bereich Umweltinformatik angeboten [6]. Der Einsatz des Lernspiels innerhalb der Lehre kann eine Möglichkeit sein, Begriffe und Definitionen auf einfache Weise zu vermitteln. Ein weiterer möglicher Einsatzkontext kann analog zum Fachgebiet Usability ein Kompetenznachweis Umweltinformatik sein, für den ähnliche Begriffsbestimmungen entwickelt werden.

Im Anschluss an den Konferenz-Beitrag soll in einer Diskussion mit Interessierten besprochen werden, welche Potentiale ein Umweltinformatik-Quiz hätte und welche Herausforderungen dabei zu erwarten sind, bspw.:

- Welche Begriffe müssen in einem Glossar zur Umweltinformatik aufgeführt werden?
- Welche Teilbereiche/Kategorien wären für die Begriffswelten der Umweltinformatik zu bilden?
- Wie können die Fragen auf einen einheitlichen Schwierigkeitsgrad gebracht werden?
- Welche Infrastruktur wird für das Hosting benötigt?
- Wer würde sich an der Bildung von freiwilligen Arbeitsgruppen zur Erzeugung und Bewertung der Fragen und Antworten beteiligen?

## 3. Ausblick

Das Usability-Quiz soll eine spielerische Annäherung an die grundlegenden Begriffe und Konzepte der Usability-Welt möglich machen. Die Umsetzung des Usability-Hypertextsystems kann jetzt schon bei der Vorbereitung auf die Zertifizierung zum CPUX-F des UXQB helfen. Die Kombination aus Hypertextsystem zum Erlernen von Begriffen und der Wissensabfrage mittels Lernspiel kann auf das Fachgebiet der Umweltinformatik übertragen werden. Dies ist verbunden mit der Hoffnung, damit einen Beitrag zur Verbreitung von Usability für BUIS leisten zu können.

Der aktuelle Entwicklungsstand soll im Rahmen des KOMET-Projektes zukünftig mit dem Ziel weiterentwickelt werden, weitere Funktionalitäten zur besseren Aneignung der Inhalte bereit zu stellen. So ist denkbar, aus den vorliegenden Daten weitere Fragetypen zu generieren und dem Usability-Quiz so mehr Abwechslung und Tiefe zu geben. Zunächst einmal bleibt abzuwarten, wie die beteiligten Unternehmen und Interessierte aus der Usability-Welt das Lernspiel in naher

Zukunft annehmen.

Weitere Tätigkeiten im Projekt sind die direkte Schulung von KMU und die Erarbeitung von konkreten Hilfestellungen zur Optimierung der Benutzerfreundlichkeit von Anwendungen. Hierzu werden im September 2014 zwei Eyetracking-Studien bei KMUs durchgeführt. Ein Beispiel einer solchen Studie wird im Rahmen der EnviroInfo 2014 unter dem Titel „Durchführung einer Eyetracking Studie zur Optimierung der Usability einer nachhaltigen Produktsuche“ ebenfalls vorgestellt.

## 4. Acknowledgement

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# Durchführung einer Eyetracking-Studie zur Optimierung der Usability einer nachhaltigen Produktsuche

Felix Hemke[1], Volker Wohlgemuth[1], Maximilian Schneider[1], Maurice Stanszus[2]

## Abstract

This Paper focuses on improvements of the web page WeGreen.de from a usability perspective. This sustainable search engine for products was tested as a case study using the eye tracking method. The main question behind the study was to evaluate the social impact of the sustainability indicator of WeGreen, i.e. if people intuitively trust this indicator and if it leads to a more ecological or social buying decision. The combination of the usability research project KOMET and the ongoing development of Environmental Management Information Systems at the HTW Berlin mean a convenient situation for small and medium sized enterprises which needs proceedings for user friendly software solutions. An introduction in the field of usability studies, the case study itself and its results shall follow.

## 1. Usability-Studien an der HTW Berlin

Um das volle Potential einer Anwendung bei ihren Benutzern zur Geltung zu bringen, muss diese nicht nur einen generellen Funktionsumfang bereit stellen, sondern so aufgebaut sein, dass die Benutzer diese Funktionen intuitiv erlernen können. Darüber hinaus ist ein ansprechendes Design unerlässlich geworden, um die Zufriedenheit bei der Benutzung zu gewährleisten. Dies gilt ebenso für betriebliche Umweltinformationssysteme (BUIS), bei denen lange Zeit zunächst die Funktionalität bei der Entwicklung im Vordergrund stand [1].

Seit November 2013 wird das Projekt KOMET [2] an der HTW Berlin durchgeführt. In diesem Rahmen werden mehrere Maßnahmen erarbeitet, um eine nutzerfreundliche und nutzerorientierte Softwaregestaltung bzw. Usability bereits in der Entwicklung von Software in kleinen und mittelständischen Unternehmen (KMU) zu etablieren und nachhaltig zu konsolidieren. Das Forschungsvorhaben ist Bestandteil des Qualifizierungsprojektes "Hochschulbasierte Weiterbildung für Betriebe an der HTW Berlin" und wird durch die Berliner Senatsverwaltung für Wirtschaft, Technologie und Forschung aus dem Europäischen Sozialfonds gefördert. Im Februar 2014 wurde mit dem KOMET-Projektpartner WeGreen eine Usability-Fallstudie durchgeführt. Die Durchführung und die Ergebnisse der Studie werden im Folgenden näher erläutert.

## 2. Was ist WeGreen.de?

Die Webseite WeGreen.de ermöglicht bereits seit einigen Jahren die Suche von nachhaltigen Produkten auf diversen Verkaufsportalen im Internet (z.B. von Intersport, DaWanda und Gravis). Die Produkte werden von WeGreen mit einer sogenannten Nachhaltigkeitsampel versehen. Dazu wird das jeweilige Produkt sowie der Hersteller hinsichtlich einer Reihe von acht Nachhaltigkeitskriterien bewertet. Diese Kriterien sind Umwelt, Klima, Arbeitsbedingungen, Gesellschaft, Transparenz, Reputation, Gesundheit und Wirtschaftlichkeit [3]. Hierfür werden

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vorliegende Informationen wie Nachhaltigkeitssiegel (z.B. FairTrade[3]), Herstellerangaben, zusätzliche Produkteigenschaften (z.B. Second Hand) oder unabhängige frei zugängliche Produktbewertungen genutzt. Die vorliegenden Informationen zu den acht Nachhaltigkeitskriterien werden außerdem nach ihrer Güte in Bezug auf Glaubwürdigkeit, Seriosität, Zugänglichkeit, Aktualität und Quantifizierbarkeit gewichtet. Die Hersteller werden ebenfalls mit Hilfe unabhängiger Bewertungsquellen allgemein gewichtet. Die Bewertung der Produkte und ihrer Hersteller wird schließlich durch eine Nachhaltigkeitsampel ausgedrückt, wobei die grüne Ampel eine gute, gelb eine mittelmäßige und rot eine schlechte Nachhaltigkeit ausdrückt. *Abbildung **1*** zeigt beispielhaft die Berechnung der Nachhaltigkeit eines Pfefferminztees mit Hilfe der Hersteller- und Produkteigenschaften.


*Abbildung 1: Bewertung der Nachhaltigkeit eines Pfefferminztees durch eine grüne WeGreen Nachhaltigkeitsampel* [3]

Somit haben die Nutzer die Möglichkeit, sich über die Nachhaltigkeit eines Produktes zu informieren. Durch die Berechnung einer einheitlichen Benotung lassen sich außerdem Nachhaltigkeitsvergleiche zwischen mehreren zur Verfügung stehenden Alternativen ziehen. Das Benotungssystem folgt dem System der Schulnoten, wobei 1,0 bis 2,5 für die beste, 2,6 bis 4,2 für mittelmäßige und 4,3 bis 6,0 für die schlechteste Auszeichnung steht. *Abbildung 2* zeigt beispielhaft die Produktseite einer Espressomaschine mit der WeGreen-Nachhaltigkeitsbewertung 2,5 und der grünen Ampel.

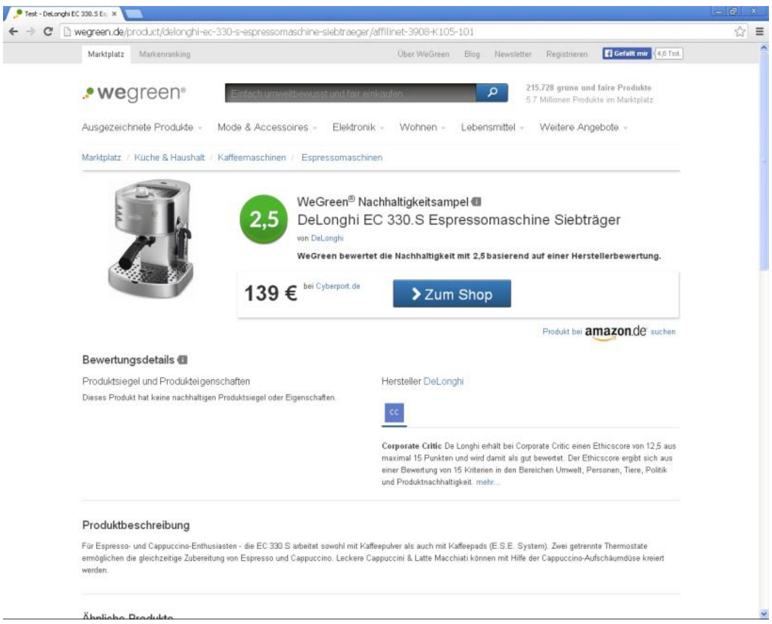


*Abbildung 2: Darstellung der Produktseite einer Espressomaschine mit der WeGreen-Nachhaltigkeitsbewertung 2,5 (grüne Ampel)*

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[3] FairTrade bezeichnet einen Handel, bei dem den Arbeitern ein vorher festgelegter Mindestlohn gezahlt wird.

## 3. Welchen Nutzen haben Eyetracking-Studien?

Um herauszufinden, ob die Nutzer von WeGreen die Nachhaltigkeitsbewertung verstehen und ihr vertrauen, können unterschiedliche Untersuchungsmethoden eingesetzt werden. Die Frage, ob WeGreen bei den Benutzern zu einer nachhaltigeren Kaufentscheidung führt und welcher soziale, ökologische und ökonomische Vorteil daraus entsteht, hängt damit zusammen, wie Menschen die Nachhaltigkeitsampel wahrnehmen, wie ausführlich sie sich informieren und wie viele anschließend eine nachhaltigere Kaufentscheidung treffen.

Dieser indirekte Einfluss lässt sich unter Anderem durch die Auswertung von Beobachtungsdaten ableiten. Dazu zählen bspw. Marktbeobachtungsdaten (Klickzahlen) oder die Auswertung von Nutzerbeobachtungsdaten mit Hilfe von Usability-Studien. Diese kommen generell zum Einsatz, um zu verstehen, welche Perspektive die Benutzer einer Anwendung haben. Dabei werden bspw. Benutzer bei der normalen Benutzung beobachtet. Eine komplexere Methode stellen Eyetracking Studien dar, bei denen die Benutzer typische Aufgaben erhalten und bei deren Bearbeitung mit Hilfe von Blickbewegungsmessungen nachvollziehbar gemacht wird, wie die Benutzer bei der Bearbeitung der Aufgaben vorgehen. Im Fokus der Analyse steht dabei die Informationsaufnahme und -verarbeitung.

Wenn die Testpersonen die gestellten Aufgaben bewältigen, lassen sich objektive Aussagen über die Effizienz und Effektivität der Anwendung stellen. Wie zufrieden die Testpersonen mit der Anwendung sind, kann darüber hinaus mit Hilfe des AttrakDiff-Fragebogens[4] nach Hassenzahl [4] bestimmt werden.

Das Ziel der Untersuchung war die Beantwortung der Frage, ob das Informationsmedium Nachhaltigkeitsampel auf neue Benutzer einen *Social Impact* [5] aufweist, d.h. wie die Personen die Ampel wahrnehmen, wie diese die Bewertung einer Produktes verändert und ob die Personen dadurch ihre Konsumentenentscheidungen ändern. Mit den aus Beobachtungen gesammelten Erfahrungen wurden entsprechende Optimierungen an der Webseite vorgenommen.

## 4. Durchführung einer Eyetracking-Studie zur Optimierung der Usability

Für die Produktsuche von WeGreen.de wurde im Februar 2014 eine Eyetracking-Studie mit acht Testpersonen mittels des UxLab der HTW Berlin [5] durchgeführt. Gegenstand der Untersuchung war die Frage, ob unerfahrene Testpersonen bestimmte Aufgaben auf der Webseite intuitiv erledigen können und wie dabei die Nachhaltigkeitsampel wahrgenommen wird.

Im Mittelpunkt des ersten Teils der Studie stand die Überprüfung des ersten Eindrucks der Testpersonen von der Nachhaltigkeitsampel. Was nehmen Menschen wahr, wenn sie neu auf die Webseite kommen und was denken sie nach dem ersten Blick auf die Ampel? Spielt die Ampel bei einer Kaufentscheidung sofort eine Rolle, ohne dass die Personen über Hintergrundwissen verfügen? Vertrauen sie ihr intuitiv? Für die Klärung dieser Fragen wurde die Produktseite einer Espressomaschine (siehe Abbildung 2) so präpariert, dass vier von acht der Testpersonen die Maschine mit einer grünen Bewertung (gut) und die andere Hälfte dieselbe Seite mit einer gelben Bewertung (mittelmäßig) sahen, wobei in beiden Fällen die Note 2,5 zu sehen war. Die Benotung selbst sollte keinen Ausschlag für die Bewertung geben, sondern nur die Farben grün bzw. gelb. Die Testpersonen hatten in der ersten Aufgabe fünf Sekunden Zeit, die Seite zu betrachten. Danach wurden sie zunächst befragt, welche maximal fünf Dinge sie auf der Produktseite gesehen haben. Eine Heatmap aller Testpersonen dieser ersten fünf Sekunden ist in Abbildung 3 dargestellt. Diese zeigt, dass die ersten Blicke neuer Benutzer grundsätzlich genau auf die zentralen Informationen

[4] Ein Fragebogen zur Evaluation der subjektiven Einschätzung der Probanden über die hedonische und pragmatische Qualität von Produkten.

[5] Sinngemäße Übersetzung: sozialer Effekt

der Produktseite gerichtet sind: die Nachhaltigkeitsampel, den Produktnamen, das Unternehmenslogo, den „Zum Shop“-Button und den Preis.

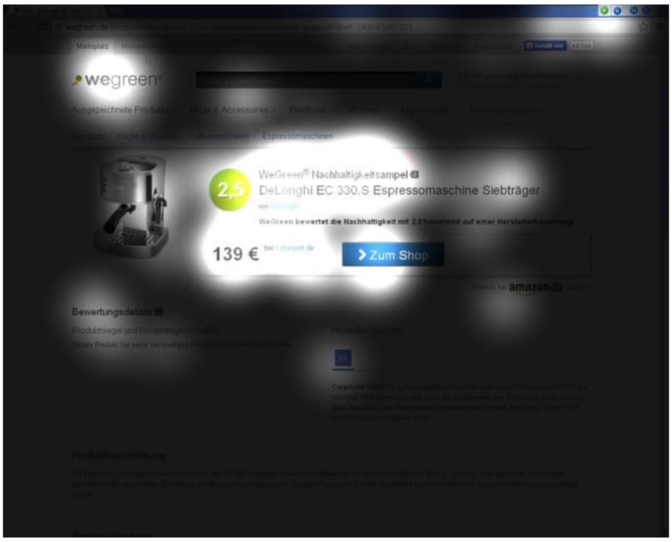


*Abbildung 3: Heatmap der ersten fünf Blicksekunden der acht Testpersonen*

Anschließend erhielten die Testpersonen weitere 30 Sekunden Zeit, sich die Produktseite anzusehen, um dann befragt zu werden, ob sie das Produkt empfehlen würden. Hierbei sollte ein Unterschied zwischen den zwei Gruppen von Testpersonen erkennbar werden. Diejenigen, welche die grüne Ampel zur Espressomaschine sahen, sollten positiver zu dieser eingestellt sein, als die Testpersonen, die auf der sonst exakt gleichen Seite eine gelbe Ampel zu sehen bekamen. Danach wurden die Probanden auch nach dem Grund für ihre Entscheidung befragt, um zu erfahren, ob die Ampel, wie beabsichtigt, berücksichtigt wurde.

Weitere Aufgaben der Studie widmeten sich der Qualität der Suchfunktionen und weiterer Navigationsfunktionen der Webseite. Bei einer Aufgabe sollte ein bestimmter Flachbildfernseher gesucht werden, eine weitere Aufgabe hatte die Suche eines veganen Gewürzes zum Ziel. Hierbei war es nötig, Sucheingrenzungsfunktionen zu verwenden. Somit wurde neben der Kernfrage der Untersuchung, des Nachweises der Wirkung der Nachhaltigkeitsampel, ein breites Spektrum an Funktionalitäten der Webseite hinsichtlich ihrer Effizienz und Effektivität abgeprüft.

## 5. Ergebnisse der Untersuchung

Die Studie ist mit acht Testpersonen geeignet, große statistische Effekte sichtbar zu machen. Sehr kleine oder mittlere statistische Effekte lassen sich nur mit größeren Probandengruppen nachweisen. Für die Erwartung, dass die Nachhaltigkeitsampel einen Einfluss auf die Bewertung eines Produktes durch die Probanden hat, sollte ein relativ großer Effekt sichtbar sein.

Aus der Probandengruppe mit grüner Ampel entschieden sich drei Personen für die Empfehlung, wohingegen die Hälfte der vier Testpersonen mit gelber Ampel eine Empfehlung gaben. Daraus lässt sich zunächst ableiten, dass die Nachhaltigkeitsampel keinen signifikanten Einfluss auf die Kaufentscheidung hat. Aus den Antworten auf die anschließend gestellte Frage, warum die Empfehlung so gegeben wurde, ist zu folgern, dass die Hälfte der Testpersonen die Bewertungsdetails im Laufe der 30 Sekunden gelesen hat. Denn in der Hälfte der Fälle wurde als Begründung nicht die Nachhaltigkeitsampel, sondern der weiterführende Bewertungstext angegeben. Die Bewertungsdetails standen auf der Produktseite neben der Nachhaltigkeitsampel ebenfalls im Blickfokus. Damit ist die Fokussierung auf die Nachhaltigkeitsampel als das alleinige Empfehlungskriterium nicht zum Tragen gekommen.

Aus den Begründungen für die Entscheidungen lässt sich die Aussage schlussfolgern, dass die Ampel einen Einfluss auf die Kaufentscheidung hat. Allerdings stehen andere Informationen auf der Produktseite ebenso im Vordergrund, sodass die Nachhaltigkeitsampel als exklusiver Indikator nicht ausreichend wahrgenommen wird und stattdessen die Bewertungsdetails die Aufmerksamkeit auf sich ziehen. Deshalb wurde die Produktseite so umgestaltet, dass die Hersteller- und Produktbewertungen, denen die Nachhaltigkeitsbewertung zu Grunde liegt, in den Hintergrund treten und die Ampel selber noch deutlicher wahr genommen wird. Für die Verbesserung der Usability der Produktseite wurden zusätzlich noch weitere Aspekte angepasst.

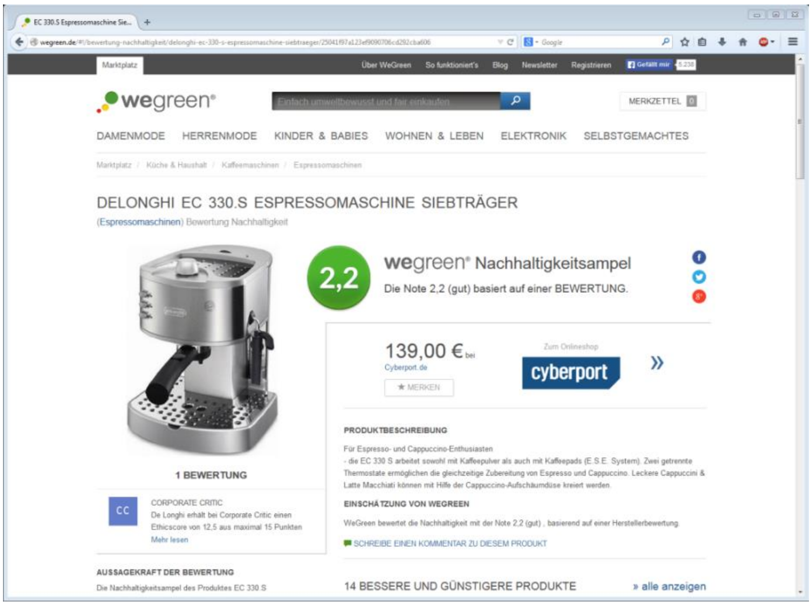


*Abbildung 4: Neu-strukturierte Produktseite von WeGreen.de*

Zu den weiteren Veränderungen der Produktseite gehören u.A.:

- Ein größeres Produktbild zur besseren Visualisierung des Artikels.
- Die Hervorhebung der Nachhaltigkeitsampel mit einer kurzen Beschreibung der Bewertung („Die Note 2,2 (gut) basiert auf einer Bewertung").
- Zugrundeliegende Bewertungskriterien wurden in den linken unteren Bildbereich verschoben, um den Blickfokus stärker auf die Nachhaltigkeitsampel als das Ergebnis und weniger auf die Berechnungsgrundlage zu lenken.
- Das Zustandekommen der Bewertung wird auf der Produktseite nun insgesamt detaillierter, aber weniger präsent, erklärt.
- Anstatt des Buttons „Zum Shop" wird das Logo des jeweiligen Onlineshops angezeigt (hier „cyberport") um deutlich zu machen, dass auf eine externe Seite weitergeleitet wird.
- Die Produktseite wurde um Empfehlungen erweitert (besser bewertete Produkte).

## 6. Usability Optimierung von betrieblichen Umweltinformationssystemen

Die Fallstudie in diesem Beitrag zeigt einen effektiven Einsatz von Eyetracking-Studien zur Verbesserung der Usability und gibt einen Einblick in die Ergebnisse. Auch wenn der Untersuchungsrahmen und die Anzahl der Testpersonen klein ausfielen, führte der Einsatz von Eyetracking zu einer Optimierung der Produktsuche. Der Vorteil solcher Studien liegt darin, Entscheidungen über das Aussehen einer Anwendung nichtmehr nur „aus dem Bauch heraus" treffen zu müssen, sondern über empirische Daten zu verfügen, die eine gezieltere Entwicklung unterstützen.

Generell gibt es nach wie vor ein großes Potential bei BUIS durch Usability-Studien den Funktionsumfang der Anwendungen besser zur Geltung zu bringen. In der Vergangenheit bezogen BUIS ihren Nutzen häufig aus der Funktionalität selbst und weniger aus der Einfachheit, diese zu benutzen [1]. Für Entwickler von BUIS bedeutet die Verbesserung der Usability eine Möglichkeit, Software zu entwickeln, mit der die Benutzer effizienter, effektiver und zufriedener arbeiten. Die Software wird somit in der Regel leichter angenommen, wodurch die volle Bandbreite der Software zum Tragen kommt. Dies ist vor allem für Nischenprodukte unter BUIS ein wichtiger Erfolgsfaktor. Aus diesem Grund werden im Rahmen des Projekts KOMET an der HTW Berlin professionelle Usability-Studien für BUIS durchgeführt. Besonders erfolgreich ist der Einsatz dieser Methode in einem frühen Entwicklungsstadium der Software, da hier die Flexibilität für benutzerfreundliche Anpassungen am größten ist.

## 7. Ausblick

Zur Messung des Erfolges der überarbeiteten WeGreen-Produktseite ist eine Folgestudie im Laufe des weiteren Projektverlaufs angedacht. Die Bemühungen zur Etablierung und Konsolidierung von Usability in den, mit den Projekt verbundenen Unternehmen, werden zukünftig weiter verstärkt. Die Mitarbeiter sollen mit Hilfe von Schulungen und kurzen, leicht konsumierbaren Lehrvideos mit den Themen der Usability vertraut gemacht werden. Dabei sollen die Entwickler und Produktdesigner für die Perspektive der Benutzer sensibilisiert werden. Die Ergebnisse werden zukünftig auf der Projektwebseite KOMET.f2.htw-berlin.de dargestellt. Dazu zählt ebenfalls ein Lernspiel, welches im Konferenzbeitrag „Usability-Quiz: Die Begriffswelt der Usability durch ein Lernspiel vermitteln“ vorgestellt wird. Das Usability-Quiz ist ein weiteres Instrument zur Verankerung von Usability in KMU der Umweltinformatik-Branche.

## 8. Acknowledgement

Dieses Projekt wird von der Berliner Senatsverwaltung für Wirtschaft, Technologie und Forschung mit Mitteln aus dem Europäischen Fonds für regionale Entwicklung (EFRE) gefördert. Die Autoren danken für die Unterstützung.

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# Complementary software solutions for efficient timber logging and trade management

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## Abstract

Timber logging and trade is a complex system with important environmental, but also economic and societal dimensions. Today, the timber market has become global, not only for high-valued timber products, but also for technical and fire wood. At the same time, illegal logging is a common hurdle in almost all stages of the timber lifecycle from forest to market, creating a positive feedback cycle that starts with local environmental degradation and leads to severe impacts on global climate change. Timber certification and traceability are key aspects that may ensure supply-chain transparency, illegal logging mitigation, and forest management sustainability. Information systems have a central role to play in an application domain that is hardly digitized, such as forestry. Providing innovative technological solutions to support the daily work of the local forest service is critical, but the integration of ICT technologies in their operations is indeed a challenging endeavour. In this paper, a set of complementary software solutions is presented that aim to assist timber logging, transportation and trade management, and consequently to support efficient wood certification. The paper also outlines how forest service staff perceptions were integrated at an early stage in the design and development phase in order to increase system usability and maximise the potential for technology assimilation.

## 1. Introduction

Illegal logging and timber trade is currently a major concern among all countries worldwide [1]. It is largely acknowledge that, if related practices are left uncontrolled, they present a substantial threat to sustainable forest management with wider environmental and economical consequences. It is, directly and indirectly, associated to global climate change, threatening ecosystems and biodiversity in forests throughout the world. The degradation starts locally, with reduced forest cover affecting rainfall patterns, surface temperatures and atmospheric CO2 concentrations. Carbon emissions from deforestation, especially in developing nations, account for 15% of global carbon emissions, according to FCPF [2]. Several numerical experiments on deforestation in Amazonia have showed that temperature rises significantly and precipitation decreases as a result of deforestation. A positive feedback cycle with increasingly negative consequences starts to develop, with lower rainfall leading to reduced river flows to agricultural systems, lower water supply and increased pollution in air and water supplies. This pattern results in increased diseases in neighbouring rural and urban environments. Influenced by deforestation, changes in rainfall and temperature patterns topped by floods and landslides have regional effects that subsequently impact global circulation patterns in the atmosphere. In other words, the local effect, related directly to illegal logging activities, creates linkages, which disrupt global atmospheric patterns and contribute to global climate change in numerous ways.

While the negative impacts of illegal logging are gradually being acknowledged, the use of technological means to combat this phenomenon is not gaining ground as quickly as would be expected. One reason for this reluctance is linked to the fact that reliable information on forest

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harvesting activities is often difficult to obtain for legal and illegal activities, due to natural, geographical and administrative factors, among others. However, another critical reason lies with the rigidness of most IT systems designed for forest management, which either demand advanced digital skills, largely unavailable among forest service staff, or request that field experts change their daily operations significantly to meet the utilisation requirements of these systems. Such technological solutions, however efficient in producing the intended result, usually fail in gaining the necessary user acceptance and often become obsolete.

The AITOLOS[4] project is an initiative building on the close interaction of two types of partners: those experienced in the design and development of complex ICT solutions and those with forest management expertise and field-work experience. Both forest domain and technology experts have actively collaborated during a two-year period, in order to achieve mutual understanding on how each side could contribute to the overarching project goal, i.e. the design and implementation of technological solutions that complement traditional forest management activities in fighting against illegal logging and timber trade.

In the following sections, the design methodological approach is described and identified IT solutions are briefly presented. The sections highlight how user needs and traditional operations on the forest field were brought at central stage during system specifications' design and solutions development. The sections also discuss the aspects that ensured minimum intrusiveness of the selected technologies and the operational planning that facilitates the integration of developed IT systems in forest service operations.

## 2. A methodological approach for solutions' design and development

Identifying suitable technological solutions that support the efforts of the local forest service in combating illegal logging activities and selecting those that would be demonstrated through the AITOLOS pilot implementation in the Greece - F.Y.R.O.M cross-border area was a challenging process. Frequent interactions among technology and forest domain experts were implemented to pinpoint the key problems and needs to be addressed, to prioritise among them, and to estimate risks involved in developing a portfolio of IT solutions for the forest service on both sides of the border. The necessary bidirectional knowledge shift between the two types of teams was initiated with an intensive 'inception' workshop and followed by several meetings, field visits and workshops. The primary objective was to facilitate the development of a common language and to achieve consensus among technical and domain scientists on the needs and the suitability of proposed solutions. For this purpose, agile methods originating in soft-ware engineering were adopted, and put in action [3].

Capturing user requirements constitutes a moving target in projects that are ill-defined or rapidly-changing, which has shed a new light to the use of agile approaches like Extreme Programming or Scrum and their potential in capturing requirements informally, i.e. as users' stories. Agile methods for requirements engineering are based on four principles [4]: a) put customers in the centre of attention, i.e. involve actively stakeholders throughout the process; b) employ early verification and validation techniques, i.e by developing acceptance tests for user stories, or use cases; c) identify early non-functional requirements and analyze them with customers; d) manage change and incorporate it in the process of requirements engineering.

Cao and Ramesh, in [5], presented an empirical study that evaluates agile requirements practices in 16 organizations, and reveals that intensive communication between the developers and customers

[4]AITOLOS stands for "Cross-border collaboration to fight illegal logging and timber trade to protect trans-boundary Greek-F.Y.R.O.M. ecosystems". It is a project implemented under the IPA Cross-border programme and is co-funded by the European Commission. The project website is http://www.aitolos.eu

as the most important one. Inspired by agile requirements practices, a methodology for engaging end-users early in the process was developed and applied in the AITOLOS project.

The methodological approach employed in all teams' interactions was built on a 3-step structure i.e. the *domain understanding* step, the *solutions identification* step and the s*ynthesis and co-design* step. The process developed with this approach was not linear, but instead several iterations of these 3 basic steps were planned and performed.

The first step, *domain understanding*, was primarily built on eliciting initial user stories, which were subsequently developed through iterations. Domain experts described their application domain and presented problems in their everyday work practice in a story-telling fashion by sharing experiences and anecdotes. They also highlighted the real-life issues faced, the extent and detail of the illegal logging problem and the limitations in the way the forest service operates. The purpose was to achieve a common understanding between domain and technology experts about the scope of the project and the role intended for the complementary technical solutions.

The second step, *solutions identification*, aimed to provide basic knowledge to the domain experts on technology-related opportunities and to enable collaborative identification of possible solutions. Technology experts presented the capabilities of various relevant technologies and proposed possible systems and applications that could be exploited to meet some of the domain challenges. Through this step, domain experts gained insight on technical capacities and limitations and the possibilities linked to the integrating innovative solutions to improve the efficiency, support, or simplify their every-day work.

The third step, *Synthesis and co-design*, was the richest one in the number of teams' interactions. Its purpose was to produce a synthesis of views between the domain and technical experts and to prepare the ground for the compilation of technical system specifications and a tailored operational plan for the adoption and utilisation of the developed solutions on each side of the border. User stories from the first step were exploited to produce high-level needs' requirements of the project at hand. The final selection of technologies to implement was preceded by a step of prioritisation in terms of IT system electiveness, implementation risk and management/ maintenance cost.

## 3. Analysing the operational framework

The timber logging and trading lifecycle can be analysed in five key phases that typically involve several authorities, regulations, operational frameworks and markets [2]. *Forest management and timber marking* is the first phase and relates to medium/long term forest management plans and possibly market needs. This phase is followed by the actual tree logging activity in the *wood felling and pilling* phase. The third phase, t*imber delivery & transport* phase is related to timber pick up and transportation from pilling areas to facilities away from the logging area. This activity is followed by the *timber storage* phase, during which timber is taken to storage or processing facilities. From this point on, wood becomes a product that is traded and processes in local or global markets and thus the fifth phase of its lifecycle is related to cross-border timber trade towards global markets. As the timber lifecycle spans across several sectors, scales and domains, typically there is limited information collected for each phase, while interoperability and common information systems are highly uncommon.

In the framework of the AITOLOS project, an ambitious goal was preset in terms of fostering cross-border collaboration and coordination between the activities of *Greece* and the *former Yugoslav Republic of Macedonia* against illegal logging and timber trade. Thus, an analysis of the overall logging and timber trade lifecycle was performed with participatory methods and agile techniques. Through this process, the domain and technology experts managed to spot the *weak links* of the added-value chain, which could potentially be improved by software solutions and tailored IT systems. The participatory process included first an initial assessment of lifecycle weak points that required attention, based on bilateral discussions with involved stakeholders and based on respective industry expertise. Subsequently, a broad stakeholders' survey was set-up to assess the identified weak points and enhance the analysis with the feedback from forest management policy experts, forest service staff members, wood traders, wood-logging partnerships, environmental NGOs, etc. The outcomes of this participatory process were not only synthesised and processed towards the development of technical solutions, but were also exploited for the development of relevant policy guidelines that aim to support the fight against illegal logging and trade.

The analysis of the operational framework yielded added value conclusions that affected the subsequent selection of technological solutions. The following representative examples can be mentioned: It was drawn that systematic operationalisation of control/check-points across key wood roads to monitor movement in and out in areas close to log landing areas was needed. These permanently set-up check-points should constantly control the vehicles entering and exiting the log landing areas in order to reduce illegal activities and relief/replace staff surveillance rounds. It was also concluded that the use of uniform templates to report import and export of wood across Greece-FYROM borders (e.g. language, volumes, destination etc.) are needed and smart identification technologies would assist control services in their work. The objective is to eliminate non-uniform documentation that escorts wood loads across the border and thus the use of a common language will ease the legality control at the border and check-points.

## 4. Technologies built to provide solutions to existing problems

The results of the operational framework analysis, along with the conclusions drawn from the application of agile and participatory methods were processed by domain and technology experts, who focused on the identified weak points of the timber logging and trading lifecycle and collaboratively selected technical solutions that would provide solutions to specific problems. The criteria for this selection primarily respected the existing mode of operation of the forest service and targeted the design of tailored IT systems that would require minimum digital literacy and would reduce the intrusiveness of technologies as seen from the users' perspective.

The design and development of the AITOLOS technical solutions, and their demonstration through a pilot activity in both countries, was based on the principles drawn from the aforementioned process: 1) wireless access technologies (smart identification, e.g. RFIDs) can increase accuracy and reach of the marking process, 2) image processing techniques can be exploited to calculate the loaded wood volume on the vehicles that transport them from the log landing areas to the warehouses, improving the accuracy of current empirical calculations, 3) wireless communication and server systems could be utilised to store and communicate required data among relevant stakeholders across the value chain (e.g. custom control to forestry offices) to manage timely information transfer and control of matters related to the legality and routes of transportation, 4) GIS/geo-systems platforms and software would enhance accuracy and efficiency of managing forest areas, whether real-time or off-line, would support the forest area monitoring activity and help authorities locate areas where illegal logging is taking place, in order to focus their efforts in controlling it, 5) electronic IDs in consignment notes would eliminate reporting fraud.

Below, we provide a list of complementary IT solutions that were proposed towards an improved *modus operandi*, enhancing process transparency and allowing for the timber-origin certification.

**S1: Electronic documents with security characteristics**. There are several documents involved in timber as logging permits and timber transportation notes (which accompany trucks from log landing areas to timber warehouses). Modern document templates may incorporate security features in the form of barcode, QR code, or e-signatures, which are instantly verifiable. Using low cost, smart devices, such features can be verified instantly.

**S2: Smart Tags for Timber Marking**: Currently, timber marking is performed with hammers that mark wood with forest office, or forester code. This is a weak point that can be significantly improved by introducing unique tags for all wood marked by hammer. This can be achieved by using plastic bar- code or RFID tags, or RFID nails from pulping compatible material. This solution is ideal both for proving technical wood log origin, and for timber certification.

**S3: Cross-border uniform, multilingual reports**. Forms attached to timber imported (or exported) are not standardized, and texts appear typically in the national language. A form standardization process that involves multilingual forms and common coding for species can remove language barriers at inspection points.

**S4: Truck load detection**. Manual estimation of timber volume loaded on trucks is another weak point of the value chain. Using a one-stop gate, equipped with low cost, low power sensors to calculate automatically wood volume loaded on a truck. This could be done for example by two depth cameras getting two viewpoints of a truck: top and rear, and detecting the contour of the volume loaded. We are currently in the process of deploying this solution, which will be presented at the conference.

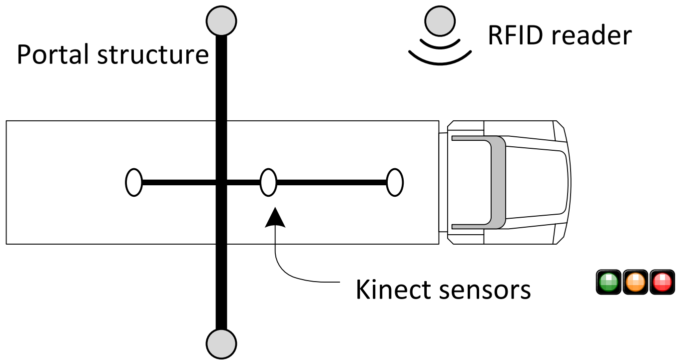


Figure 1. Load volume measurement

**S5: Truck motion detection**. While effective monitoring of timber transport and access control to forest areas has been identified as a key to combat illegal logging, this is a very difficult task, as forests are not fenced and a dense network of dirt roads and paths exist. However, a typical fleet management scenario that uses GPS/GSM network to detect truck routes, and report them online could be easily deployed.

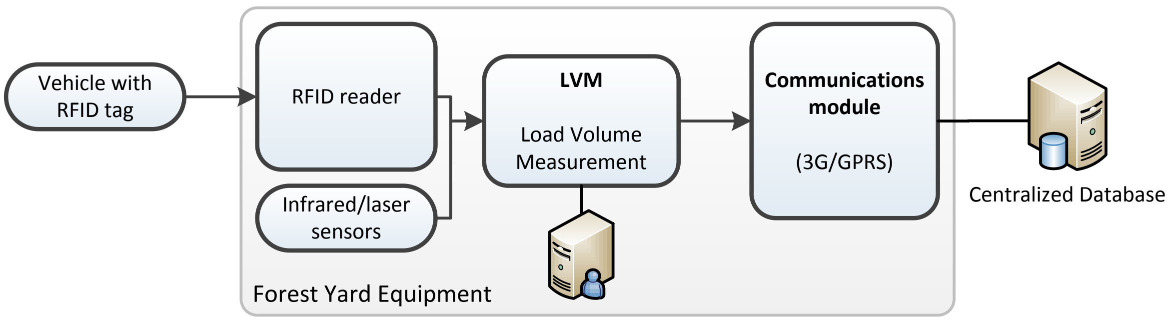


Figure 2. System architecture for vehicle tracking on forest yard gate

**S6: Satellite imaging**. Image processing algorithms may be applied on satellite images to detect areas of intervention and protection. Such tools have been applied extensively in forest fire monitoring. With respect to timber logging and trade, we identify two scenarios: The operational scenario, where images are used on demand, in order to identify illegal logging at the time it happens, and the strategic scenario, where the same techniques may apply on low-cost, historical images, to estimate forest degradation due to illegal logging and prioritize future intervention actions.

**S7: Systems integration**. In the current situation, information doesn't flow across the borders, neither between the various national services involved in the inspection of timber trade value chain (i.e customs, taxation, police and forest authorities). An integrated Environmental Information System could be deployed to link customs with taxation offices and forest services, in order to share information related to authorised timber transport, timber storage in warehouses, etc.

## 5. Discussion

Environmental Information Systems may become extremely valuable for efficient timber logging and trade, and support for both timber provenance certification, and forest forensics. Timber certification and traceability are the main two elements to ensure supply-chain transparency, illegal logging mitigation, and forest management sustainability. Environmental Management Information systems may become a key element for such an endeavour, and in the framework of the AITOLOS project we previewed a set of complementary solutions that spans across the lifecycle of timber value chain and currently we are in the process of deploying a subset.

The AITOLOS project pilot designed and currently deploy a prototype for detecting trucks load using low-cost depth cameras and RFID technologies. The two pilot sites have been selected, the first is in Goumenissa, Greece and the second in Bitola, The former Yugoslav Republic of Macedonia. The pilot implementation is expected to yield important results and insights on how Environmental Management Information Systems together with low cost sensors can assist in fighting illegal logging and timber certification, and how illegal logging is performed in the local cross border environments.

## Acknowledgements

This work have been partially supported by the IPA cross-border programme `Greece-The former Yugoslav Republic of Macedonia 2007-2013' under grant AITOLOS, which is co-funded by the European Union and by national funds of the participating countries. More about the project at: http://www.aitolos.eu.

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# GSBL: Giving Germany's Most Comprehensive Chemical Substances Data Pool a Convincing Face

Stefan Barthel[1], Karsten Zischner[2], Gunnar Minx[3]


## Abstract

This paper describes the concept of the user-oriented redesigning process of the Joint Substance Data Pool of the German Federal Government and Federal States (GSBL). The GSBL contains at all relevant information on 63.000 pure chemical substances, 320.000 mixtures of substances and 207.000 concerning legal regulations. Redesigning is necessary, because current and potential users are not satisfied with the usability of the retrieval application and the search result presentation. The substance search is partially so complex that trainings courses and detailed instruction manuals are inquired. In order to achieve a tailor-made solution for current and potential key users as well as for user that have or have not been used the GSBL's retrieval application before, a promising redesigning process is introduced and established usability techniques are utilized.


## 1. Introduction

Imagine there is a database that holds tens of thousands of chemical substances, mixtures of substances and substance groups as well as relations and coherences among them and even searchable chemical structures. Furthermore, that database contains for every single object a wide range of verified features involving information on physical and chemical properties, on ecotoxicological and toxicological parameters, descriptions of environmental hazards, health dangers, fire and other technical hazards and could give information on relevant chemicals-related legislation as well as on environmental fate. A database like this could be used by all people, including governmental authorities, emergency forces and the general public that have an interest in properties and the harmfulness of certain substances, their environmental fate as well as degradation.

And now imagine all of the information and functionality contained in the database cannot be exploited due to a misleading user interface. To be honest, the described scenario is not fictional, rather, it is an exaggerated description of the current status of the Joint Substance Data Pool of the German Federal Government and Federal States (GSBL). Exaggerated in way that in practice of course governmental authorities and emergency forces use the GSBL for several intensions, but some of them are not satisfied with the usability of the front end (resp. retrieval application). In addition, new or infrequent users with chemical background complain that, in their point of view, the substance search as well as the search result presentation is partially to complex and trainings courses and/ or detailed instruction manuals are demanded. However, they recognize the value of the contained data, whereas users with basic knowledge in chemical substances are rather overcharged than enthusiastic by trying to find the information which is the aim of their visit. Thus,


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it can be concluded that GSBL's retrieval application is not that attractive on the first glance. But without research, there is no opportunity to clearly quantify whether and how damaging the partially misleading user interface is and accordingly, how to do better.

The concept presented in this paper is devised by an internal project team of the Federal Environment Agency – in the sequel denoted as SIFT team – that organised themselves to analyse potential solutions and to advice GSBL's executive committee with this perceptions. The aim of this redesigning concept is to improve GSBL's usability by evaluating and scheduling further procedure as well as depicting which methods and techniques should be used.

## 2. Evolution of GSBL

First of all, it is necessary to mention that the GSBL as a data pool has been offering his data for almost twenty years now. More precisely, between 1991 and 1993, GSBL was developed based on a former information system named INFUCHS [1] that held data about environmentally relevant chemical substances and mixture of substances. The aim of INFUCHS was the provision of instructions and supporting measures in the event of accident related to chemical substances (health risk, environmental threat, legal regulation). Since, INFUCHS was only developed by the Federal Government and several Federal States were running their own systems, Federal Government and Federal States agreed to join forces by supporting a joint substance data pool (GSBL). Up to 1998, data of the GSBL were only accessible via a locally installed client-server application that was then replaced by an online-accessible retrieval application. In 2007, this more or less spartanic retrieval application, in consequence of limited design possibilities, was replaced by the retrieval application that is still in use. Nevertheless, during whole time the system architecture changed only slightly by adding some more extensions or fixing malfunctions partially with fallback solutions. Furthermore, almost all parts of the system are proprietary developments, because twenty years ago ready-to-use solutions out of the box did not exist. As a result of this, all components of the system are hardwired and based on each other which did not make the overall situation in the field of enhancements any easier. In consequence, there is almost no opportunity to redesign parts of the systems and a complete reconstruction seems to be the only feasible way. However, in this paper we are focussing only on the user-friendly redesign of the online retrieval application (user interface).

## 3. Redesigning Process

To be able to examine and characterise the redesigning process itself as well as motivations and causes to do so, uniform definitions of process phases have to be determined for further use. We come up with five phases as well as our own phase definitions due to incompleteness or non-existence of matching alternatives [4,5].

*Decision phase:* We call that part of the redesigning process as *decision phase* where decisive events occur in a way that the satisfaction with the system (slightly) changes up to the point where the entirety of occurred circumstances are back-breaking and it is unavoidable to redesign. This happens, for example, if more and more user start complaining about the system and single users finally resign.

*Evaluation phase:* In the *evaluation phase*, we bring together and analyse all reported deficiencies and evaluate them with tools to measure usability. The aim of this phase is to expose which functionalities and components are annoying and need to be altered, but also those ones that should continuously enrich the system functionality.

*Subjective redesigning phase*: Within our *subjective redesigning phase*, a redesign draft is created that already involves most system functionality specified in the *evaluation phase*. The redesign draft is then realised as a prototype. System functionalities that are either too expensive or too complex to integrate in a prototype, should be suggested and are detailed described in the redesign draft. This approach is related to paper prototyping [8], but performed in a much more practical, realistic and user oriented way.

*Agreement phase:* In the *agreement phase*, key users need to assess the prototype also by using tools to measure usability. The exclusive choice of key users is intended, because they are the majority of all users and we cannot meet all needs down to the last detail. Suggestions to improve the redesign draft are desired, whereby, the transition to the objective redesigning phase is fluid.

*Objective redesigning phase*: We call that part of redesigning process as *objective redesigning phase* where the redesign draft with included objections of key users is finally implemented. If the prototype is already developed in applicable manner, a further development should also be considered. Because minor change requests will repeatedly arise, in this phase, it is possible to step back to the *agreement phase*.

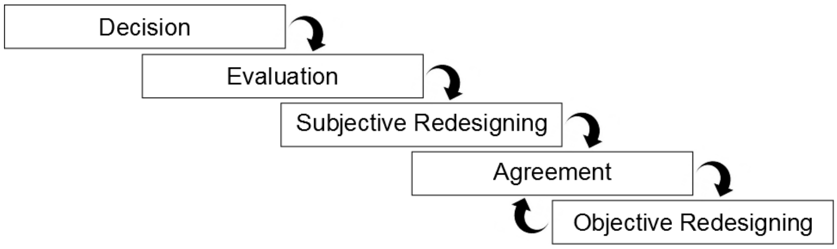


*Figure 1: Phases of Redesigning Process*

For a better understanding of the sequence of all phases, see figure 1. In the following, we are mapping the above described phases to actions of GSBL's redesigning process.

### 3.1. Decision Phase

As stated before, the entire GSBL exists almost twenty years, whereas GSBL's retrieval application was developed "only" seven years ago. Nevertheless, we have to admit that the retrieval application was not independently designed from structural conditions of the existing system. Since, a web framework was taken that was on the one hand safe against tampering and theft and on the other hand compatible to the existing database management system (*Fulgor*). Furthermore, the web retrieval application was not developed on the basis of user requests that have been approved and evaluated by usability tests. Instead, some parts of the well-known design of the former web retrieval application were adapted, which was again with respect to design, almost a copy of the prior locally installed client-server application. Because usability test and some few stakeholder interests have not been taken into account, initial dissatisfaction and related improvement suggestions started occurring shortly after completion of the retrieval application. Over the past years, several improvements and enhancements of the retrieval application have been performed, but they were limited by the frameworks abilities. In addition, most improvement suggestions were submitted by specialist users who are the main user group. But they primarily wanted more detailed functionalities what led to a rather complex than intuitive ease of use. For named reasons, the length of the *decision phase* is a little different than what might be expected, because it already began with the completion of the retrieval application seven years ago.

### 3.2. Evaluation Phase

After the decision will be made to rebuild the GSBL's retrieval application from scratch, all deficiencies to improve as well as all strengths that should continuously enrich the system functionality are figured out. Furthermore, all kinds of users are involved that might be interested in getting information about chemical substances out of the GSBL:

- *Group 1*: Users with deep chemical knowledge (e.g., key users, chemists, data manager, etc.).
- *Group 2*: Users with chemical interest or background (e.g., employees of public authorities, universities or research institutes, etc.).
- *Group 3*: Users with basic knowledge only searching for specific information (e.g., journalist, general public, affected people, etc.).
- *Group 4*: Users who have not been used GSBL's retrieval application before.
- *Group 5*: Users who are familiar with GSBL's retrieval application.

Moreover, the consideration of all these kinds of users with potentially different ideas of searching, navigation and result presentation, dependent on their varying backgrounds, is necessary. Hence, there is no single method to be able to cover all these kinds of user in deep.

In detail, we introduce four rounds of reviewing as sub-phases of the evaluation phase to obtain all achievable statements of advantages and disadvantages of the current system (resp. retrieval application) as well as suggestions for enhancements of the new system.

In the 1st round of reviewing – *consolidation* –, as a first step, members of the SIFT team bring together and unify all issues and benefits that have been reported so far. This potentially yields information from all above named groups, but mostly from group 1, 2 and 5. Furthermore, an external contractor is commissioned to run and evaluate a user and acceptance analysis which is performed in personal interviews with key and long-time users (group 1, 2, 5) as well as an online survey with access to everyone. With this procedure, information from all above named groups without a specific expression for a certain group can be obtained. Lastly, pre-formulated search scenarios are released to subjects that are contemporary members of group 3 and 5 to gain more detailed information from users that are obviously daunted at present time. By doing so, SIFT team could rely on the cooperation with Anhalt University of Applied Sciences and draw on students.

In the 2nd round of reviewing – *requirement specification* –, requirements are gathered and harmonized that are demanded by end user. This includes users who are using the retrieval application (group 1 to 5), but also responsible administrative staff and data suppliers (editors, researchers, etc.). To be able to ascertain all possible requirements, the task force "GSBL2020" – a project team appointed by GSBL's executive committee – is instructed to figure out system requirements for the new version of GSBL. To do so, an external contractor is commissioned, who introduce the use case method [2] to derive requirements by creating use cases of the future system.

3rd round of reviewing – *expert evaluation* –: To evaluate the usability of the portal "www.gsbl.de" and to give concrete evidence for the relaunch, several methods can be used. Based on the findings, which are obtained from the definition of the target group and from data out of the online survey (1st round of reviewing), an expert evaluation (group 1, 4 and 5) should be performed in the 3rd round of reviewing. For the exact definition and classification of the problem areas, the research method *Heuristic Evaluation* [7] can be applied. Nevertheless, recognized heuristics have already been formulated in 1990 [6]. Until today some revisions of these heuristics were carried out. Currently also *Joy Of Use* and intercultural aspects are included [3]. The application of the heuristic evaluation is helpful for the so-called bottom-up approach, whereby, level of detail improvements can enhance the whole.

In the 4th round of reviewing – *end user test* –, the results of the expert evaluation (3rd round of reviewing) are reused for the preparation of a user-test that can be conducted in the usability lab of Anhalt University of Applied Sciences as one possible partner, e.g., within a student project. To perform the test, real users of the portal are invited as test subjects. These test subjects have to solve one or more defined tasks with the GSBL portal. This process is recorded and logged using the Rich Recording Software *Morae*[4]. In this approach, statements of the experts from the heuristic evaluation as well as the findings from the real user can be considered.

### 3.3. Subjective Redesigning Phase

As a next step, a prototype is set up which already contains most system functionality. System functionalities that are either too expensive or too complex to integrate in the prototype are suggested and are detailed described in the attendant design specification (redesign draft). Figure 2 depicts the current version of SIFT team's prototype, whereby, tabs for searching in the GSBL data pool are functional and the other ones are non-functional/ suggested. The layout of SIFT team's prototype is influenced by Google[5] and ChemDB[6].


*Figure 2: Prototype of our Online Retrieval Application*

In addition to the visible online-accessible retrieval application that is the focus of this paper, SIFT team also has to think about the best possible variant to store and manage the data that constitute GSBL's data pool. Here, especially the kind of database management system and best schema are demanded. However, this is not the focus now and will be discussed in another paper.

### 3.4. Agreement Phase and Objective Redesigning Phase

In the agreement phase, the on defined requirements and past experience based prototype is presented to key users who have to assess the prototype. Because suggestion to improve the redesign draft and detection of barriers are desired, tools to measure usability are also used. At this point, appropriate mechanisms and tools that have already been presented in the evaluation phase (Heuristic Evaluation, real user-test) are utilized. By reusing such mechanisms, results before and after reconstruction can be compared. During this phase, the requirements that the system has to meet are constantly refined. Due to the fact that most of the system functionalities are already

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[4] Morae: A product of TechSmith Corporation; URL: http://www.techsmith.de/morae.html

[5] URL: https://www.google.de

[6] URL: http://www.chemdb.de

defined at this stage and it has pretty much only to be fine-tuned, the final implementation is started. Also because of this, the transition to the objective redesigning phase is fluid.

In the objective redesigning phase, the redesign draft with included objections of key users is finally implemented. In case the prototype is used, it will be further developed. Because minor change requests repeatedly arise in this phase, it is always possible to go back to the agreement phase by simply involving key users or by using usability techniques.

## 4. Conclusion and Future Work

As described so far, SIFT team is currently working on the user-oriented redesign of Germany's most comprehensive chemical substances data pool – GSBL – which is not finished yet. The primary importance within the redesigning process is the inclusion of as many end user proposals for improvement as possible. In case of the online-accessible retrieval application, the renewal process considers key users, chemists, data manager, employees of public authorities, universities or research institutes, journalist, the general public, affected people as well as people that have or have not been used GSBL's retrieval application before. Because some of them have similar interests and knowledge, users are clustered into five groups that have been examined on preferences. Thereby, the aim is to obtain all achievable statements of advantages and disadvantages of the current system (resp. retrieval application) as well as suggestions for enhancements of the new system. With all these information, SIFT team is currently developing a prototype that will be evaluated with end users by utilizing different methods and usability techniques. Afterwards, the prototype is evolved by an external contractor, who is also responsible for an evaluation up to near-perfection. However, due to the number of employees and policy constraints of a project of German Federal Government and Federal States, the whole process cannot be implemented in the short term. Furthermore, not only the online-accessible retrieval application has to be considered, SIFT team also needs to pay attention to an online-accessible submission and delivery application for data suppliers and to the optimal choice of a well fitting database management system. But as already announced, these considerations are the content of future papers.

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# A Data Classification to Support Collaboration in an Enterprise Network

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## Abstract

To face contemporary environmental problems, we have to find every possible new way to use the available potentials of saving environmental and natural resources. The collaboration in environmental management networks is one of these ways that opens new alternatives for environmental systems. One of the main constraints to facilitate collaboration in a network is the ability to exchange information and data. However, most enterprises are not willing to give any data to other organizations in the sense that they give away corporate secrets. The purpose of this paper is to discuss how to facilitate the work of enterprise networks by developing a data classification method to solve the problem of data exchange between companies. This developed approach should help enterprises to trust collaborating with other companies, or more specifically methods that initiate interaction and support the development of trustful relationships.


## 1. Introduction

Trust is foundational for intercompany (B2B) cooperation and the possibility of information exchange builds the constraints for the applicability, effectiveness and synergy effects of enterprise collaboration. This latter is not ecologically worthwhile if partners in such networks are not prepared to exchange information and data. Besides new services, using instant messaging apps (like WhatsApp) increases the communication ways and the possibilities for interaction and collaboration. It is important to notice that the members of a virtual community are its real creators. Through their interactivity and participation on a community, they create additional benefits. To compare it with Google+, Facebook or any other community business approach, only the presence of active user makes it valuable for others to collaborate in such communities.

Firms are increasingly using networks and other partnering arrangements to accomplish their environmental goals in Germany[3]. Networks in the environmental management scientific domain are rare especially on the corporate environmental management information systems. The lion's share of existing research in this realm has focused on questions such as sustainable supply chains [1] and intercompany collaboration in so called eco industrial parks as part of the industrial ecology research [2]. However, the application of information system to support the creation of enterprise networks or to facilitate the work of intercompany cooperation is so far barely discussed in scientific research.

Trust building in the context of enterprise cooperation is one of the main questions to enable the processes of resource sharing, connections, communication, direction, and the work in temporary groups as specificities of collaboration. This paper presents an architecture to reduce the technical barriers for applicable environmental management collaboration.

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[3] The German federal government initiated several programs to increase the building of networks for reducing energy and material consumption, e.g. http://www.30pilot-netzwerke.de/nw-de/, neress.de

The proposed solution assumes that business networks already exist; partners know each other and work in projects before together. It is also important, that collaboration is one of the aims of the network. Strategies of building or implementing mutual trust is not part of this paper.

## 2. Trust Building

There are many procedures to develop trust building in enterprise networks. It is always useful to initiate connection and relationships, non-work and low-risk activities like initiating projects in small groups [3]. The communication can be separated into two aspects, the frequency and the quality of communication [4]. Frequent face-to-face interactions may lead people to better understand each other's expertise [5]. Stable and standardized roles besides clearly defined tasks are required to build swift trust [6]. Furthermore, swift trust may develop over short, intense periods of interaction in temporary groups. As social interaction and collaboration, which are necessary for collaborative environmental management, seem to be included in these trust-building processes. The main problem is to facilitate processes of connections, communication, direction, temporary groups and resource sharing at the network level. Furthermore, the processes must encourage organic growth and internal legitimacy. The importance of this approach is building a competence-based trust on both sides.

Independent of trust building, most existing enterprise networks in the German-speaking region don't use new information and communication technologies. The cooperation is still based on email, telephone and fax [7, p. 86]. Additional to the social behavioural activities of building trust, using specific technologies and be aware of the information that should be exchanged will help network partners improving the collaboration by providing own data in a network. From information systems point of view, such activities requires a data exchange by sharing data and information. It is difficult to assure companies sharing portions of their data. However, to improve intercompany cooperation's effectiveness and efficiency, data exchange is recommended.

## 3. Enterprise Network and Virtual Communities

This paper doesn't present the process of building enterprise network. It supposes that there are existing networks with more than two enterprises (dyad). Independent of business branch, supply chain and the relation between the partners (edge) is at least as high as the amount of enterprises (nodes) in the network (see Figure 1).

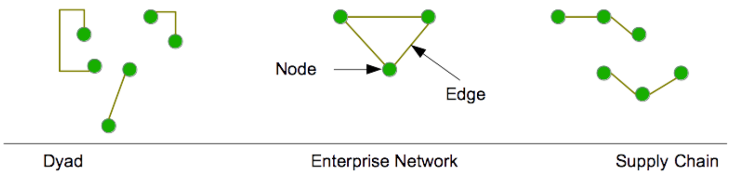


*Figure 1: Different relation types of enterprises*

Based on the existence of enterprise networks and their usual communication ways, a new communication level must be developed using an information system to manage the cooperation in such enterprise networks. The existing virtual communities provide a lot of experience that can help understanding and structuring the new way of cooperation between firms.

The beginning of virtual communities can be seen where scientists form interactive research communities that existed not on a physical campus but also on the Web [8, p. 4]. Today, we can separate virtual communities based on classification of Hagel und Armstrong [8]. Although, the possibilities and functionalities of communities are changed in the last 17 years, the kind of use is comparable and the communities' functionalities aren't any more clearly separated. In other words, communities may overlap.

The types of communities existing on the Web are [8]:

- Interest: Communities of interest are built based on special fields of people interests like travel, entertainment, IT, etc. Usual characteristic of such communities help in finding solution of a specific problem or sharing knowledge of specific topics. In addition, asking a question where different people can post answers help most people to profit from these conversations as passive user where they profit from prior discussions or questions. People may want to develop their skills in learning how to export a CSV from an excel-sheet or implement a search algorithm in their Webpage. Many communities target the interest need by bringing together a group of people who share interest and expertise in a specific topic.
- Relationship: The primary value of this sort of community is its capability to bring people together independent of their location. The ability to keep in touch with schoolmates or people you met in a conference years ago is today nothing special in social networks like LinkedIn, Facebook or Google+. As referred by Hagel & Armstrong in [8, p. 19], the communities of relationships are not based only on people with similar experiences. Rather, the relationship communities with their functions help people finding partners to stay connected with them. The functionalities of communities of interest and relationship can be merged.
- Business Communities (Transaction): There are different Web applications that provide a place for commercial interactions. Web Services like eBay and Amazon changed the kind of transaction. A peer in such communities can be dealer and consumer at the same time. How products are advertised and how people buy their products is still a changing process and it is difficult to preview how it will become in the next 10 years.
- Communities of Fantasy: The Web gives people the opportunity to come together to build and explore new worlds of fantasy and entertainment. The market of such communities provides multiple platforms with different functionalities and possibilities.

Another way to distinguish the types of enterprise networks is in the long-term goal of such networks. The first type of enterprise networks is the learning type that aims at bringing companies together to learn from each other on a specific topic. A good example of such networks is the project "30 Pilotnetzwerke" [9]. The main activities of the learning networks based on the results of this project are [9, p. 9]:

1. An initial consultation for each participant by an experienced engineer;
2. An agreement development on a common target with a time horizon for energy efficiency improvement of the network;
3. Regular meetings (four times per year) with presentations on technical and organizational issues by invited senior experts and exchange of experiences among the energy managers and
4. A monitoring of the progress and improvement of energy-related developments for each company and the network.

Characteristics of such networks include that they are well organized with support of external players like the Chamber of Commerce, regional industrial platform or governmental institutions.

The second type of enterprise networks is more related to the geographical location of an enterprise. An example of these networks are industrial parks or areas in cities where many small and medium sized companies are located. The diversity of activities in such network is big so they offer traineeship in cooperation, initiate climate protection projects, organize purchasing pool and organize street festival [10], [11]. The geographical proximity and the high frequency of seeing each other's might build a foundation to develop a new form of collaboration that doesn't exclude data and information exchange in specific realm.

## 4. Problems and Barriers

Giving the participants in a business network the possibility to interact with each other and exchange data to solve problems induces that an information system should be implemented and used in the network. However, such approach has some problems and barriers.

The barriers of an intercompany information system is similar to the barriers for an information system used in one company. In addition to the cost of buying, implementing and training, there are different problems that should be solved before and during such process:

1. Success of an intercompany information system is dependent on all partners who are part of the whole implementing process;
2. An information system in a company is always prone to changes. This will result in a more burden to the partners in sense of losing control over their work. The reluctance of change and transparency may let partners refusing the utilization of such system.

Another problem is the compatibility with the enterprises' existing information system and data structures that make the process of integrating two different information systems more complex and difficult to manage.

The presented approach in this paper aims at showing one way to overcome the aforementioned barriers. Companies will not permit any external partner to access their data because this can endanger them. It is reasonable why companies refuse software solutions where they provide data that can be accessed from external firms. Considering that every material order is an information exchange with external supplier, it is not extraordinary in business world to exchange data with external organizations. It is the question of the purpose, framework conditions and what kind of data to be exchanged. An improvement of the ways to exchange data in companies provides a possibility to handle the data exchange in business network.

The cooperation in a network should have the possibility to adapt to change. This dynamicity should be supported. A successful cooperation in a network in environmental issues presumes adopting new knowledge of environmental management and resources saving. In addition, it should take into account that companies can leave a network and a new partner can join. An information system that supports the collaboration should recognize this, especially from the data point of view. Data protection, data security and data integrity must be ensured as well.

## 5. Data Classification

To fulfill the known security standards, business software solution is usually required. Data safety is considered one of the most indispensable factor for companies. Furthermore, any adopted solution should give the possibility to exchange data. Apart from the developed trust between network partners, no firm allows other firm to access their data. The solution should allow the possibility of active data release if companies decide to cooperate on a specific matter. Thus, the company has all time full control over their data. The decision to provide data to another partner can every time be canceled.

Taking a holistic view of company data and their relevance, it needs more than the data on its own to become a secret or a relevant information for the company. In other words:

- Companies might publish data in yearly reports or for other reason.
- As mentioned before, companies already exchange data for different purposes. The order of materials, the use of consultant services and any interaction with suppliers or customers is in part data exchange (see Figure 2).

- Most data in any company are not secrets. Information about cleaning a metal surface or the used amount of any specific material are in the most cases not a company secret and doesn't endanger it.
- Data without the context of their creation have in most cases a limited value as information but it can help other companies solving problems. For example, the information of replacing a hazardous material with less dangerous one helps a company without giving further information of location, amount, etc.
- Aggregated data can be less dangerous as subject of betrayal for a company. For example, to know how many energy is consumed in a process can help another company to make a conclusion about the amount of produced articles. Aggregating data of different companies doesn't allow this kind of conclusion.

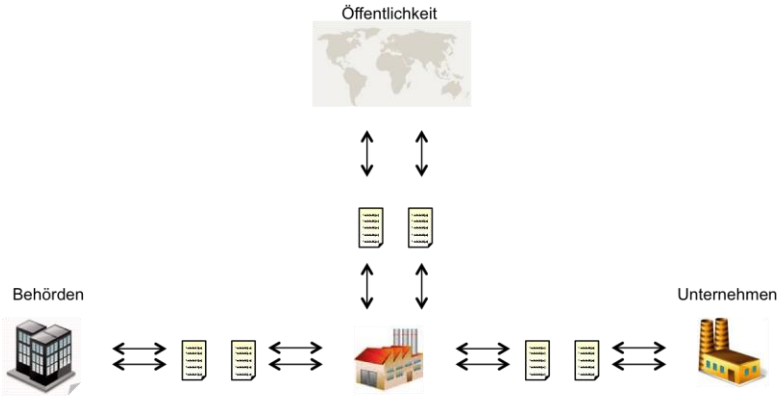


*Figure 2: Companies already exchange data*

Based on the five points above, five classes of data and information types can be defined:

1. Open data: Data that can be provided for all partners in a network. Published data can be clearly associated with the enterprise as a source of it.
2. Anonymous data: Data that can be searched by an algorithm to provide additional information for network partner. The prevented data doesn't show any context or relation to the data source or the company that provided this data.
3. Aggregated data: Information that is part of this class can be presented in an aggregated form with a link to the company.
4. Network data: Allows data to be aggregated in the context of the whole network.
5. Dyad data: Data can be made available for specific company or a group. This means that a company starts a project in a specific domain with other partners in the network and only those partners can access the data.

Based on this classification, a data model is developed to implement the possibility of providing data depending on the abovementioned classes.

## 6. Data Access Framework

An approach for a system architecture (Figure 3) that implements data components to recognize the data access is based on the aforementioned classification. Every data insert goes through the "data classifier" which adapts defined roles to classify the data. On the other hand, every data read access goes through an encryption component. The job of this encryption component is to hide the part of requested entity that shouldn't be seen by the requester based on the predefined roles.

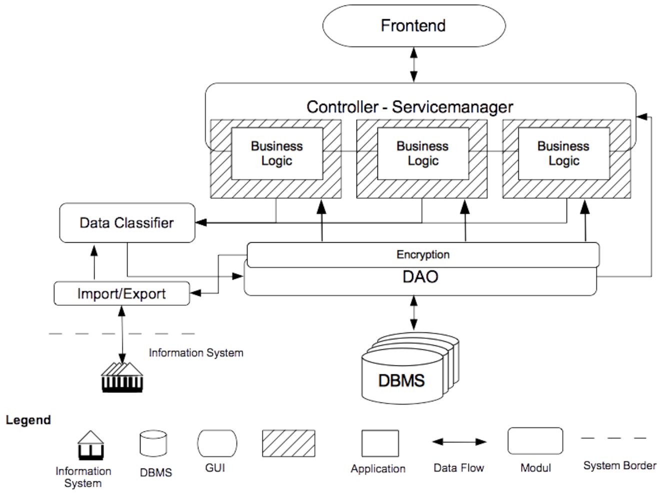


*Figure 3: The Overall Architecture*

Data that should be hided are encrypted to allow the business logic to apply calculations on the data. This makes it possible to use the data in the second layer but leaves it hidden from the frontend layer. This paper just introduce and doesn't give full details of the overall architecture.

## 7. Conclusion

Data access authorization can be granted using an information system based on the proposed classification presented in this paper. The data classification system does not only hides the information from the unauthorized users (or groups), rather it allows the access to individual services for internal calculations. A virtual community must address the needs of its members. Enterprise networks has different structures and therefore, they have different needs. An information system that meets all the needs of different networks is a hard challenge. Therefore, the aimed information system should provide basic functionalities to represent a network and communication structure that allows collaborating. This system must give the possibility to be customized for a specific network needs. The provided approach here presents one way of how data exchange in an enterprise network can be kept under control.

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# Verbesserung der Nutzerfreundlichkeit einer Simulationssoftware für die integrierte Betrachtung verschiedener Nachhaltigkeitsperspektiven in Produktionssystemen

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## Abstract

This paper depicts the design and development of an EMIS which is used for the modelling and simulation of sustainability aspects of production systems. The main intention of the development was the integration of different sustainability perspectives into a single model, which reduces the workload needed for the modelling of the production relevant entities. In this regard this contribution will shortly present the convictions that have led to the development and consequently the key features resulting from it. In addition it will highlight changes made to the software to enhance usability aspects further. Finally, it will conclude with a summary and present an outlook of future steps.

## 1. Einführung

Bereits seit einiger Zeit werden Modellbildung und Simulation zur Analyse komplexer Systeme genutzt [1]. In der Fertigungs- und Produktionsplanung stellt die Simulation dabei ein Werkzeug für Unternehmen dar, welches die genauere Betrachtung einer Umsetzung in der Produktion ermöglichen kann, noch bevor diese in den operationalen Betrieb geht. Gleichzeitig können auch bei schon laufendem Betrieb Änderungen an den Betriebsprozessen simuliert und somit auf ihre Wirksamkeit hin untersucht werden. Der Einsatz des klassischen Verfahrens dient dabei dem Ziel der Optimierung eines Produktionssystems in Bezug auf einen oder mehrere ökonomische Zielgrößen (z.B. hohe Termintreue, kurze Durchlaufzeiten, hohe Auslastungen oder niedrige Lagerbestände, u.v.m.). Diese stehen teilweise in einer konkurrierenden Zielerfüllungsbeziehung, was die bereits bestehende Komplexität noch vergrößert und dazu führen kann, dass andere mathematische Analyseverfahren nicht die gewünschten Ergebnisse liefern können (bspw. Operations Research).

In den letzten Jahrzehnten wurde verstärkt im Bereich der ökologischen Optimierung geforscht. Gerade das Interesse an Ressourceneffizienzlösungen ist aufgrund der deutlichen Korrelationen zu ökonomischen Faktoren kontinuierlich angestiegen. Dabei wurde jedoch die Integration neuer Funktionalitäten in die entsprechenden Simulations-Softwarelösungen nur langsam vollzogen. In den heutigen Simulationswerkzeugen sind die notwendigen passgenauen Komponenten kaum Bestandteil des Funktionsumfanges. Ökologische Zielstellungen werden folglich nur selten mit Simulationswerkzeugen integriert betrachtet. So sind bspw. Energie- und Stoffverbräuche pro Produktionsschritt in der Regel nicht abbildbar. Sollen beide Sichtweisen, d.h. die ökologische und die ökonomische Sichtweise, trotzdem untersucht werden, machte die Nutzung eines weiteren Softwaretools bisher zwei Modelle erforderlich [2]. Dies verursacht in der Regel zusätzlichen Kosten- und Zeitaufwand und ist daher kein erstrebenswerter Zustand. Die Betrachtung sozialer Wirkfaktoren

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wird in entsprechenden Softwarelösungen so gut wie gar nicht betrachtet [3], sondern vielmehr mit Managementmaßnahmen bearbeitet und gelöst. Durch diese Trennung gleichzeitig wirkender Kräfte gehen teilweise Wirkungskorrelationen und somit zwangsläufig Optimierungspotentiale verloren. Abgesehen von dem methodischen Neuland der Integration aller drei Perspektiven im Bereich der Produktionsanalyse, liegt dies auch daran, dass unterschiedliche Fachkräfte für die verschiedenen Bereiche zuständig sind und bei der Parametrisierung der entsprechenden Modelle helfen müssten. Werden mehrere verschiedene Werkzeuge zur Modellierung benötigt, ergeben sich darüber hinaus weitere Probleme, die die Nutzung von Simulationen in Unternehmen wiederum hemmen, wie z.B. Medienbrüche, Dateninkonsistenzen beim Austausch der Daten zwischen den Werkzeugen. Um diesem Problem zu begegnen, wurde das Konzept der ereignisdiskreten Stoffstromsimulation entwickelt, welche die stoffstromorientierte Perspektive in die auftragsbezogene Simulationssicht eines Produktions-betriebs integriert und so die umweltrelevanten Ziele mit abbilden kann [2]. Diese Methodik wurde über mehrere Forschungsprojekte hinweg zu einem Softwarekonzept entwickelt, welches in verschiedenen Prototypen umgesetzt wurde (siehe mehr unter Punkt 2).

Der Einsatz einer solchen Software ist jedoch insbesondere in kleinen und mittleren Unternehmen (KMU) nicht verbreitet. Ursache ist zumeist die hohe Komplexität der Simulationssysteme, die ein hohes Fachwissen der Anwender erfordern. Diese hohe Komplexität wirkt sich auch in der Anwendbarkeit und generellen Nutzerfreundlichkeit der Softwarelösungen aus, sodass bestehende Lösungen vielfach nicht ohne entsprechendes Fachpersonal genutzt werden können. Dazu kommen die nicht zu unterschätzenden Kosten, welche durch Erwerb und Betrieb solcher Anwendungen entstehen können. Konsequenterweise werden die Kosten durch das notwendige Fachpersonal noch vergrößert, was die Einführung bzw. das Betreiben noch unwahrscheinlicher macht.

Im Folgenden wird der Lebensweg des Stoffstromsimulators MILAN beschrieben, dessen Ziel es ist die Brüche zwischen den verschiedenen Perspektiven nach und nach aufzuheben, um einerseits den Modellierungsaufwand einer ganzheitlich nachhaltigen Betrachtung zu verringern und andererseits bestehende Wirkungskorrelation integriert betrachten zu können. Daran anknüpfend wird auf die Verbesserung der Nutzerfreundlichkeit eingegangen, indem ausgewählte Funktionen vorgestellt werden und schließlich neue Ziele formuliert werden.

## 2. Historische Entwicklungen und Abgrenzung

Im folgenden Abschnitt werden die entscheidenden technologischen Verbindungen skizziert, indem zunächst eine chronologische Aufarbeitung der Entwicklung gegeben wird. Ziel ist es, aufzuzeigen, wie der Forschungs- und Entwicklungsstand gewachsen ist und damit die Kern-Methoden der Software, bestehend aus der Modellbildung und Simulation, Stoffstromanalyse sowie der Lebenszyklusanalyse, vorzustellen.

### 2.1. Entwicklungen vor 2006

An der Universität Hamburg wurde schon früh die Nutzbarkeit von Modellen und Verfahren der Simulation auf ihren Gebrauch als Analyseinstrumente bzgl. Betrieblichen Umweltinformationssystemen (BUIS) hin geprüft. Dabei wurde als ein Resultat die Anwendbarkeit von Simulationen als Unterstützung des Stoffstromnetzansatzes als sehr empfehlenswert eingestuft. Dieser Ansatz wurde im Laufe der Jahre weiter ausgebaut und in verschiedenen betrieblichen Anwendungsfällen in der Praxis angewandt. Hierzu wurde eine Reihe von Modifikationen an der bestehenden Theorie der klassischen Produktionssystemsimulation vorgenommen. So mussten bspw., um die Stoffstromsichtweise anwenden zu können, an verschiedenen Punkten im Produktionssystem das Betrachten und Bewerten der Stoff- und Energieströme möglich gemacht werden. Dazu wurden u.a. eine Materialverwaltungskomponente und ein Stoffstrombuchungssystem sowie Funktio-nalitäten, um diese in die Produktionssystemsimulation einzubinden, softwareseitig entwickelt.

## 2.2. Entwicklungen von 2006 bis 2009

Um die Vorteile moderner Softwarearchitekturansätze nutzen zu können wurde der Ansatz zwischen 2006 und 2009 weiterentwickelt. In dem Forschungsprojekt EMPORER wurde zunächst ein Anwendungsrahmenwerk erstellt, welches als offenes Plugin-Framework EMPINIA veröffentlicht wurde. Auf diesem Anwendungsrahmenwerk und dem Konzept der voran-gegangenen Jahre wurde die Software MILAN neu entwickelt. Um Produktionssysteme in MILAN modellieren und simulieren zu können, wurde bereits im EMPORER-Projekt begonnen, die hierfür benötigten Komponenten in Form von EMPINIA-Erweiterungen zu schaffen. Diese wurden kontinuierlich um Funktionalitäten ergänzt, sodass seit ca. 2008 Komponenten entstanden sind, welche die Methodik der Simulation und der Stoffstromanalyse spezifisch für Produktionssysteme bedienen können.

## 2.3. Entwicklungen seit 2009

Anschließend an die Neuentwicklung der Software wurde diese mit Funktionen aus der Lebenszyklusanalyse angereichert. Die Einbindung von sog. Life Cycle Assessments (in der Folge LCA) erfolgte aufgrund der gewonnenen Erfahrungen in mehreren Projekten mit einem Kooperationspartner aus der Schweiz, der Eidgenössischen Materialprüfungs- und Forschungsanstalt (EMPA) (siehe bspw. [4). Die bestehende Simulationssoftware beschränkte sich zu dem Zeitpunkt darauf, Schwachstellen für eine nachhaltige Optimierung bzgl. der Produktionsprozesse von Unternehmen aufzuzeigen. Dabei wurden ökonomische und ökologische Kriterien integriert, wobei der größere Kontext, die Nachhaltigkeit, bzw. der ökologische Fußabdruck eines Produktes über den gesamten Lebensweg auf Basis notwendiger Systemgrenzen weitgehend vernachlässigt wurde. Aufgrund der gestiegenen Qualität von LCA Daten im letzten Jahrzehnt und positiven Erfahrungen aus früheren Projekten (siehe bspw. [5]) wurde die bestehende Methodik der Simulation von Produktionsprozessen mit der Einbindung von LCA-Daten bzgl. der genutzten Rohstoffe und Energiearten verbunden, um so die Aussagekraft der bestehenden Resultate zu vergrößern.

## 2.4. Abgrenzung zu in Beziehung stehenden Forschungsansätzen

Die klassischen Ansätze der Simulation der ökonomischen Perspektive von Produktionssystemen und der damit einhergehenden Output-orientierten Sichtweise sind bereits vielfach vorgestellt worden und werden hier daher nicht weiter erläutert (Beispiele hauptsächlich für die ereignisorientierte Sichtweise u. a. in [6]). Im letzten Jahrzehnt ist die ökologische Perspektive und eine ganzheitlichere Wahrnehmung stärker in den Vordergrund der Forschung gerückt worden. Beispiele für den Fokus auf die Nachhaltigkeit von Produktionssystemen in Verbindung mit Simulation sind zu finden in [7], [8] und [9]. In [10] ist darüber hinaus eine (nicht mehr ganz aktuelle) Auflistung existierender Simulationswerkzeuge und eine Statusübersicht über die Einbindung von Nachhaltigkeitsaspekten gegeben, zudem werden speziell Material- und Energie-flüsse in [11] genauer betrachtet.

Der Großteil bestehender Simulationswerkzeug bezieht allerdings den Lebenszyklus von Produkten nur unzureichend mit ein, da die Systemabgrenzung der Simulation (auf den Produktionsbereich) dies logisch verhindert (Gate-to-Gate-Fokus). Um auch Vorketten, der im Betrieb verwendeten Rohstoffe und Energien zu berücksichtigen, sind zwei Strategien zu beobachten, die teilweise miteinander verknüpft werden. Einerseits werden durch die Einbindung von LCA Daten zumindest die ökologischen und teilweise sozialen Aspekte der Vorketten mit einbezogen (siehe bspw. [12] Kellens et al. , [13] Zhao et al. , [14] Andersson et al. ) und andererseits verschiedene Simulationstechniken, bspw. ereignisdiskrete Simulation (DES) mit System Dynamics (SD) oder agentenbasierter Simulation (ABS), miteinander verknüpft, um so verschiedene Teile des Lebenswegs von Produkten in verschiedenen Detailstufen modellieren und simulieren zu können, welche dann im Nachhinein aggregiert werden. Die Verknüpfung dieser verschiedenen Methoden erfolgt aber in der Regel schnittstellenbasiert und nicht integriert in einem Modell.

Soziale Kriterien werden zurzeit bei der Simulation von Produktionssystemen kaum berücksichtigt. In Heilala et al. [15] wurden ergonomische Aspekte als Teil der sozialen Komponente betrachtet. Weiterführende Ansätze (bspw. Einbindung von Social LCA (SLCA) - Daten oder die Anbindung von Stresskonzepten) werden bisher nur selten mit in den existierenden Ansätzen berücksichtigt. Zwar haben auch die SLCA Daten in den letzten Jahren beträchtliche Fortschritte gemacht (siehe bspw. Jørgensen [16] und Benoit [17]), jedoch ist die Verknüpfung dieser Verfahren mit der Simulation von Produktionsbetrieben noch relativ unerforscht. Erste Ansätze können in [18] und [19] betrachtet werden.

## 3. Verbesserung der Nutzerfreundlichkeit der Software

In der Folge werden ausgewählte Funktionalitäten vorgestellt, die erläutern sollen mit welchen Maßnahmen die Benutzerfreundlichkeit der Simulationssoftware verbessert werden konnte. Dies erfolgte insbesondere zur Vereinfachung der Modellierung der Produktionsprozesse, aber auch bzgl. der generellen Nutzung der Software.

### 3.1. Vereinfachte Auswahl von Materialien/Einbindung von LCA Daten

Gerade bei der Auswahl bzw. Suche von einzelnen Elementen aus einer großen Menge an Möglichkeiten hat sich in der näheren Vergangenheit die sog. „string search“ als Methodik etabliert. Der Konzern Google hat u.a. mehrere Patente angemeldet, um seinen Algorithmus diesbezüglich zu schützen. Die neuerlichen Autovervollständigungsoptionen sind dabei nur eine methodische Änderung die zur Vereinfachung der Suche geführt hat. Ein ähnliches Prinzip wurde in MILAN angewandt, um eine einfache, schnelle Zuordnung von Materialien zu ermöglichen. So gibt es die Möglichkeit, LCA-Daten über die Ecoinvent Datenbank (siehe ecoinvent.ch) in das Modell zu integrieren, sodass mit der Auswahl des in einem Produktionsschritt verwendeten Rohstoffes automatisch der mit diesem Rohstoff zusammenhängende ökologische Rucksack bei der Simulation der stofflichen Gesamtbilanz berücksichtigt wird. Dazu gibt es die Möglichkeit, Materialien und Stoffe im integrierten Ecoinvent-Browser zu suchen (siehe Abbildung 1, auf der nächsten Seite).

Dieser Browser ermöglicht sowohl einfache als auch komplexere Suchabfragen nach bestimmten Rohstoffen. Je nach Auswahl ist es auch möglich, dezidiert, bspw. nach einer CAS Nummer oder nach einer bestimmten Beschaffenheit von Materialien (Eigenschaften), zu suchen, um diese dann ins Modell aufzunehmen.

Schließlich können auch sonstige Kostenflüsse, wie bspw. Abschreibungen von Maschinen oder andere Kostenarten, in derselben Modellperspektive definiert werden und gehen somit bei der Betrachtung nicht verloren. Diese werden dann in den Reports getrennt dargestellt oder, falls anders spezifiziert, einzelnen Posten zugeordnet.

Der Material-Browser erlaubt die Umrechnung von Energie- und Stoffströmen, die im Modell verwendet werden, in verschiedene Einheiten. Die zur Verfügung stehende Ecoinvent-Datenbank umfasst ca. 4000 Prozesse, was zwar schon eine gewisse Menge darstellt, jedoch in Anbetracht einer hoch spezifizierten Industrie nicht alle Prozesse mit einschließen kann. Daher erlaubt die Komponente ferner das Anlegen und Bearbeiten sowohl komplett neuer als auch vorhandener Stoffe und Materialien, um gleichzeitig die notwendige Anpassbarkeit zu gewährleisten.

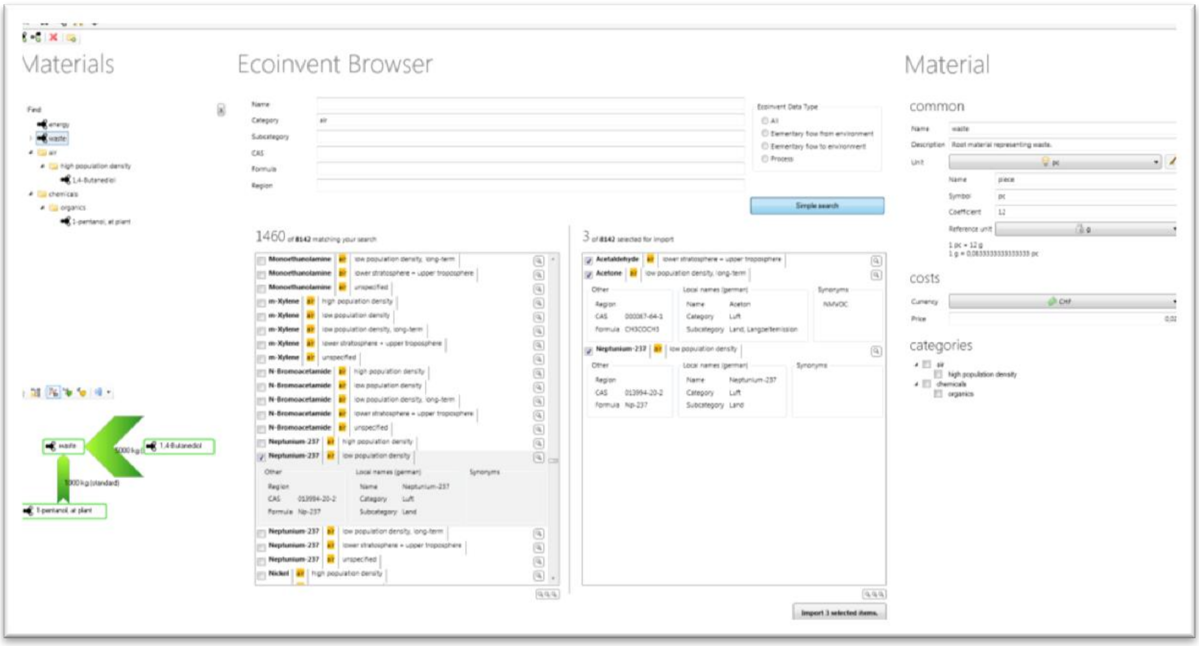



Abbildung 1: Modellierung von Materialien

### 3.2. Reduktion des Modellierungsaufwandes am Beispiel des Experimentierens

Für das Experimentieren mit einem Modell gibt es viele Einstellungsmöglichkeiten welche die Güte der Simulationsergebnisse beeinflussen. Es stehen daher Voreinstellungen zur Verfügung, die es auch unerfahrenen Nutzern erlauben sollen, schnell Simulationsläufe durchzuführen. Der Großteil der Einstellungen dient generell dazu die Aussagekraft der Simulationsergebnisse zu garantieren. Unerfahrene Nutzer könnten hier bspw. zu kurze oder unnötig lange Simulationszeiten eingeben, gleichzeitig könnten auch vorherige Eingaben, bzgl. bspw. der Aufwärmphasen, die Ergebnisse verfälschen. Grundsätzlich ist auch die Unterscheidung zwischen Realzeit und Simulationszeit zu beachten, die ein Nutzer bei der Einstellung eines Experiments berücksichtigen muss.

Durch angepasste Voreinstellungen und methodische Veränderungen der Software kann die Nutzerfreundlichkeit so verbessert werden, dass die Fülle an Einstellungsmöglichkeiten nur dann zum Tragen kommt, wenn diese tatsächlich benötigt werden. Beispielsweise kann die Anzahl an Experimenten anstelle sich auf eine Zahl zu beziehen (bspw. 10 Experimente, 100, mehr) über einen Regler (siehe Abbildung 2) gesteuert werden, der als Feedback nur einen Sicherheitswert widergibt (schwache Aussagekraft, mittlere, starke). Im Hintergrund wird dann zwar eine Anzahl durchgeführt, die abhängig von der Modellgröße, bzw. –komplexität automatisch angepasst wird, diesen teilweise komplexen Prozess bekommt der Nutzer jedoch nicht mit. In diesem Sinne können auch unerfahrene Nutzer, ohne größeres Hintergrundwissen entsprechende Simulationsstudien durchführen.

Von diesen Voreinstellungen und softwareseitigen Verbesserungen gibt es eine Reihe, die alle darauf abzielen eine Komplexitätsreduktion bei der Modellierung und der Einstellung der Simulation zu ermöglichen. Mögliche Assistenzsysteme könnten diese in der Zukunft noch weiter unterstützen und den Prozess der kontinuierlichen Heranführung an tiefergehende Einstellungen begleiten.

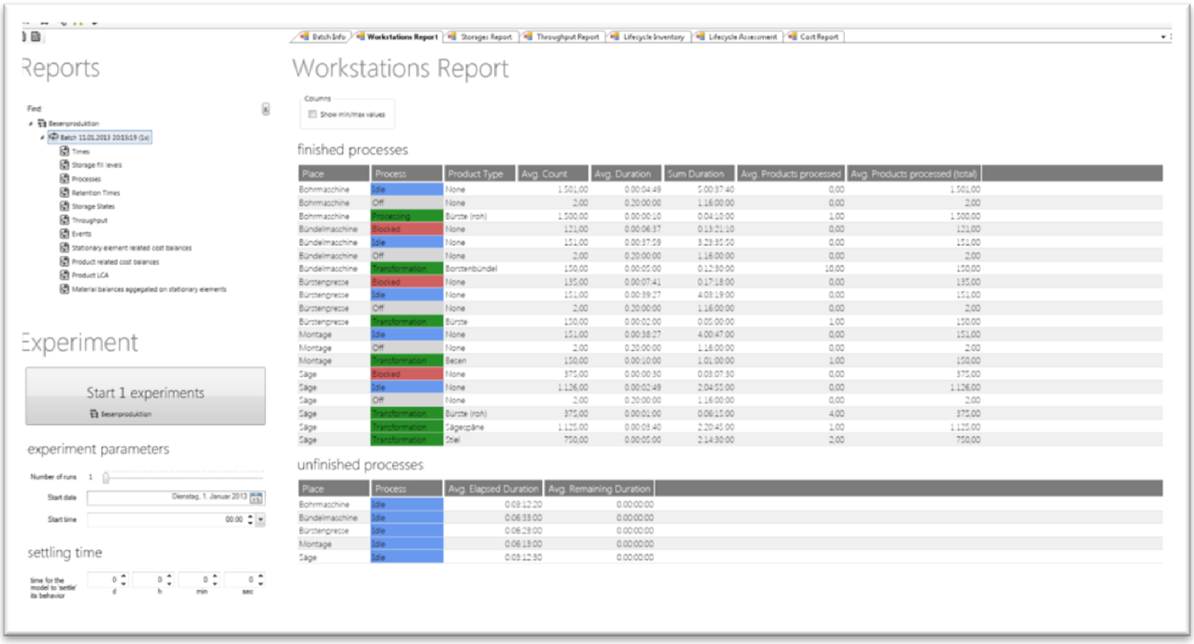
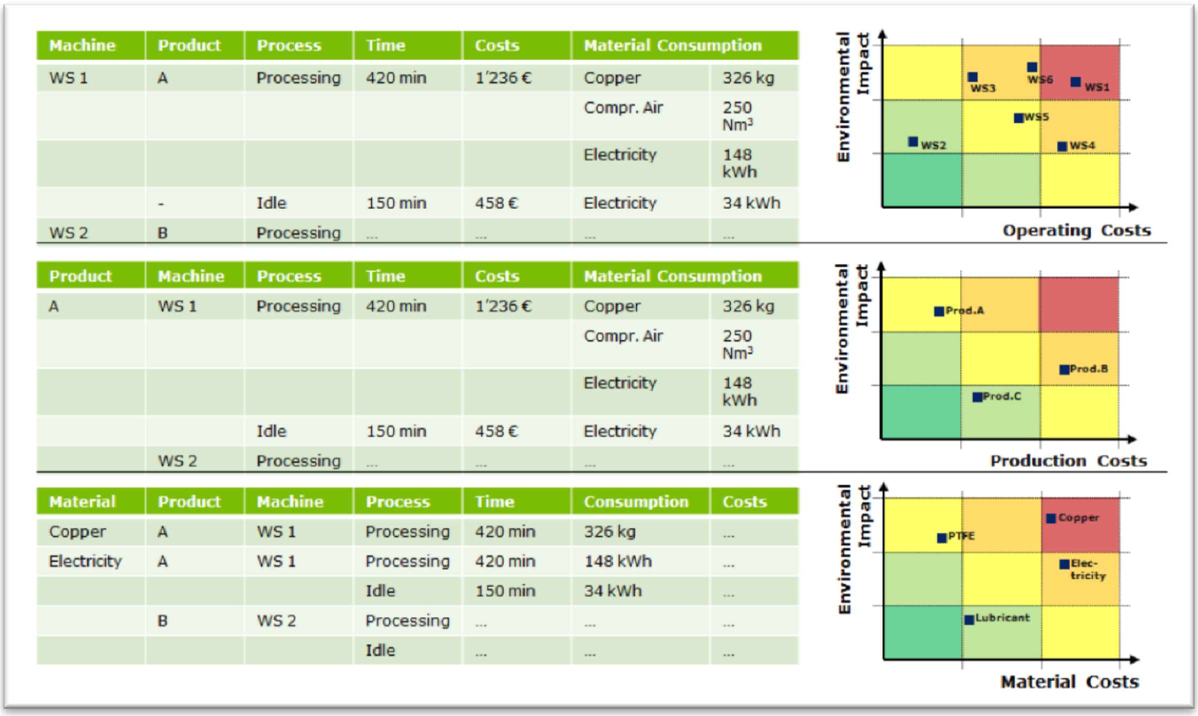



Abbildung 2: Experimentieren und Reporting

### 3.3. Verbindung verschiedener Nachhaltigkeitsperspektiven

Wie bereits angesprochen wird in MILAN eine methodische Verbindung von den Verfahren der Modellbildung und Simulation mit der Materialflussanalyse und der Lebenszyklusanalyse hergestellt. Das Ziel dieser Verbindung ist vormals getrennte Wirkungen nebeneinander betrachten zu können. In Abbildung 3 auf der rechten Seite kann man einen Vergleich der verschiedenen Kosten mit der gleichzeitigen Betrachtung der ökologischen Auswirkungen betrachten. Durch diese kombinierte Darstellung wird es ermöglicht die essentiellen Treiber schneller zu identifizieren und somit beim Experimentieren schneller auf die kritischen Elemente einzugehen um schließlich zu verbesserten Nachhaltigkeitsergebnissen zu kommen, ohne die Kosten aus den Augen zu verlieren.



| Machine | Product | Process | Time | Costs | Material Consumption | |
|---|---|---|---|---|---|---|
| WS 1 | A | Processing | 420 min | 1'236 € | Copper | 326 kg |
| | | | | | Compr. Air | 250 Nm³ |
| | | | | | Electricity | 148 kWh |
| | - | Idle | 150 min | 458 € | Electricity | 34 kWh |
| WS 2 | B | Processing | ... | ... | ... | ... |

| Product | Machine | Process | Time | Costs | Material Consumption | |
|---|---|---|---|---|---|---|
| A | WS 1 | Processing | 420 min | 1'236 € | Copper | 326 kg |
| | | | | | Compr. Air | 250 Nm³ |
| | | | | | Electricity | 148 kWh |
| | | Idle | 150 min | 458 € | Electricity | 34 kWh |
| | WS 2 | Processing | ... | ... | ... | ... |

| Material | Product | Machine | Process | Time | Consumption | Costs |
|---|---|---|---|---|---|---|
| Copper | A | WS 1 | Processing | 420 min | 326 kg | ... |
| Electricity | A | WS 1 | Processing | 420 min | 148 kWh | ... |
| | | | Idle | 150 min | 34 kWh | ... |
| | B | WS 2 | Processing | ... | ... | ... |
| | | | Idle | ... | ... | ... |



Abbildung 3: Verbesserte Vergleichsmöglichkeiten durch Verbindung von Perspektiven

# 4. Zusammenfassung und Ausblick auf mögliche zukünftige Entwicklungen

## 4.1. Zusammenfassung

Die Simulation durch Software stellt bereits eine Vielzahl von Ansprüchen an mögliche Nutzer. Dabei kann man bemerken, dass je komplexer ein System ist, umso mehr Fachwissen erforderlich wird, um die gewünschten Ergebnisse zu erzielen. Gerade wenn es darum geht ganzheitliche Ansätze zu verfolgen ist eine Komplexitätsreduktion ein Muss, um es Nutzern zu ermöglichen in angemessen Zeiten Studien bzgl. ihrer produktionsrelevanten Fragestellungen durchzuführen. Die hier vorgestellten Mechanismen stellen dabei nur einige softwareseitige Anpassungen dar, welche dabei helfen sollen dies zu ermöglichen. Gerade im Bereich von BUIS ist ein Fokus auf Benutzerfreundlichkeitskriterien sehr wichtig, da die Akzeptanz solcher Systeme zu großen Teilen davon beeinflusst wird. In der Folge werden Ausblicke gegeben, welche zukünftigen Anpassungen es noch geben könnte.

## 4.2. Parametrisierung durch Einbindung mobiler Endgeräte

Eine weitere interessante Entwicklung ist die mobile Erfassung von Produktionsdaten, die für die Parametrisierung der Produktionssystemmodelle benötigt werden. In diesem Bereich werden vom Studiengang Betriebliche Umweltinformatik an der HTW Berlin mehrere Projekte durchgeführt. Unter anderem wurde eine EMPINIA-Komponente entwickelt, die die Synchronisation der mit den mobilen Endgeräten erfassten Daten über eine Middleware erlaubt (vgl. [20], siehe auch [21]). Mithilfe einer weiteren Komponente, wurde es bereits ermöglicht, die mobile Datenbeschaffung zu planen und beispielsweise Begehungspläne zu generieren. Dies kann zur Unterstützung der Modellierung und Verifizierung verwendet werden. Darüber hinaus könnten mobile Endgeräte wie beispielsweise Smartphones und Tablet-PCs zum Monitoring autark ablaufender Simulationsprozesse eines Simulationsservers eingesetzt werden. Diese Ansätze könnten auch zur Erfassung simulationsrelevanter Daten für MILAN genutzt werden, was Medienbrüche weiter reduzieren könnte und die Modellierung noch vereinfachen würde.

## 4.3. Ausarbeitung der sozialen Komponenten

Die Abbildung und Beachtung des Menschen als integralen Bestandteil der meisten Produktionssysteme beschränkt bis dato noch auf eine simplifizierte Ressourcenbetrachtung. Erst letztes Jahr wurde dabei vom VDI ein neues Datenblatt bzgl. der Abbildung des Menschen in der digitalen Fabrik herausgebracht [22]. Zurzeit wird in MILAN die Ausarbeitung von Komponenten abgeschlossen, welche es in der Zukunft auch ermöglichen werden Produktionssystem auf ihre Verträglichkeit und Wirkung auf die in ihnen aktiven Menschen hin zu prüfen. Diese Überprüfungen könnten weiter dazu führen die noch immer existierenden getrennten Wahrnehmungen zwischen ökonomischen, ökologischen und sozialen Wirkungen weiter aufzuweichen, mit dem Ziel die Akzeptanz, auch von Nutzern, dieser Softwarerichtung weiter zu verbessern.

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# GIS-Based Emission Analysis Using Car-Borne Sensor Data

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## Abstract

The concept of Extended Floating Car Data (xFCD) allows to analyse traffic-related $CO_2$ emissions by reading out electronics of cars. In urban environments, $CO_2$ peaks caused by traffic congestion or inept traffic infrastructure are of special concern. This paper gives an overview of GIS-based methods and workflows that can be applied to xFCD in order to appropriately detect those emission peaks. Based on literature and former studies in related fields, three methods are introduced and applied in a case study to investigate their viability. The results suggest that two of three methods are able to detect these kind of spatial patterns even though the data source is restricted in terms of amount and quality. Furthermore, the paper researches the potential benefits that xFCD-based information products might provide for urban planners in climate protection. Expert interviews with pertinent communities are conducted to gain a well-grounded basis for an assessment. Results of those indicate that the factual need of this information does not yet exist and that according information products only conditionally provide valuable benefits at the moment. The work in climate protection rather focus on projects that address emotional aspects in order to change the mobility behaviour of people. Nonetheless, future legally binding guidelines might also require exact emission quantifications. The concept of xFCD could serve those requirements.


## 1. Introduction

The worldwide amount of cars has grown over the last couple of years to approximately 1.1 billion of cars on the road today. This number is predicted to double until 2030 [1]. Nearly every kind of motorized transportation encompasses the combustion of fossil fuels. It is required to produce energy to be transformed into motion [2]. That is why cars are considered to be major sources for the global air pollution leading to manifold negative effects on the environment and the human health [3].

One of the critical pollutants produced by fossil fuel combustion is carbon dioxide ($CO_2$). Although this product is not considered as harmful to human health, $CO_2$ is the principal gas for the greenhouse effect. It contributes to the global climatic change and causes an increase of average temperature [4]. A dominant sector of carbon dioxide emission is transportation and traffic, which globally accounts for 23 percent of the total amount of $CO_2$ from fossil fuel combustion. This leads to a share of 15 percent in overall greenhouse gas emissions [5]. In Germany, every citizen produces around 11 tons of $CO_2$ per year on average whereas 1.56 tons of $CO_2$ originate just from the motorized individual transport, excluding modes of transportation such as train and airplane [6].

In the last decade, the rising worldwide attention of the critical issue ‘climate change’ triggers new international and national guidelines and directives. They have the goal to reduce carbon dioxide emissions in the long term. Furthermore, automobiles became much more efficient in terms of fuel combustion and energy efficiency. But not only the car engine technology improved, also new technologies on the car-related hard- and software market have been developed. The term Floating Car Data (FCD) refers to data being collected (continuously) by single or a fleet of vehicles which can be considered as a distributed network of sensors. This concept was originally designed and

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developed to build an embedded traffic management system that determines the average travel time in parts of the road network [7]. With the technological progress in positioning and communication systems such as GPS, GSM and GRPS, appropriately equipped vehicles are able to act as moving sensors across the road network. They collect data of the car's position and thus also of the car's velocity and direction. Beside the speed of the vehicle, modern bus systems like OBD-II and CAN are also able to provide a more detailed range of other operating and switching data in digital form, basically sensoring the electronics of the car. These data refers to as Extended Floating Car Data (xFCD) and includes for instance information of the car's assistance, light and warning systems [8]. Furthermore, the electronics of the engine can be accessed as well. The MAF sensor measures the amount of absorbed air in proportion to the consumed fuel. This allows to estimate the car's fuel consumption. Given the fact that carbon dioxide emissions are directly proportional to fuel consumption [9], the concept of xFCD enables the collection of data that can be used in an environmental context as well, e.g. for carbon dioxide emissions related questions and problems.

## 2. Problem

Traffic emission estimates have been used to allow decision makers to manage regional air quality effectively [10]. But previous emission analyses were mostly conducted at a small scale, usually on regional or national levels. However, greenhouse gas mitigation efforts require to improve quantification of emissions in order to create emission baselines, verify emission trajectories and to identify efficient, economically viable mitigation options [11]. So the quantification of $CO_2$ at a fine space and time resolution is emerging at a critical need in carbon cycle and climate change research [9]. There have been efforts to break correspondent analyses down to a larger, mostly urban scale [12, 13]. But the results are considered as sensitive since their reliability is strongly related to the data on which the emission models are based. The mapping of vehicle emissions at fine scales is mainly challenging due to data limitations [13]. Former studies used a top-down approach in which simple emission factors like population or totally consumed fuel were disaggregated to the areas of interest.

The concept of xFCD enables spatial referencing of real, non-modelling based fuel consumption data of vehicles, and thus also spatial referencing of emission pollution at much finer scales. Nevertheless, very little is known about according emission analyses based on xFCD data and spatial analysis concepts [14]. This car-borne sensor data has certain specifics and constraints that need to be addressed in spatial analyses in order to produce valid results. On the one hand, these results might be able to leverage decision making in local traffic management in order to reduce the impact of $CO_2$ as a greenhouse gas. On the other hand, it can serve as the basis of according information products which might help to enhance the public work of traffic-related carbon dioxide emission.

While former research claims these kind of products for enhanced decision making in the transport sector of climate protection, very little is known about the factual potential benefits of xFCD-based information products such as $CO_2$ maps for urban planners. Furthermore, so far it is an uncertainty in research if local planning authorities have the actual necessity of these information.

## 3. Research Questions

In order to provide fine-scale emission analysis to detect $CO_2$ emission peaks, it is necessary to spatially analyse the car-borne sensor data in a valid way. In that context, this paper tries to provide answers to the following research question: *"What methods and workflows are appropriate for a spatial analysis of automobile sensor data in order to assess local peaks of $CO_2$?"*

The results of those analyses support the establishment of information products such as $CO_2$ maps and statistics. To be able to assess the additional benefits of these information products for urban planners in the context of climate protection, this work also raises the hypothesis *"Car-borne sensor data based information products provide additional benefits for communities and urban planners in climate protection and emission reduction."* To either reject or accept the hypothesis, the potential benefits for two aspects of the urban planners' work are assessed: the quantification of $CO_2$ emissions and the public work and awareness raising.

## 4. $CO_2$ emission peak analysis for the city of Münster

To answer the research question, a case study for the city of Münster is conducted, using xFCD from 'enviroCar'. The enviroCar platform was developed in the framework of a student's project at the WWU Münster (Westfälische Wilhelms-Universität) in cooperation with the open R&D network 52° North. This citizen-science-driven project aims at supporting urban planners in climate protection and traffic planning by providing a freely available xFCD source. Based on that data, the case study proposes three different GIS-based (Geographic Information System) methods and workflows that can be applied to xFCD: a statistically driven hot spot analysis, a road segment based emission analysis and a density analysis of top emission locations. Because comparable spatial analyses concerning these exact matter have not been applied yet [14], the selection of methods is based on literature of related studies as well as on studies which have been performed at a different scale or based on a different input data. The spatial analyses are implemented using the Esri software ArcGIS 10.1.

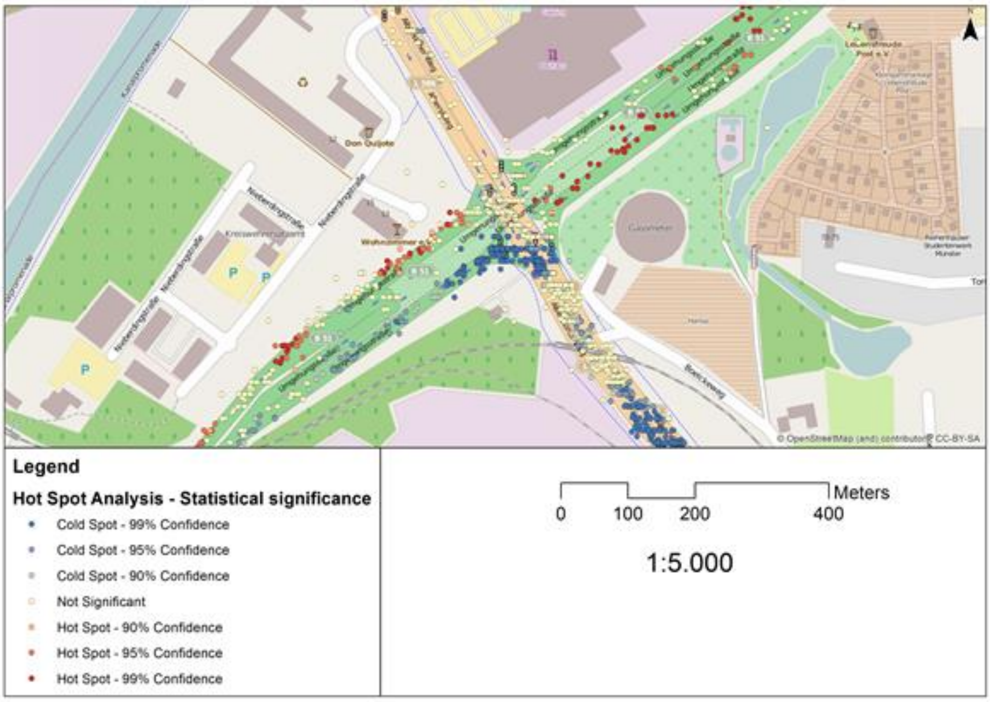


*Figure 1: Result of the Gi* hot spot analysis – showing logical differences in $CO_2$ emissions at a highway exit.*

Figure 1 exemplary illustrates results of the hot spot analysis at a federal highway exit, including according on-ramps and exit lanes. The used algorithm, the Gi* statistics, calculates the statistical significance of every measurement feature of the input xFCD to be either a hot spot, a cold spot or a statistical not significance measurement [15]. To do so, every feature is evaluated according to the similarity of high or low values in his neighbourhood, which was defined as 40 meters. It can be seen that on-ramps are dominated by $CO_2$ hot spots while exit lanes are dominated by cold spots. The federal highway itself is rather populated with not significant measurements. Within the context of real world traffic conditions, these observations might indicate reasonable results because cars usually accelerate on on-ramps and slow down on exit lanes.

For the GIS-based density analysis, the top ten percent of the xFCD data set for the city of Münster were filtered. In a next step of the workflow, the density of those locations were analysed using the KDE algorithm (Kernel Density Estimation). Figure 2 shows an excerpt of the results, highlighting the detection of $CO_2$ peaks which were caused by speed bumpers. So the analysis can be linked to real world traffic infrastructure. That insights might be a chance for traffic planning authorities in order to create a sustainable traffic infrastructure in the future, or to rebuild the existing infrastructure.


*Figure 2: Detection of local $CO_2$ peaks according to the density analysis (left) and the real situation, showing speed bumpers as the cause for the peaks (right).*

The presented results might deliver valuable information about the degree of sustainability of a city's traffic infrastructure as well as enable the detection of local emission peaks. However, there are several issues regarding the viability of those analysis: missing map matching of xFCD leads to impracticality of results in the neighbourhood of bridges and bigger roads with more separated lanes. Map matching describes the process of aligning a sequence of observed user positions with the road network on a digital map [16]. Furthermore, xFCD is collected in defined time intervals which leads to the issue that faster vehicles produce less data on the same stretch of way than slow cars. This influences the results because high emission values tend to be underrepresented in the calculation.

Among others, those main issues have the strongest influence on the road segment based analysis where firstly xFCD measurements were collected in 10 meter buffers around a road segment (road network data source: OpenStreetMap). As a second step, the mean of those measurements per road segment is calculated and re-assigned to the road. However, due to the given issues, this concept is not considered as an appropriate tool to detect local $CO_2$ peaks with xFCD.

## 5. Assessment of potential benefits of xFCD-based information products

The analyses shown in Chapter 4 deliver certain results which can be used for the creation of information products like maps and statistics. Those products might support the work of urban planners and environmentalists in climate protection. On the one hand, they might support the detection of local emission peaks. On the other hand, they might help to raise environmental awareness among citizens, and to leverage communication among deciders and stakeholders. To evaluate the potential benefit for climate protection planners, four expert interviews are conducted. The interview partners are a selection of urban planners and environmentalists of public authorities and climate protection related non-profit organizations in Germany. The concept and the guideline of the conducted expert interviews is focusing on to two main aspects: the potential benefit of xFCD-based information products for communal planners in emission modelling, and the potential benefit of those in the public work and awareness raising in the process of climate protection related $CO_2$ reduction. Accordingly, the results were grouped in two sections.

The first one enlightens the status of emission models in the work of communities. It is shown that the importance of such models is mostly restricted to the use in climate protection plans. Beyond that, the quantification of $CO_2$ emissions is constantly taken only as coarse evidence to prove the necessity of measures which fight emissions from the transport sector. Besides, the georeferencing of emissions is neither a topic so far nor planned for future projects. The communities tend to focus on starting projects that address the modal shift. Here, the goal is to totally avoid car driving and to leverage modes of transportation like going by food, by bicycle or by train. Measures that address the $CO_2$ reduction based on traffic infrastructure concepts are not planned explicitly. Since this is the assumed number one mitigation measure at which xFCD-related information products aim, the additional benefit of those is seen critically by the experts. Moreover, there are more disadvantages in the process of xFCD-based information products: the necessary data acquisition is considered as too cost intensive and time consuming. Since the concepts of communal emission monitoring intends to create time series in order to see the temporal change of emissions, several data acquisitions would be necessary, and thus requiring an even bigger financial and time effort. Although potential benefits were named by the experts too – mostly highlighting the opportunities of real data such as model validation – the conclusion is that xFCD-based information are at the moment not creating additional benefit for planners in the field of climate protection related emission modelling.

The second aspect of the results is concerning the potential benefits of xFCD-based information products in public work and awareness raising of the topic. Here, the experts stress the general importance of public work and communication, which intends to lead to a change of mind and an increased consciousness of the issue. However, the evaluation of potential benefits from xFCD are cleaved: on the one hand, the communities stress the benefits of maps showing the actual $CO_2$ emissions and the opportunity to positively influence the mobility behaviour. On the other hand, the communities highlight the complexity of the topic and doubt that $CO_2$ maps have the potential to communicate that topic. Therefore, the strategy of communities is more focusing on the emotional aspects as well as raising incentives for $CO_2$ reduced mobility behaviour.

## 6. Conclusions

This paper presents the concept of Extended Floating Car Data and evaluates its ability to enhance decision making of urban planners in climate protection. The presented case study proposes three different GIS-based methods and workflows. As shown, two of those methods (a, hot spot analysis and b, data extraction and density analysis) lead to largely valuable results, while the applicability of the third method is lacking due to missing map matching and the inconsistency in the xFCD data acquisition process. Although, compared to other emission models and methods, xFCD generally provides the means for fine-scale emission modelling. The paper shows that GIS-based methods might allow to appropriately analyse the data to draw conclusions on local emission peaks, as the example of speed bumpers shows (cf. Figure 2).

Nevertheless, this concept is not yet adopted by communities that are dedicated in communal climate protection. Their strategy focuses more on a complete avoidance of $CO_2$ emissions in traffic planning than on the mitigation of existing emissions with a smarter traffic infrastructure. However, social research amongst groups that have a different focus in their work, for instance traffic planners, might lead to different results.

In the future, there is the need to research the usability of xFCD in emission modelling. xFCD has the power to serve as an advanced data source for car-based emissions, which might feed bigger emissions models that also consider several other $CO_2$ sources like aircrafts and industrial plans.

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# Telemetric Transport Mode Validation

Alexander Sandau[1], Daniel Stamer[2]

## Abstract

This paper introduces a model for the validation of transportation modes by processing sequences of geospatial data in a telemetric fashion. This deals with a validation problem, if a customer is in an specific transportation mode or not. In order to derive a model that is capable of such a task, we set up a web-based architecture, which has a central HTTP server and a SQLite database at its heart. Several mobile clients (we are mostly targeting smartphones) will gather geospatial positioning data via GPS satellite, connect to the central server and upload the recorded data sets. The server will hold a stack of the recorded geospatial data and analyse it in order to make an attempt in validating the used transportation modes. The validation process is based on comparing the plan data from the superordinate traveller information system, which the customer used before, with the recorded data from the smartphones. For the purpose of distinguishing between public and individual transportation and to increase the validation accuracy, it is vital to consider data sets from other travellers (as in from other sensors/smartphones). The results from the published work will be implemented in a next-generation traveling information system (nTIS), which is embedded in the *Schaufenster Elektromobilität* project *IKT-Services* in *AP 7000 – Kundenorientierte Mobilität*. The implementation will be tested and evaluated in the context of said project. The GPS recording capability will be implemented within the guidance and assistance functionality of the mobile application. The validation method will be part of the nTIS server application.

## 1. Motivation and objective

The mobility of the future has a lot of demands and challenges. Through the continuously growing population and wealth we suppose that more and more people become travellers [1]. To satisfy the growing demand for mobility it is critical to design a sustainable mobility infrastructure, which is able to satisfy the needs of the many.

Mobility management is understood as the concept of providing travellers with information and incentives to converge towards a sustainable infrastructure for mobility. The main methods are prevention, reduction and improvement of traffic to create an efficient and more environmentally and socially acceptable mobility for everyone [2]. This is generally achievable by raising the share of public transportation and lowering individual, motorized mobility through the provision of incentives or customer-oriented information on the (especially environmental) sustainability of each individual's mobility. These methods can be delivered by complex next-generation traveling information systems (nTIS), which will be capable of planning trips, providing assistance during a trip and raising sustainability awareness by analysing mobility behaviour on a personal scale individually for each traveller [3].

Kramers [4] conducted an empirical analysis and evaluated modern traveling information systems. The evaluation states that all of the compared systems are absent of critical features or only equipped with a limited extent of said features. This conclusion substantiates when looking at sustainable aspects of mobility. State of the art traveling information systems are not able to provide their users with enough information on the extent of the environmental impacts of their personal mobility. In order to raise the sustainable awareness of travellers, it is vital to inform the

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travellers on the effects and consequences of their personal mobility and especially their choices of transportation modes.

The project IKT-Services aims to develop a nTIS, which meets the requirements specified by Kramers [4] to overcome this lack of sustainability awareness. The system will provide functionality to track modal choices of a traveller, analyse and summarize his mobility behaviour and deliver reports on the ecological, environmental and social impacts of his travels. The customer access and guidance is enabled through a mobile application. In order to realize this concept, it is indispensable to come up with a model to use sequences of transmitted geospatial data to extract certain meta-characteristic features from it and hence enable telemetric transportation mode validation.

The objective of this work is to generate a system for the validation of a transportation mode by using information from the nTIS, the smartphones GPS sensor and additional data from open information services such as OSM.

## 2. Related work

Generally, a lot of work is done in detecting the transportation mode (subfield of activity recognition), which is usually based on the use of a smartphone's GPS or accelerometer sensor or a combination of them. The accelerometers have the advantage of a low power consumption and a high density of measures per second, in which the GPS sensor provides the context of a person. Most studies use smartphones as sensor, because they have a large market penetration, are easily programmable and most of the time they are held on the person (cf. [5]). In the past, special sensing platforms were used. One relevant part of the validation is the detection of a transportation mode. In this case we analysed the work done on detection to derive the approaches for the work on validation. The table below list some of the relevant work in transportation mode detection, which focuses on the application of the previously introduced smartphone sensors.

| Author | Information base | Objective |
|---|---|---|
| Hemminki et al., 2013 [5] | Accelerometer, conjunction of sensors possible | Tracks the acceleration during travel time and records an acceleration pattern, which is typically unique to a certain type of vehicle |
| Kjaergaard et al. 2011 [6] | Accelerometer and GPS sensor | Separate motorised transportation from stationary mode |
| Stenneth et al., 2011 [7] | GPS pings from smartphone and vehicle | Combined the GPS sensor data provided from the user with GPS data provided from the vehicles of the public transport |
| Reddy et al. 2010 [8] | Accelerometer and GPS sensor | Use of decision tree and first order HMM classifier based mainly on GPS speed for detecting motorised transportation |
| Kim et al. 2010 [9] | Accelerometer | Detect stationary mode trough the variance of the accelerometer sensor |

*Table 1 Relevant work for transportation mode detection*

The detection of a transportation mode is not part of this work. The transportation mode is pre-defined by the traveler, because the traveler selected a specific route in the nTIS before. Hemminki [5] evaluated the approach in an android application to motivate people to reduce their CO2 footprint. They also mentioned that different smartphones could influence the precision through different sensors of different quality.

## 3. Use case

The telemetric transportation mode validation will be implemented in a next-generation traveling information system (nTIS). This system is currently under heavy development and part of the German national project landscape Schaufenster Elektromobilität. It is located in the project IKT-

Services (IKTS) under AP7000 Kundenorientierte Mobilität [10]. The goal of this work package is to create a web-based traveller-oriented application, which will not only enable the traveller to plan multi-modal mobility (pre-trip), but also provide context-sensitive support along the actual travel (on-trip) as well as reporting summaries after completed trips (post-trip). The system will feature various techniques to implicitly enhance (environmental and social) sustainability of its user's mobility. A key requirement to enable context-sensitive assistance and attractive incentives on the way to a more sustainable mobility is an accurate estimate of the utilized transportation modes. A concrete use case is to observe and validate, whether the traveling person is taking the bus as planned or not. This can be abstractly seen as a navigation system for public transport. Furthermore it is possible to calculate exact values for the end-user reporting. The work introduced in this paper attempts to meet the requirements of the travel assistance for transport mode validation needed in the work package AP7000.

## 4. Design decisions

### 4.1. Design

In the context of the previously described use case, the validation of a used transportation mode (based on a sequence of geospatial data) deals with a validation problem. This problem consists of different likelihoods and probabilities on whether or not a certain transportation mode has been used to record the analysed data. In consideration of the superordinate research project (IKTS) we have an assumption of the used transportation modes in a journey. The assumption is based on a chosen traveling option of a customer, who has explicitly started the route. We divided a route in connections, each connection is separated by a switchover of a transportation mode. The connections consist of several transportations, each switchover of a transportation is a stop. The transportation contains scheduled arrival and departure times and actual (real time) arrival and departure times.

The main use case is to observe if a traveller is in the proposed transportation mode and vehicle. Through the nTIS we know the departure and destination of the travellers. This is basically separated in two dimensions, time and position. So we are able to validate these two dimensions. In consideration of the classification of a journey we can validate different positions and timestamps. In principal, we have to validate if the person is really "on-trip". Through incoming GPS signals from the smartphone, it is possible to detect a general movement and to determine an "on-trip" state. If no GPS signals are arriving, the customer doesn't want to be assisted or the smartphone is offline, then no validation will take place. For our test application we imply, that a customer is on-trip and sending GPS signals to our backend.

The GPS signals from the customer are aligned with the data from the nTIS on a central system. First we compare the dimension of time. The first GPS signal should arrive at our backend in a time period close to the departure time. The position should also be in a specific range, since the latitude, longitude and accuracy values have a specific calculated distance to the departure stop of the journey. In relation to nearby signals with a relative minimum distance and time, the GPS signal is selected and compared to the transport stop. In this approach we selected the GPS points, which are in a 15 second range to the departure time. In the distance dimension we include points, which are in a radius of 15 meters plus the average GPS accuracy (15 + average accuracy). On every transport stop it is possible to validate the transportation mode, especially in public transportation, where there are a lot of validation points. Walking and biking are much harder to validate, since it is necessary to validate the trip via a public router. Even so the customer can take another route to the destination. In this case the minimum limitation of the distance and time period for validation should be extended, although it cannot be granted to be adequate. In locations the customers knows well, there might be a preferred route, which could differ from the recommended one. The validation of a car trip is possible when observing the changes of street types. At these points we divided the connection in transports with "stops" (departure and destination). Therefore, the time range for validation should be extended, because each person is driving at a different velocity and the times of changes are fixed in the nTIS.

As mentioned above, the guidance through the application must be activated. Relying on that, there are two possible cases, which can occur. The users are following the selected route or not. In case the customer is not following the route, the guidance application has to intervene. The detection of an aberration is done by detecting the distance of the last GPS point and the next stop. If the distance between the next stop and the latest GPS signal does not decrease or even grow, the user is on a wrong way. This distance is not simply the air-line, since it has to be calculated by a router like Google Maps for any specific location. Also, there has to be a threshold in which the GPS signals can diversify. Nevertheless, the calculation of the distance between GPS point and location of the next stop for every incoming GPS point is very time consuming.

Additional to the above comparison, some rudimentary checks are implemented. One part is the validation of the GPS signal gathered from the smartphone with an online map service like OpenStreetmap (OSM). A comparison of the route way with the street type from OSM is done, e.g. if the user is on a highway or railroad.

In one of our first attempts we recognized that there is an inaccuracy in the GPS data between high-end and low-budget GPS sensors in smartphones (cf. [5]). This was manifesting as we recorded identical routes with different types of smartphones. Cross-checking the smartphone GPS sensor data from several people can increase the validation statement of the transportation mode. Especially public transportation modes with a lot of passengers (and a lot of GPS signal data) promise to return valuable results, which can also aid in the positioning of the vehicle.

### 4.2. Implementation

For development and testing we set up a relational database based on SQLite and a web-based backend developed with Ruby on Rails. The recorded data from a smartphone GPS sensor features a unique identifier (integer) for every measured point and a consistent device identifier and route title to group these points (varchar 255). The actual data consists of latitude and longitude values with an estimated accuracy guess (decimal), a sensor timestamp at which the data has been recorded and an insertion timestamp at which the data set has been saved on the telemetric server side (datetime). Also included are speed and bearing (decimal).

As second step we developed a rudimentary mobile Android application. The purpose of this application is to globally position the mobile host device via the built-in GPS sensor and to transmit the observed position via HTTP to the web-based backend server (described before). The mobile application is able to start and stop the GPS observation in consideration of the trip context. In addition it is possible to set the observation interval in steps of 5 seconds up to 30 seconds. The Android SDK utilizes an easy way to use the data from the GPS sensor and is automatically initiating the data transfer to the backend server. Later this rudimentary application should be replaced by the application from the IKTS research project. The positioning is necessary for the traveller guidance and assistance, but it is not obligatory.

First we tracked basic some routes to check the functionality of the prototype. Next we travelled via various modes of transportation and recorded the generated geospatial data. These journeys were simultaneously planned in the nTIS, giving us the stops and switchovers of the trip. Afterwards the relevant data sets from the nTIS were selected and exported for developing and testing of the validation process.

### 4.3. Visualization and evaluation

The processing in R is done with the support of the following libraries "RSQLite, rgl, ggmap". First we visualized a cube with the dimensions latitude, longitude and travel time in seconds (Figure 1). Most of the trips started at the same point, the University of Oldenburg. The lines in pink indicating, because of the greater distance between the points, that these were routes with higher speed (motorized). The blue line in the centre of the cube, which is almost parallel to the travel time axis, contains some green points. This route was recorded from two separate smartphones, which were in the same transport medium. The points are very close and feature a low speed, which indicates that this route was travelled on foot.

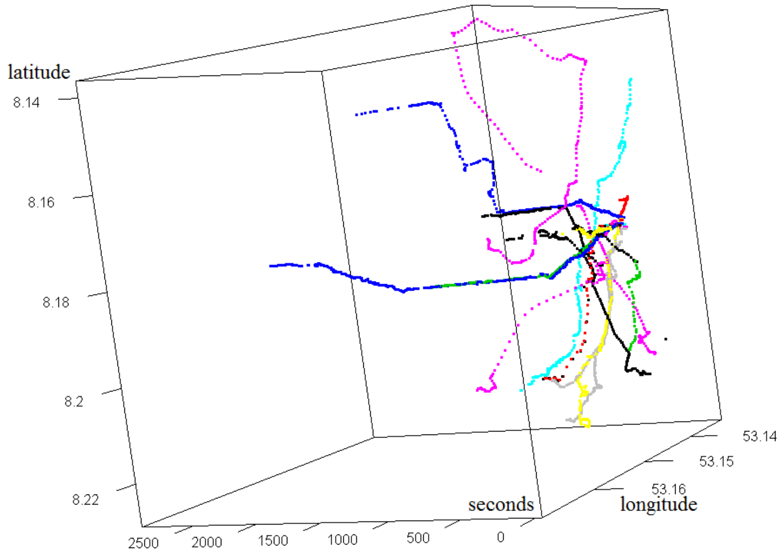


*Figure 1: Sample visualization of different routes*

In Figure 2, a sample route was taken and exemplarily visualized. The red dots are the stops (and switchovers) of the trip. The blue squares are GPS pings from the smartphone sensor in a radius of 15 meters. The green triangles are GPS pings, which are in a 15 seconds time range of the departure time. Multi-modal trips with bus sub-connections as shown below, indicate that the time dimension is not the best attribute to measure. The distance is much more meaningful, but the combination of both, the distance and time dimension is the key to validate the transportation mode.

The trip contains 17 stops or switchovers and 482 sensor pings from the test user. The average accuracy is 18.88 meters. 79 of these points are in range to a stop of 15 meters + the average accuracy (around 34 meters). In a 15 second time period 172 points are relevant for validation. 34 of these points conform in the dimensions of time and distance. On 17 stops there are 34 pings, which meet the requirements of the validation process. This leads to a validation rate of 2. It is significant that the test user is in the pre-selected transportation mode for this section of the route.

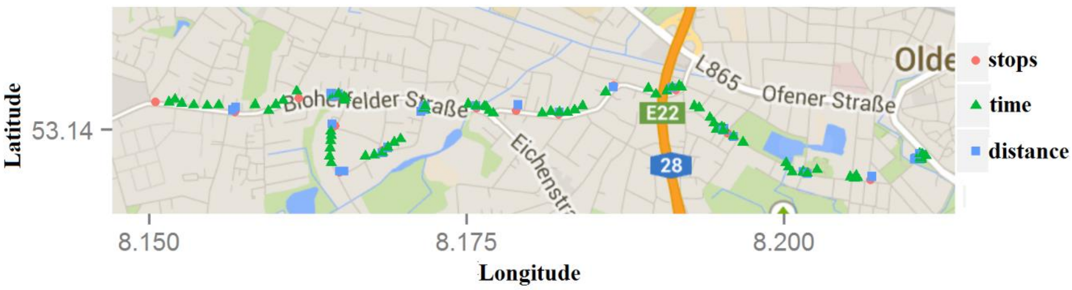


*Figure 2: Validation of stops*

## 5. Privacy

In terms of the validation of transportation modes it is not necessary to save the GPS points. It is sufficient to process the data stream as it comes in. Nonetheless, the design of a privacy concept is not part of this paper nor the superordinate research project (AP7000). A possible solution is the use of a disclaimer to increase transparency, in line of “Which data is collected and what is done with the data?”.

## 6. Conclusion

The validation is very important in terms of the proposed superordinate research project, but any real-world deployment of continuous transportation mode validation on smartphones requires that the detection has minimal impact on the operational time of the smartphone. A possible solution is to activate the GPS signal recognition only in specified intervals (near to upcoming stops/in a specific time range). The transmission could be done as batch job, which would be capable of transmitting whole sets of pings. Statistical methods such as interpolation could be applied additionally.

In the next steps, the system can be extended to a transportation mode detection system. Therefore it is necessary to save the data temporarily for the use (and training) of artificial intelligence methods. Also it is not required to have personalized data sets. A possible approach could be the adaptive boosting, as described by Hemminki [5].

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# Applying the Smart Grid Architecture Model SGAM to the EV Domain

Mathias Uslar[1], Jörn Trefke[2]

## Abstract

Within this contribution, we will introduce the so called Smart Grid Architecture Model (SGAM) which has been developed in the European Commissions' M/490 mandate. After having proved successful in dozens of projects and especially standardization, the SGAM can be considered as state of the art to document smart grid architectures on a high level. However, as electric mobility is a part of the overall Smart Grid, a better fit to this domain can be achieved with tailoring the SGAM to an Electric Mobility Architecture Model (EMAM). This paper outlines the transfer process, an overview on standards to be applied and a final recommendation how to use the EMAM in context with existing SGAM processes.

## 1. Introduction to Smart Grid Standardization

A future smart grid is a complex system-of-a-systems or often also called a cyber-physical system. One particular important aspect in such grids is the growing need for using ICT for communication between the various components involved in the processes. Particular goals to be achieved by the smart grid may be related to aspects like the optimization and coordination of the various elements and their operation in the transmission as well as distribution grid. For instance for aspects of critical infrastructure protection, the level needed for the different protection scenarios of the components involved is rather ambitious and elevated. Also, the importance of the aspect of (system) availability and uptime for the electric power distribution system is undeniably high.

Additionally, the dependability of the infrastructure as well as of its basic components is the focus of system and interface design at design-time, even before actual deployment. At design time, interoperability and interchangeability have to be taken into account to ensure a meaningful analysis of the technical and non-technical requirements. To achieve this goal, one particular way is to standardize technical solutions at both international and national level.

To fulfil the interoperability requirements in a holistic architecture and to enable a smarter, ICT-controlled transmission and distribution grid, the system openness as well as the necessary amount of data exchange between participating parties and components inside a smart grid ecosystem has to rely on an agreed set of concepts. This basically leads to standardization of data models, interfaces, processes and communication protocols. Without standardization (e.g. in terms of data models and interfaces), overall costs for integrating (distribution automation) components as well as applications would increase due to the large number of new interfaces and processes involved. After the first standardization initiatives were raised by both IEC and NIST, the very idea that standards do answer most questions became apparent. But non-interoperable standards can still occur. So the NIST framework and roadmap for interoperability as well as the European initiatives derived from the M/490 Smart Grid mandate focus on properly using, expanding and adopting so called IEC core standards as well as various related ones.

The objective of the M/490 [1], [2] mandate has been to develop and/or update a set of consistent standards within a common European perspective as well as integrating a variety of digital compu-

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ting and communication technologies and electrical architectures, their associated processes, and, finally, services. Business models are out of scope for standardization but have been included in the foundational work of the mandate. The consistent set of standards shall achieve interoperability and, thus, will enable and facilitate the implementation of the different high level Smart Grid services and functionalities in Europe as defined by the Smart Grid Task Force. This set should be as well flexible enough to accommodate future developments. Building, Industry, Appliances, and Home Automation are out of the scope of the M/490 mandate; however, their interfaces with the Smart Grid and related services have to be treated under this mandate.

This initiative was a huge leap forward in Smart Grid standardization for Europe as, first time after the Joint-Working-Group Smart Grids report, communication (ETSI), electrical engineering (IEC) and automation (ISO) worked alongside a common storyline covering the integration of their best-practices using shared technologies and ICT. In addition, a link to the Northern American's National Institute of Standards and Technology (NIST) initiatives was built with the Smart Grid Advisory Committee (SGAC) groups and regular discussions and round-tables about architectures, roles, actors, domains, and use cases. One of the main items developed was the so called Smart Grid Architecture Model SGAM [3] enabling a holistic architecture definition.

The remainder of the paper is organized as follows: based on the Smart Grid Architecture Model overview in Section 2, Section 3 will outline the need for a transfer of the general design principles for new use cases like the Smart City Infrastructure Architecture Model suggested by the German Standardization roadmap for Smart Cities as well as problems occurring when design principles are violated. For the German funding schema "IKT für Elektromobilität II", we propose a possible solution for a better architectural modelling of the aspects of electric vehicles and their connection to the smart grid in Section 4. Section 5 concludes the paper with an outlook on future work and preliminary results.

## 2. SGAM – Smart Grid Architecture Model

In the context of the European Commission's standardization mandate M/490 a holistic viewpoint of an overall Smart Grid infrastructure named Smart Grid Architecture Model (SGAM) has been developed. This work is based on existing approaches and subsumes the different perspectives and methodologies of the Smart Grid concepts. The SGAM comprises five so called core viewpoint layers, which address particular concerns in terms of interoperability, also addressing business aspects which are usually out of scope of standardization. These layers are named Business, Function, Information, Communication, and Component. They were adopted from the Gridwise Alliance Architecture Council (GWAC) stack and its context-setting framework (CSF). Therefore, the eight layers of the GWAC stack can be mapped onto the five distinctive layers of the SGAM for backward compatibility of US approaches like the NIST Conceptual Model or the context setting framework for the Gridwise Alliance.

The Business Layer provides a Business viewpoint focusing on strategic and tactical goals, business processes and business services as well as regulatory aspects. For standardization purposes, this layer could be considered out of scope. The Function Layer includes IT-oriented, technology independent descriptions of general Smart Grid use cases, their functions and used technical services. The Information Layer makes for information about data and information models to support the exchange of business objects and data models of the Function Layer to enable interface interoperability. The Communication Layer presents protocols and procedures for the data exchange between components based on the Information Layer. The Component Layer provides a physical and technical view on Smart Grids components. Besides power-system related infrastructure and equipment, ICT-infrastructure and -systems are also considered as possible items.

Each of the layers mentioned above consists of five domains which subdivided in six zones. Domains are constituted according to organizational cohesion to allow for simpler identification of organizational boundaries to identify inter-organizational interfaces. The domains are in particular made up from the supply chain in the energy sector in their order from generation to use. Accordingly they are named Generation, Transmission, Distribution, DER, and Customer Premises.

The zones are defined according to zones of automation, i.e. from enterprise-level automation down to the process level. This is essential to distinguish between different types of technologies and standards used. The zones are named Market, Enterprise, Station, Operation, Field, and Process.

An overall graphical representation of the SGAM (SGAM cube) can be found in Figure 1.

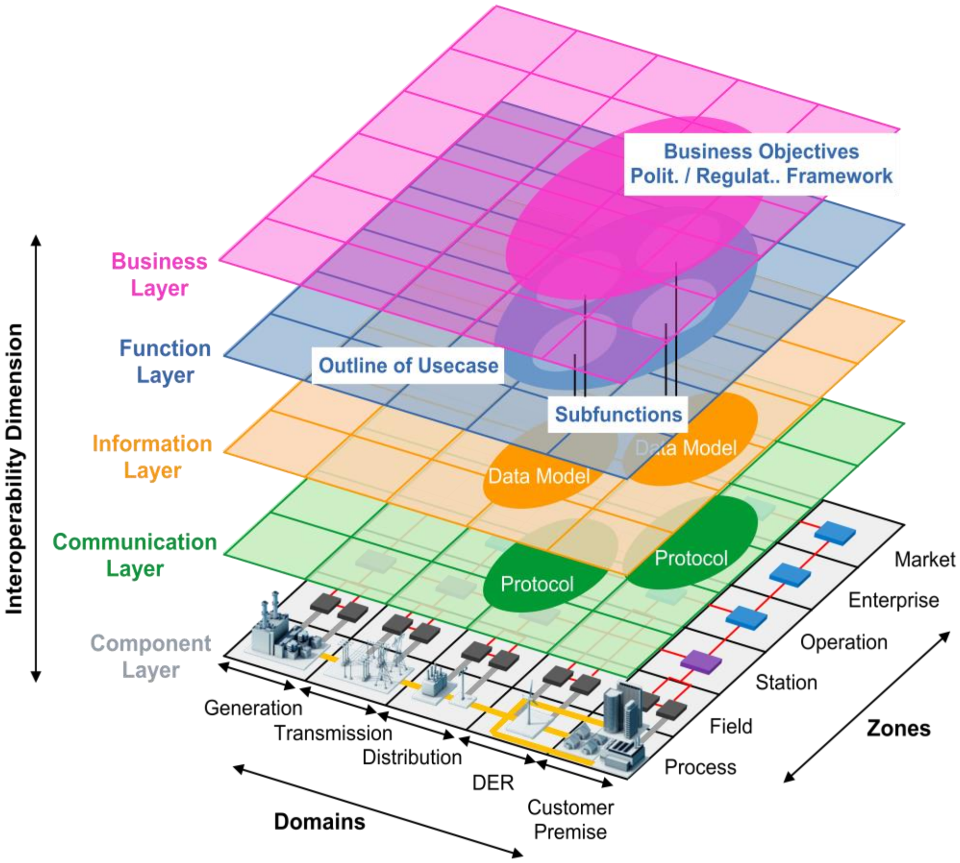


Figure 1: The Smart Grid Architecture Model as developed in the EU mandate M/490 for Smart Grids

## 3. Design principles and extended models

The SGAM provides a tool for the static analysis of systems, their interdependencies as well as their context in the electricity value chain and the utilities' organizational dimension and structure [5]. Yet, no formal model has been defined to properly assess the semantics of the graphical elements to be painted on the SGAM canvas, however some recommendations from the enterprise architecture context exist in the mandate work and other early approaches exist [4]. Prerequisites for filling out the SGAM model by standardized use case and user story descriptions have been evaluated and put in the very context of the SGAM meta-model [6], [7].

The SGAM can be used to create a description of static architecture states, i.e. of a current infrastructure, the possible data flows, the status of a future architecture envisioned, standards to be applied in the individual layer, domains and zones and documenting overlap between standards. It has been solely developed with the focus given in [5]. One of the key aspects is the visualisation of complex system-of-systems from a holistic perspective to show heterogeneous stakeholders, if they have to interact, and with whom.

Additionally, services [8] can be made more transparent to show which devices at field level finally contribute in which way to the overall business function and result. Creating an SGAM model always leads to one system being exact at one place and layer. Communicating about SGAM models has proven to be a useful solution in several EU FP 7 projects and national roadmaps [9]. Due to its success, different initiatives have tried to re-use both the use case process and the system documentation process suggested by the SGAM. Tools like the SGAM toolbox [7], implemented in Sparx Enterprise Architect as a UML profile have proven to be useful to start a holistic requirements engineering [10] process and trying to re-use model-driven architecture engineering principles.

Two of the most prominent adaptions are the Smart City Infrastructure Architecture Model (SCIAM) [11] and the DKE Smart Home Architecture Model (SHAM); the SCIAM can be seen in Figure 2.

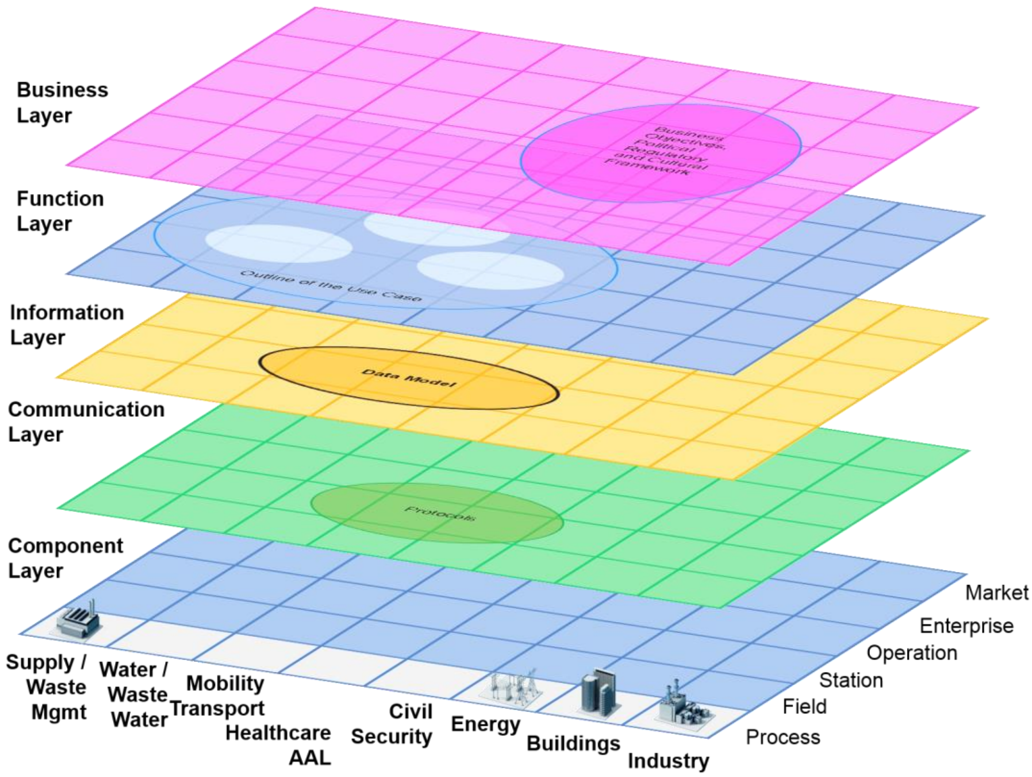


Figure 2: The Smart City Architecture Model (SCIAM) based on the SGAM (adopted from [11])

However, in the SCIAM there is a violation of the general SGAM principle in terms of the value chain for the domains. The domains are in no particular, logical order, leading to the fact that systems which are used on a plane for, e.g., energy as well as AAL (e.g., Smart meter Home Gateway) have to be put into the graphical representation twice due to the fact, that domain Civil Security them in terms of the graphical representation. Similar problems exist for the SHAM with its zones; therefore, one main aspect of re-using SGAM modelling visualisations is the aspect of insisting on ordered items for both domains and zones. The proposed EMAM will adhere to the principles depicted.

## 4. A focus on EV – the Electric Mobility Architecture Model

Recent work has been done to transfer the overall SGAM concept to deal with vehicles and charging infrastructure, thus making all analyses functions and modelling for the SGAM-like standards assignment, technical migration paths, risk assessment to technical components, and reliability calculation also available for this part of the smart grid domain. Previous work has been done by [12], proposing the re-use of SGAM with no emphasized focus on the design principles and use cases for SGAM communication. A meaningful morphological analysis on EV integration into the grid is provided in [13] to outline scenarios for EV to derive an information systems architecture. Later work of the authors [14] proposes to adapt the SGAM for EV purposes shortening the zonal dimension by field and process, renaming it scope and distinguish in the domain character between moving infrastructure and immobile infrastructure. Still, the SGAM is considered a good base.

We suggest changing the SGAM as little as possible to make for highest compatibility with the existing methods, meta-models and tooling and changing only limited aspects of the domain value chain. The aspect for immobile assets and mobile assets is taken into account, but it has to be kept in mind that SGAM has no dimension of time, so all aspects shall be treated static. This and the aforementioned aspects lead to the following proposal for the EMAM in a first edition.

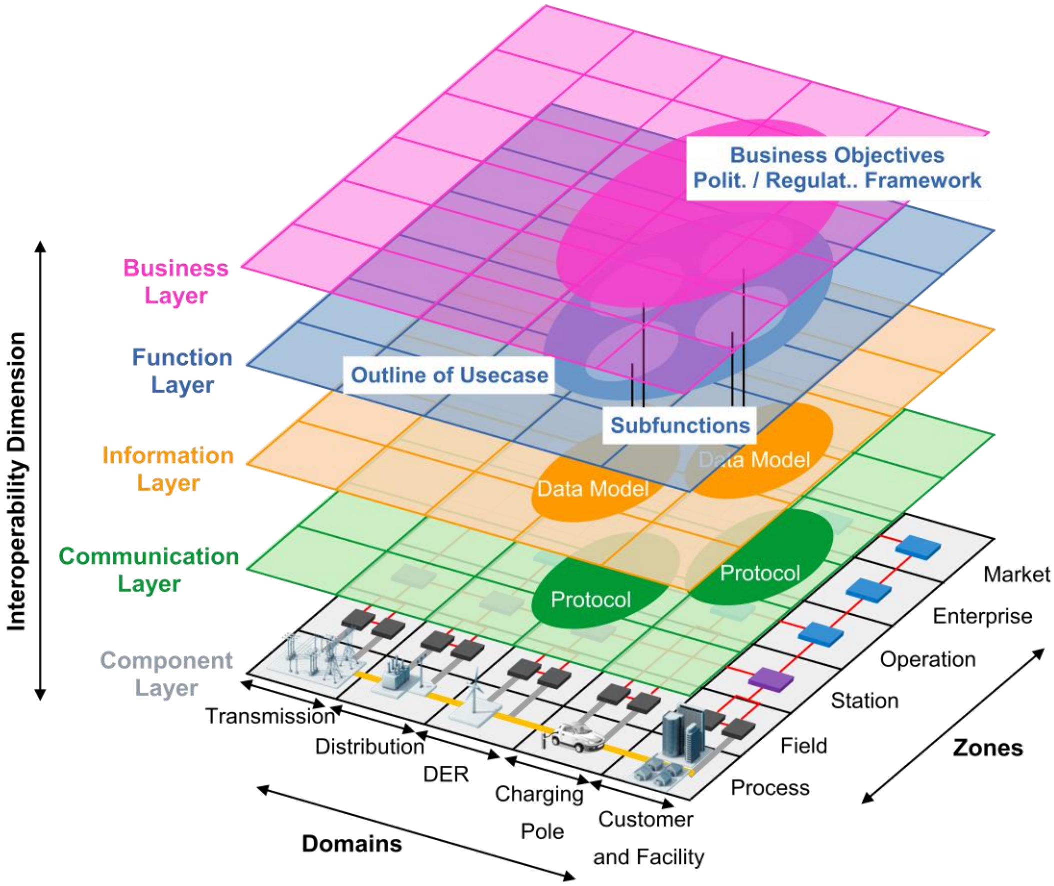


Figure 3: Proposal for an Electro Mobility Architecture Model (EMAM) adhering to SGAM principles

## 5. Conclusion and outlook

This contribution presented the SGAM presented as a standardized, accepted way to describe smart grid architectures in the form of models and a visualization in the SGAM cube. Additionally, extensions based on the SGAM were presented and design and use principles discussed. Based on previous work, we proposed to adhere to those principles creating a so called Electric Mobility Architecture Model which has been discussed beforehand.

The EMAM is still work in progress and future work will elaborate formal models supporting the definition of EMAM architectures and analyses based on that foundation. Furthermore the EMAM will in future be checked for modelling all the scenarios described in [15], [16] and [17] in the context of the IKT-EM II program and the M/490 mandate.

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# How GIS can help to promote safe cycling

Martin Loidl[1]

## Abstract

Geographical information systems (GIS) offer an integrated platform for relating, modeling and analyzing multiple perspectives on the road space. They can thus be employed in all stages of better understanding bicycle safety from an explicitly spatial perspective and provide the basis for informed decisions in the context of cycling promotion.
In the following it is briefly sketched why safety issues need to be addressed in all cycling promotion initiatives. It is further shown how GIS can be employed in accident analysis and integrated safety risk models and how these single steps can be consolidated in a single workflow. The benefit of employing GIS in this context is demonstrated in a case study where a GIS modeling approach forms the basis of a routing application which recommends safe routes for bicyclists. Based on experiences from the case study and findings from literature a brief outlook describes the road ahead.

## 1. The bicycle as sustainable mode of transport

Numerous negative impacts of motorized traffic – from air pollution [1] to economic externalities [2] and social inequities [3] – have led to a growing demand for sustainable modes of transport; especially in densely populated, urban environments. This development has increasingly brought the bicycle, as sustainable and cost-efficient mode, into the focus of researchers, planers and decision makers [4]. Masterplans for bicycle traffic and numerous bicycle promotion initiatives from local to transnational levels are indicators for this (re-) discovery of the bicycle [5].

### 1.1. Bicycle traffic and safety concerns

Due to extensive bicycle promotion initiatives, many cities in Europe have successfully built or extended their bicycle infrastructure. This has significantly contributed to a constantly rising number of bicyclists on the roads [6]. But still, there are some influential factors which keep people from using the bicycle for their everyday mobility needs, above all safety concerns [7]. Although sound exposure data are rare [8], there are indications from literature and official statistics, that cycling is healthy, but dangerous related to the travelled distance [9, 10]. These findings are in line with a recent report by the European Commission on road safety. There, the EC points to the fact, that contrary to the overall trend, the number of killed bicyclists has been increasing during the last couple of years [11]. Thus, it can be stated, that safety is a key issue in the context of promoting the bicycle as sustainable mode of transport [12].

### 1.2. Improving bicycle safety

In order to improve safety for bicyclists, at least three issues ("safety pillars", adapted from [13]), which are interrelated, need to be addressed:

- First of all, the infrastructure and regulative interventions need to be designed in a way that potential risks for bicyclists are minimized [14]. This can be done, for example, by separated bike lanes, controlled intersections or actions to reduce motor vehicle traffic and speed [15].
- Secondly, the bicyclist's physical condition, experience, compliance with road traffic rules and the technical condition of the vehicle must be taken into account. Although "individual" factors

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do not fully explain all incidents, it is noteworthy, that 5-30% of fatal injuries to bicyclists are caused by single-bicycle crashes [16]. However, targeting the mentioned individual risk factors requires an integrated approach comprising actions from traffic control to awareness initiatives.

- As a third aspect, bicycle safety can be improved by specific information offers about optimal (safe) routes [17]. Such routing recommendations aim to minimize the bicyclist's exposure to risk factors, such as primary roads with a high traffic load or roads without any bicycle infrastructure.

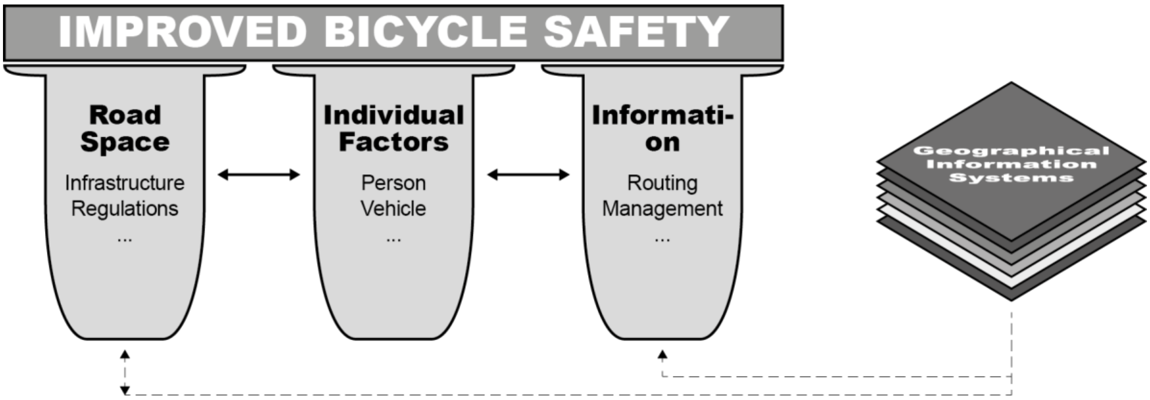


*Figure 1: Three approaches for the improvement of bicycle safety, adapted from [13].*

Individual factors which potentially contribute to an improved bicycle safety cannot be explicitly targeted by geographical information systems. But GI systems allow for a systematic, digital representation of the road space, including the physical and legal characteristics. These data can subsequently be managed, modeled and analyzed and in turn serve as basis for innovative information applications.

## 2. What GIS can offer

Bicycle safety is – if only external risk factors (inherent characteristics of the road space) are considered – a complex spatial phenomenon with multiple influential factors, such as the built infrastructure, the traffic volume or weather conditions. In order to better understand this multi-facetted phenomenon, an integrated perspective is required. Geographical information systems allow for such a perspective as external risk factors are spatial by their very nature or can be spatially related (geo-located). Thus they can be captured, related, analyzed and mapped.

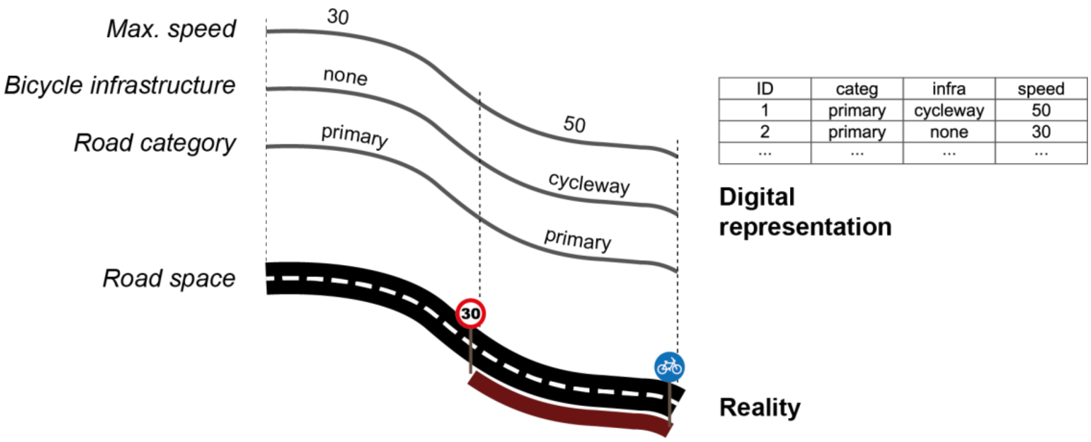


*Figure 2: GIS as integrated platform for multiple perspectives on the road space.*

Whereas established domains dealing with mobility and transportation, such as traffic engineering, telematics or planning, have a specific, rather "technical" view, geographical information systems can beyond that serve as integration platform where multiple perspectives – "technical" as well as qualitative – on the road space can be merged. GIS thus facilitate an integrated approach for modeling and analyzing bicycle safety.

In the next section a generic workflow is introduced which facilitates an integrated analysis of bicycle safety with GIS. The applicability of this approach is than demonstrated in a case study.

### 2.1. GIS employment in a multi-stage workflow

Providing a sound data basis in the context of the promotion of safe cycling is of great importance for informed decisions. The consideration of explicit spatial characteristics is especially valuable in the analysis of bicycle accidents and in the assessment of the road network's quality in terms of bicycle safety.

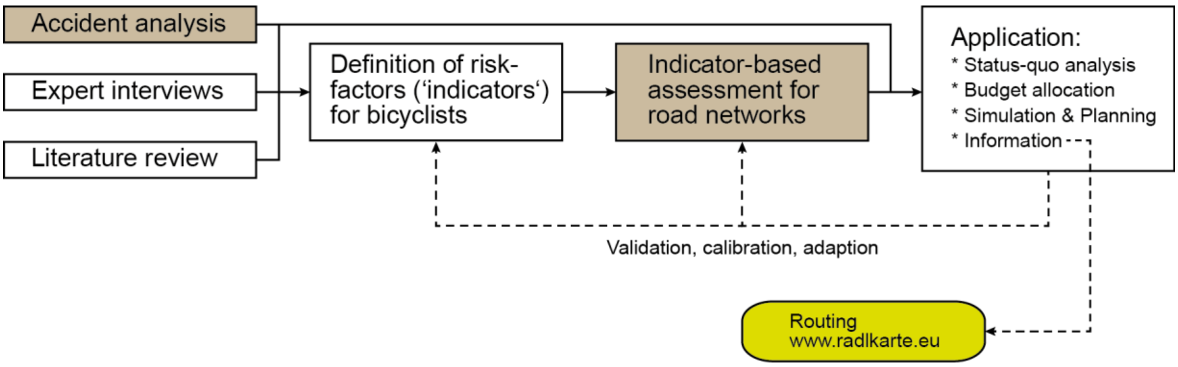


*Figure 3: Multi-stage workflow to provide sound data and analysis results for informed decisions in the context of bicycle safety. The employment of GIS especially allows for additional insights in accident analysis and assessment approaches (light brown, see [18]). The result of an integrated spatial approach can then form the basis for applications, such as routing (green; case study see below).*

Analyzing bicycle accidents with GIS helps to better understand where, when and under which physical conditions accidents did or are more likely to occur (ref. figure 4). For example the significance of accident hotspots can be tested in comparison to a random distribution or the risk exposure can be calculated (given the necessary data are available) for a network. Once the spatial determinants are identified from accident analysis this information can be merged with expert knowledge and results from related studies (e.g. non-spatial studies in epidemiology). These inputs allow for the identification of risk factors for bicyclists, which in turn can be used for a global assessment of road networks (see [18] for model details).

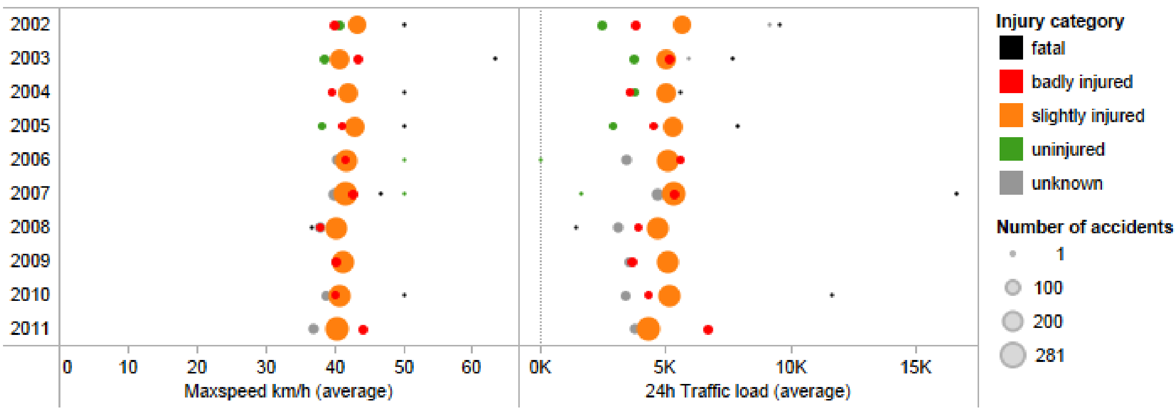


*Figure 4: Accident analysis of 3,096 bicycle accidents in Salzburg (Austria): fatal accidents tend to occur on roads with high maximum speed and traffic volume (figure from [18]).*

The assessment model itself can be employed for simulations as the input indicators and their weights can be easily manipulated. The results of the assessment routine form the basis for status-quo analyses (e.g. weak-point analysis), but can also be used for planning purposes. In a current project the assessed, digital road network was used as input for a web-based routing application. Thus it could be successfully demonstrated how a spatially driven modeling and analysis approach can be employed in several stages of better understanding bicycle safety and based on this, helps to promote safe cycling.

### 2.2. Case study

Salzburg – capital of the homonymous federal state, with approximately 150,000 inhabitants – has been following a sweeping strategy for bicycle promotion for more than two decades. A fixed sum is invested into infrastructure projects every year, resulting in a tight network of bicycle facilities with radial and tangential high-capacity connections (ref. fig.5). Through these substantial efforts, together with different accompanying actions, the city administration was able to reach a modal share of at least 16% for the bicycle [19].

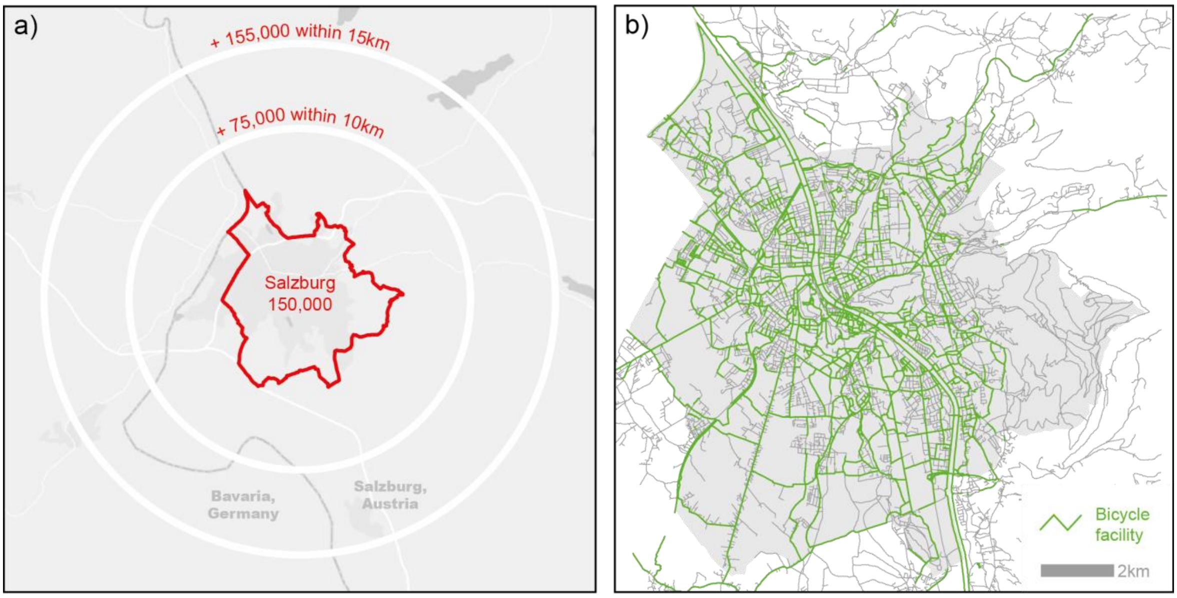


*Figure 5: Central location of Salzburg in the Austrian-German border region (a). Tight network of cycleways and -lanes covering the whole city (b).*

In order to further increase the number of bicyclists, the city administration, together with the federal state's department of transportation, have expanded their promotion strategy and started to invest into user-specific information.

The flagship of this information offer is a bicycle routing platform which is based on the results of the aforementioned (ref. figure 3) indicator-based assessment model [20]. This model results in an index value which expresses the suitability (or relative safety) for bicyclists on the level of segments. The amount of the index value corresponds with the potential safety risk (the higher the value, the higher the potential safety threat). This relation allows the index value to be used as impedance in a routing engine. With such routing engines the optimal path, in terms of minimized cumulative impedance values, between given points can be found. Feeding the engine not only with the travel time and distance of each segment, but additionally with the safety index value, enables the user to calculate the safest – additional to the shortest or fastest – route (ref. fig.6).

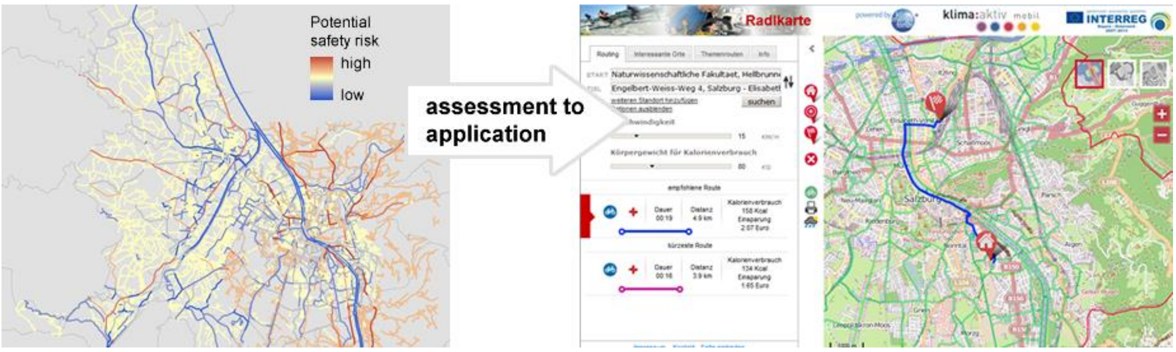


*Figure 6: The indicator-based assessment model, run in a GIS, results in an index value which can be used as impedance in a routing application. Thus safe routes, reflecting the multi-facetted, user-specific perspective on the road space, can be calculated.*

The routing application is freely available on the web (www.radlkarte.eu). It is intended to be an additional building block of a comprehensive bicycle promotion strategy, which considers both, the infrastructure and the user-specific information offer. Such offer about safe routes aims to support everyday bicyclists in their route choice and raises awareness for the bicycle as sustainable (and safe) mode of transport.

### 2.3. Conclusion and outlook

Referring to the threefold safety concept, sketched in figure 1, this case study shows how an integrated spatial perspective, operationalized in a GIS, can be employed in addressing two of the mentioned aspects. A thorough analysis of bicycle accidents as an explicitly spatial phenomenon and the consideration of various parameters contributing to the overall safety threat, allow for a reliable assessment of the road network's quality in terms of bicycle safety. This assessment approach can either be employed in more efficient infrastructure ("What's the effect of building a cycleway at a particular road?") and regulative actions ("To what degree would the road become more bicycle-friendly, if the maximum speed is lowered?") or as basis for innovative information applications such as the routing platform mentioned above.

As [21] and [5] state, bicycle promotion needs to be more than simply providing adequate infrastructure. A pro-active administration which offers relevant information and fosters a bicycle culture is indispensable for the establishment of the bicycle as sustainable mode of transport. In this context an integrated spatial approach facilitates status-quo analysis, informed decisions in planning and management contexts and user-tailored information applications.

In order to further enhance bicycle-specific, spatial information, the three following topics should be addressed in further researches: personalization, socialization and contextualization. Personalization means that individual preferences and perspectives on / perception of the road space can be integrated in the assessment model and consequently contribute to personalized information products. How individual peculiarities can be transformed to code-readable model inputs and how those inputs should be weighted is subject to research. Socialization in this context comprises all (technical and organizational) efforts that contribute to a more social environment where experiences, feedback messages and updates are shared among several instances (bicyclists, authorities, event organizers, public transportation operators etc.). Examples for research topics would be, just to name three: inter-bicycle communication, participatory planning processes or a vivid administration 2.0 environment. What all these efforts have in common is the explicit spatial context. Here the power of GIS comes into play: it offers the ideal platform or framework for building relations between various instances and data and thus allows for the generation and retrieval of relevant information. In this sense, GI systems significantly contribute to the “intelligence” for the promotion the bicycle as sustainable transportation mode.

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