Hanse-Studien / Hanse Studies

Hanse-Wissenschaftskolleg (HWK) –
Institute for Advanced Study

Herausgegeben von
Reto Weiler und Heidi Müller-Henicz

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Hanse-Wissenschaftskolleg (HWK) –
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Alexandra Pehlken, Andreas Solsbach,
Wolfgang Stenzel (Eds.)

Sustainable Material Life Cycles –
Is Wind Energy Really Sustainable?

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Preface

In 2011 Alexandra Pehlken, then at the University of Bremen, learned about a new program at the Hanse-Wissenschaftskolleg (an Institute for Advanced Study, HWK), and the idea to organize a conference on the topic of "Sustainable Material Life Cycles – Is wind energy really sustainable?" was born. This new program at the HWK allowed young researchers from the Bremen-Oldenburg region to apply for Associated Junior Fellowships – and with that to apply for support for a special purpose, for example a conference. The HWK with this program wants to support young researchers in their efforts to try something new, and to build up an international network.

Alexandra Pehlken was one of the first to apply for this program, and she indeed became one of the first Associated Junior Fellows. In her successful application she described her idea to bring together researchers and practitioners from different fields to discuss a topic that only very slowly is gaining the attention it certainly deserves. Is wind energy really sustainable when we look into material life cycles and all the processes that are connected with it, be it onshore or offshore?

Together with Andreas Solsbach of the Carl von Ossietzky University Oldenburg and supported by colleagues at the HWK, she organized the conference that took place in Delmenhorst in June of 2012.

The presentations that you will find in this volume approached the topic of the conference with a special focus on global aspects. One keynote speaker, Jeteendra Bisht, of Suzlon Energy Ltd in India, spoke about the Indian market and Suzlon's activities. The second keynote lecture, delivered by Athanasia Arapogianni of the European Wind Energy Association EWEA, focused on the European market and its developments.

The conference was structured into sessions on the most relevant issues: Material Flows and Sustainability, International Developments, Life Cycle Approach, Logistics, and Rotor Blades. After these sessions, which were characterized by stimulating presentations and exciting discussions, the conclusion was that wind energy is a young field and much more research, especially concerning aspects of sustainability, needs to be conducted. Two areas were identified as especially relevant: offshore wind park maintenance and material efficiency. With this volume, we hope to stimulate more interdisciplinary discussions and related research.

We would like to thank all contributors for their presentations, posters, and articles for this book. We are also very grateful to all conference participants for their helpful questions and comments.

Special thanks go to ForWind, the joint Center for Wind Energy Research of the universities of Oldenburg, Bremen, and Hannover, for their helpful ideas and comments during the organising phase, and, last but certainly not least, we wish to thank the members of our scientific committee:

Dr. h.c. Jos Beurskens, SET Analysis.Scientific Director We@Sea

Prof. Dr.-Ing. Martin Faulstich, TU München

Dr. Stefan Gößling-Reisemann, Universität Bremen

Prof. Dr.-Ing. Andreas Reuter, Fraunhofer IWES, Bremerhaven

Prof. Dr.-Ing. habil. Raimund Rolfes, Leibniz Universität Hannover

Prof. Dr.-Ing. Peter Schaumann, Leibniz Universität Hannover

Prof. Dr.-Ing. habil. Klaus-Dieter Thoben, Universität Bremen

We hope the conference was a good starting point for ongoing discussion, and we hope to continue these discussions in the future.

The editors,
Alexandra Pehlken, Andreas Solsbach, Wolfgang Stenzel

Keynote

Wind in Power: 2011 European Statistics

A. Arapogianni[1], M. Dragan[1], J. Moccia[1]

1 European Wind Energy Association, Brussels, Belgium

1 Introduction

Wind energy plays an important role in the European electricity mix. This paper summarises the developments in terms of capacity and electricity production for the year 2011. Some information on trends for wind turbines is also presented.

2 2011 annual market

During 2011, 9,616 MW of wind capacity were installed in the European Union. The onshore wind power sector accounts for 90% of annual installations (8,750 MW), with offshore (866 MW) accounting for the remaining 10%. This amount of capacity corresponds to investments of €12.6 billion, €10.2 billion for onshore and €2.4 billion for offshore.

Looking at the EU member states, during 2011, Germany was the largest market, installing almost 2,100 MW of wind capacity (Figure 1). The UK followed with almost 1,300 MW of wind power, of which 58% was built off-shore.

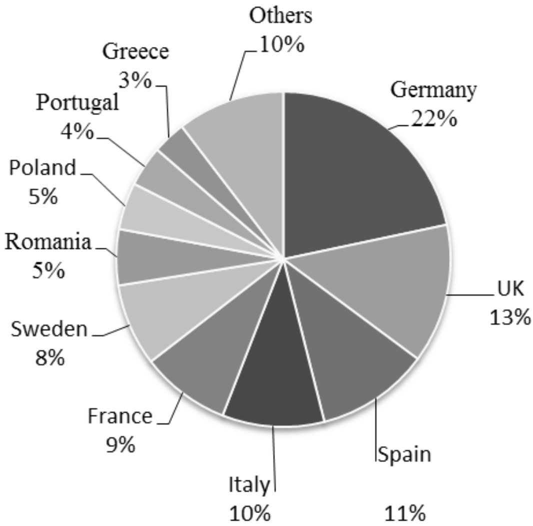

Figure 1: EU member state market shares for new capacity installed in 2011 (MW)

Looking at all power installations in the EU in 2011, wind accounted for 21.4% of all new capacity. The 9,616 MW of wind capacity place wind in third place of all power technologies behind solar PV (21,000 MW) and gas (9,718 MW). Figure 2 shows the shares of new power installations in the EU for 2011.

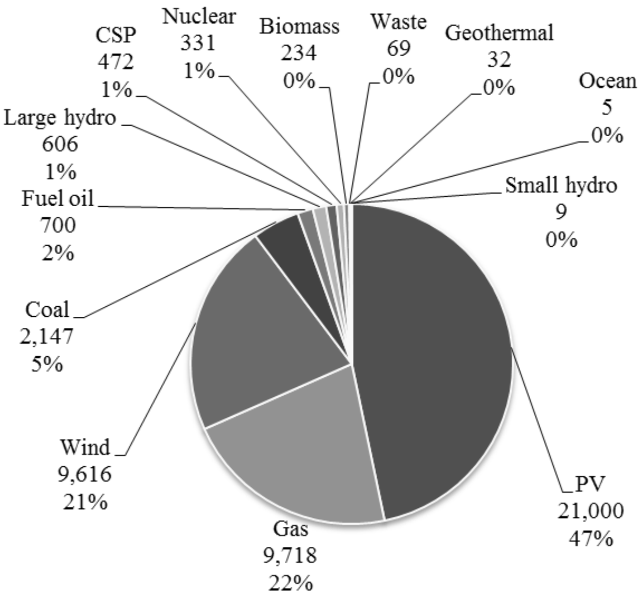

Figure 2: Shares of new power installations in EU in 2011 (MW)

The annual installation of all technologies other than solar PV, gas, and wind accounts for only 10% of power capacity installations in 2011. In total, 45 GW of power capacity were installed in the EU in 2011, and 40.3 GW were the latter three technologies. Moreover, during 2011 over 6.2 GW of nuclear power and over 1 GW of fuel oil capacity were decommissioned (Figure 3).

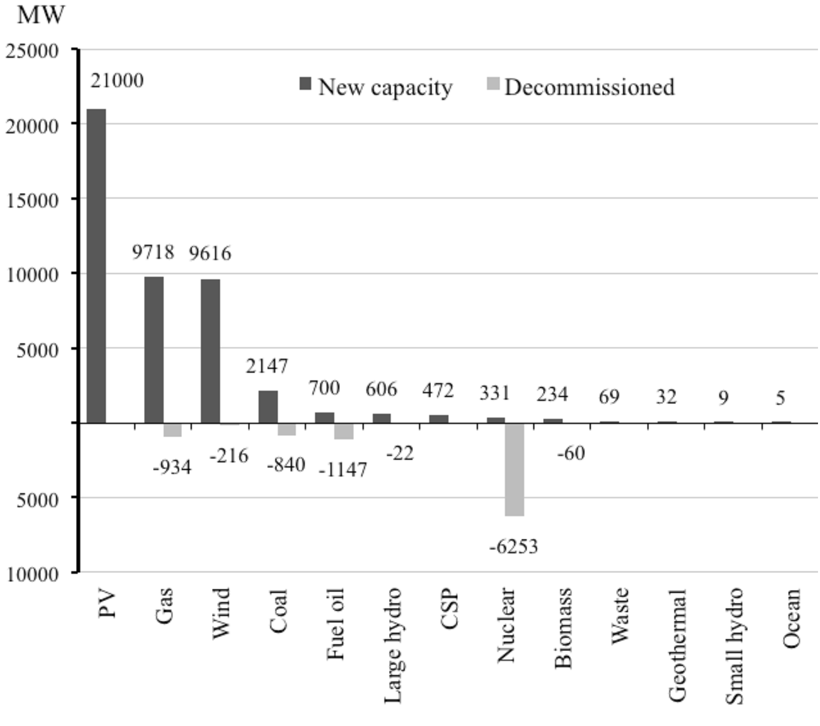

Figure 3: Installed and decommissioned capacities in 2011

2011 was a record year for renewable generating capacity. With slightly over 32 GW, it accounted for 71.3% of all new installations. Figure 4 shows the share of each renewable technology.

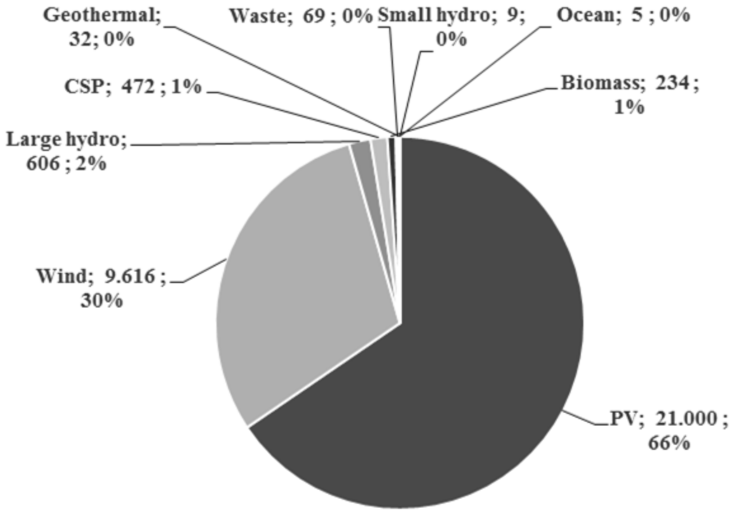

Figure 4: Shares of new renewable capacity installations in 2011

3 Cumulative installations

The European power sector has changed significantly over the past two decades, mainly due to investments in renewables. Figure 5 shows new annual installations of electricity generating capacity since 1995 in the EU. Whereas in 1995 only 14% of new installations were renewable technologies, since 2008 they represent over 50% of all new installations, indicating a move towards the de-carbonisation of the EU's power mix.

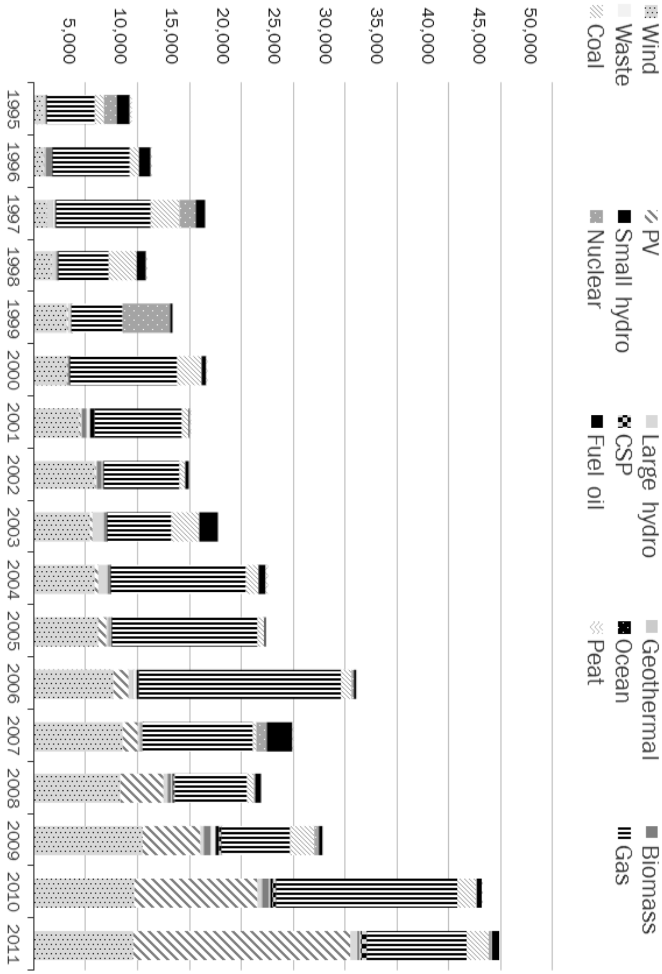

Figure 5: Electricity generating capacity in the EU

Cumulative wind power capacity reached 94 GW at the end of 2011. Amongst the EU Member States, Germany has the largest installed capacity, followed by Spain, Italy, France and the UK (Figure 6).

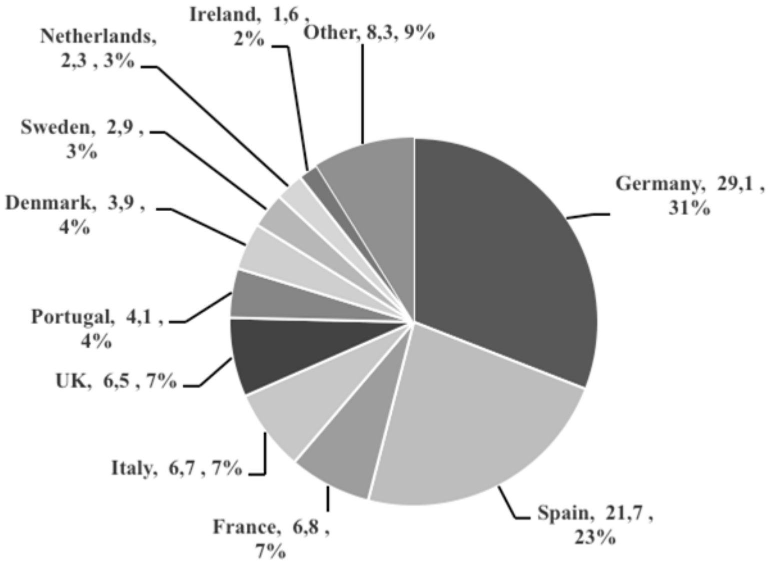

Figure 6: Member state shares for cumulative installed capacity at the end of 2011 (MW)

At the end of 2011, the installed wind power, in a normal year, will produce around 204 TWh, meeting 6.3% of the EU's gross final electricity consumption. The penetration of wind power in electricity consumption of each Member State is shown in Figure 7.

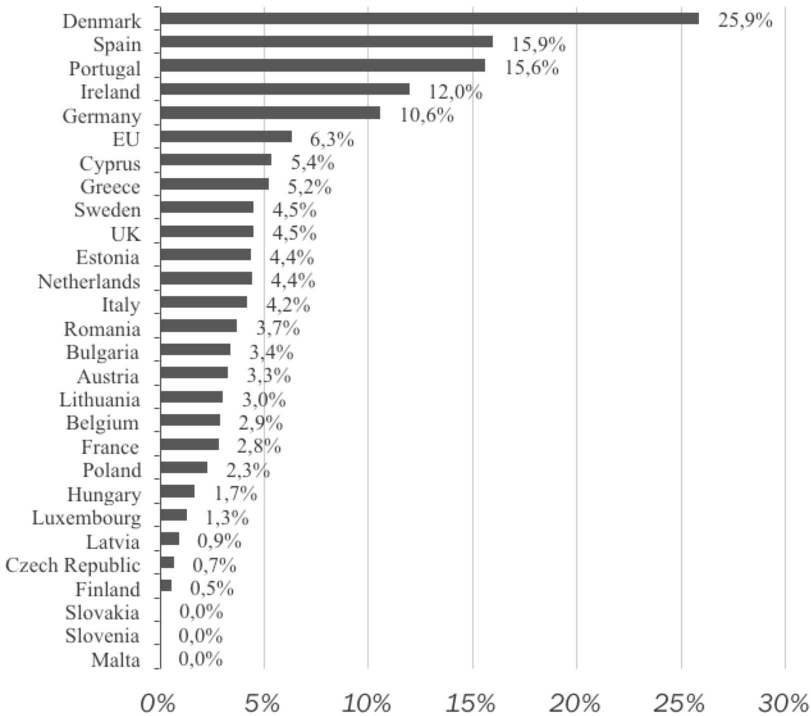

Figure 7: Shares of total electricity consumption (end 2011)

4 Wind turbines

The European wind energy industry has been developing since the early 1980s. Over the past thirty years, wind turbines have become larger and more sophisticated. The number of wind turbines installed per year since 1991 is shown in Table 1, together with the annually installed capacity.

Table 1: Number of wind turbines installed annually in the EU[1]

	Annually installed capacity (MW)			Number of wind turbines installed annually in EU		
Year	*Onshore*	*Offshore*	*Total*	*Onshore*	*Offshore*	*Total*
1991	185	5	190	827	11	838
1992	215	0	215	1,017		1,017
1993	367	0	367	1,303		1,303
1994	470	2	472	1,224	4	1,228
1995	809	5	814	1,790	10	1,800
1996	962	17	979	1,985	28	2,013
1997	1,277	0	1,277	2,343		2,343
1998	1,697	3	1,700	2,728	5	2,733
1999	3,225	0	3,225	4,389		4,389
2000	3,205	4	3,209	4,622	2	4,624
2001	4,377	51	4,428	3,893	27	3,920
2002	5,743	170	5,913	4,109	85	4,194
2003	5,203	259	5,462	3,622	116	3,738
2004	5,749	90	5,838	4,551	38	4,589
2005	6,114	90	6,204	4,107	30	4,137
2006	7,499	93	7,592	4,560	31	4,591
2007	8,217	318	8,535	4,760	111	4,871
2008	7,889	373	8,263	5,315	129	5,444
2009	9,917	582	10,499	4,745	200	4,945
2010	8,449	883	9,332	4,633	308	4,941
2011	8,750	866	9,616	3,940	246	4,186

Table 1 illustrates that due to technological evolution, fewer turbines are needed to reach the same installed capacity. Ten years ago, 4,194 wind turbines added up to 5,913 MW of capacity. At the end of 2011, the installation

1 Data for number of turbines taken from: "World market update 2011", BTM consult, March 2012

of 4,186 wind turbines corresponds to 9,616 MW of capacity, an increase of 64%.

The continuously increasing size of wind turbines means that more power can be installed in less space.

For the onshore sector, the average size installed annually surpassed the 1 MW size around the year 2000, reaching 2.2 MW in 2011 (Figure 8).

The same happened for the offshore sector, where after 2000, the average size of wind turbines installed annually is above 2MW, reaching 3.5MW in 2011 (Figure 9).

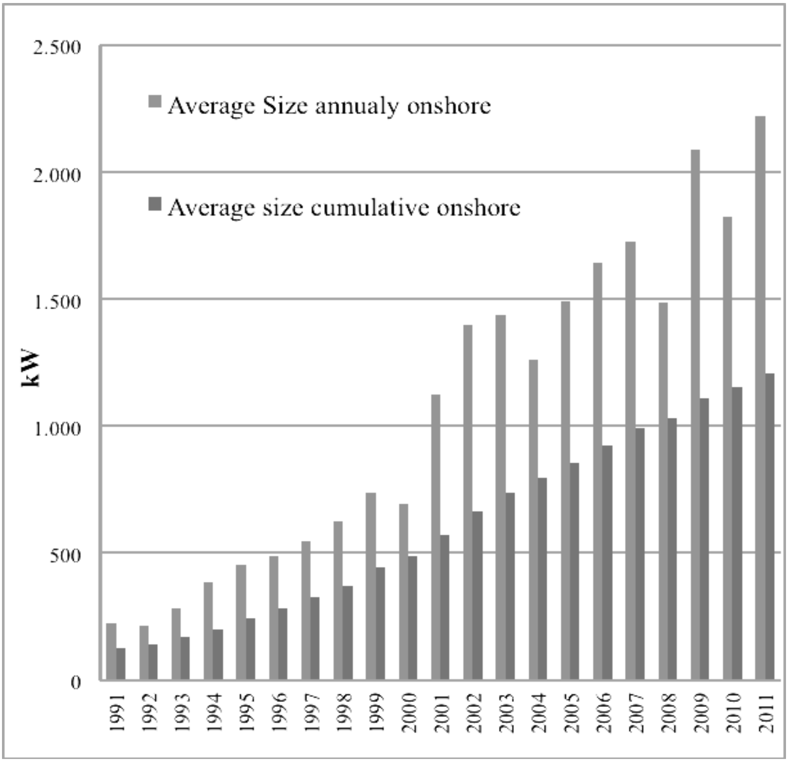

Figure 8: Average size of wind turbines (onshore)

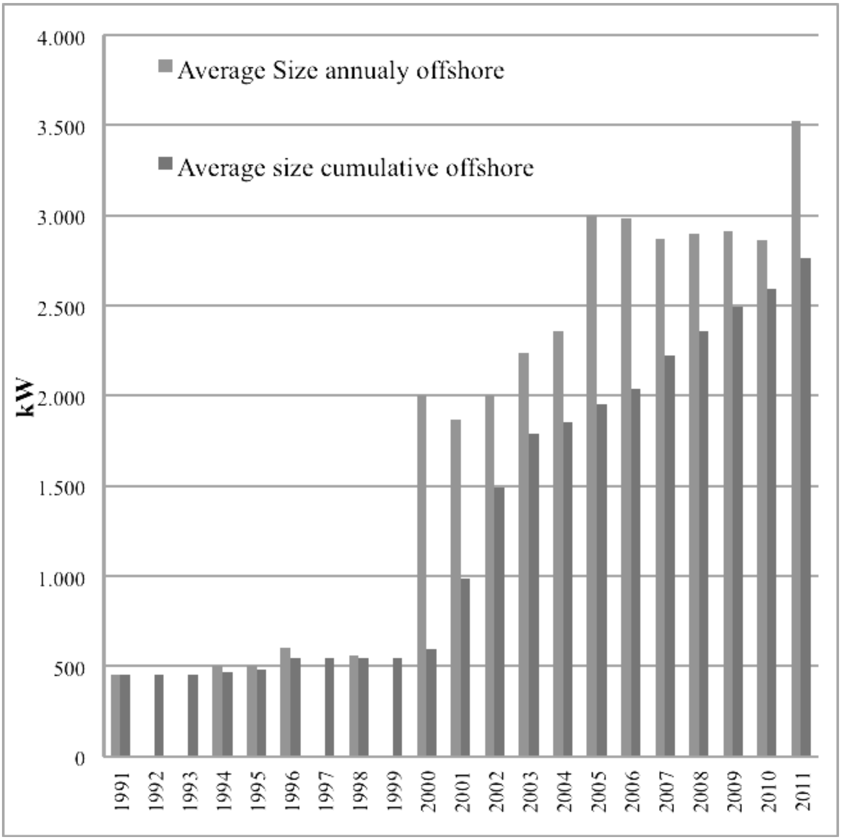

Figure 9: Average size of wind turbines (offshore)

The rapid evolution of the wind energy sector and turbine technology was achieved through continuous investment in R&D and innovative up-scaling solutions to maintain optimal turbine functioning even in the harshest environments, such as offshore or in cold climates. The sector has been devoting considerable resources to meet the technological challenge. It is estimated that the European wind energy industry has invested over 5% of its turnover in R&D over the past years, more than double what is invested in R&D economy-wide[2]. The same analysis shows that of the four main subsectors of

2 Green Growth – The impact of wind energy on jobs and the economy, EWEA April 2012.

the industry, wind turbine manufacturers have invested up to, and over, 10% of their turnover in R&D.

5 Conclusion

Wind energy has gone from a marginal to a mainstream power technology through its rapid deployment and continuous R&D efforts. The EU wind energy industry expects 230 GW of installed wind capacity in 2020, of which 40 GW will be offshore. Compared to the 2012 level, this amounts to almost 1.5 times further capacity to be installed in the coming eight years. This capacity would cover 16% of the EU's electricity needs. By 2030, industry expectations are of 400 GW, of which 150 GW offshore, meeting almost 30% of the EU's electricity needs. New, bigger and more efficient wind turbines will need to be developed to reach these goals. New materials and manufacturing processes will be required to ensure a sustainable development of the sector.

Talks

Sustainability Assessment of Steel Constructions for Offshore Wind Turbines

P. Schaumann[1], A. Bechtel[1], H.-J. Wagner[2], C. Baack[2], J. Lohmann[2], N. Stranghöner[3], J. Berg[3]

1 ForWind – Center for Wind Energy Research, Institute for Steel Constructions, Leibniz University Hannover, Hannover, Germany
2 Chair of Energy Systems and Energy Economics, Ruhr-University Bochum, Bochum, Germany
3 Institute for Metal and Lightweight Structures, University of Duisburg-Essen, Essen, Germany

1 Introduction

Environmental and operational loads are the design drivers of steel support structures for Offshore Wind Turbines (OWT). Besides design and installation, a holistic design also includes sustainability aspects that dominate the decision making process and the cost effectiveness of future renewable constructions. Within a large research project with three research institutions consulted by over thirty industrial partners, sustainability issues for renewable energies have been investigated. This paper deals with the sustainability assessment regarding steel constructions for Offshore Wind Turbines.

Motivated by recent market forecasts and the potential of the future development for renewable energy, carefully selected renewable constructions are analyzed. Recent forecasts, e.g. the German Reference Scenario 2009 raised by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, show the expected growth of the national renewable energy market and the resulting essential expansion. The wind energy market in particular will contribute significantly to regenerative electric power in the future (Schaumann et al., 2011a).

The annual installation of onshore and offshore wind energy plants in Germany from 2000 to 2030 shows a growing market, especially for the offshore section (Figure 1). The peak for annual installation of onshore wind energy turbines was in the year 2002, whereas the peak for offshore wind turbines is expected to be in 2022. In the future, onshore wind power will mainly be affected by repowering. Until 2030, the cumulated capacity regarding off-shore wind is expected to reach 30,000 MW, leading to a huge expansion of the offshore wind sector.

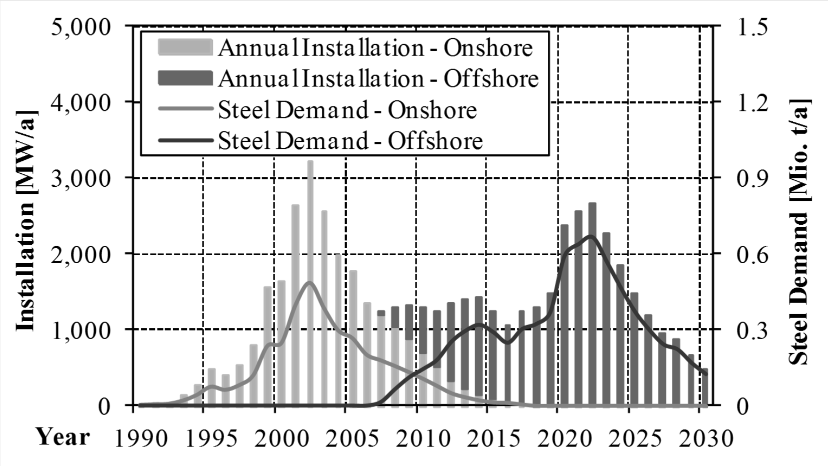

Figure 1: Cumulated capacity and annual steel demand for the German wind energy market (Dewi (2009))

By an average steel demand of 150 t/MW for onshore and 250 t/MW for off-shore wind turbines and a supposed 80–100% market share of structures built with steel, the annual demand of about 700,000 tons of steel in 2020 indicates the huge potential of wind energy constructions and steel demand. The expected offshore capacity of 30,000 MW in 2030 means, on average as from 2012, an annual installation of 320 wind turbines with 5 MW capacity per turbine leading to a demand of 400,000 tonnes of steel every year. To reach the targeted expansion, the offshore industry needs to adopt serial effects for production and installation. Regarding possible series production techniques of support structures for wind turbines, an optimised design leads to an increase of the overall efficiency. Even the optimisation of small structural details can increase the total efficiency significantly. Mass production paves the way for the expansion of offshore energy, along with a great potential for optimisation.

The material steel, representing 90% of the material mass used in OWT, has the biggest effect on environmental aspects, as Wagner et al. have pointed out (Wagner et al., 2010). 80% of the cumulated energy demand can be ascribed to the manufacturing and erection process of the steel structure. Altogether, these facts present potentials and needs for an evaluation method to assess the sustainability of steel constructions for OWT.

2 Research Objective

Regarding the structural design of buildings, sustainability aspects are already taken into account. Established rating systems, such as the German Assessment System for Sustainable Building (BNB, 2010) or the German Sustainable Building Council (DGNB, 2011), facilitate the evaluation and certification of buildings. Due to a lack of methods for steel constructions of renewables, the research objective deals with the development of an assessment method to evaluate the sustainability of steel constructions for regenerative energies.

3 Existing Methods

Existing rating systems for buildings, such as the German Assessment System for Sustainable Building (BNB, 2010) and the rating system of the German Sustainable Building Council (DGNB, 2011), are the background for a sustainable rating system for steel constructions of renewables.

The rating system of the BNB and DGNB consists of the six sustainable categories: environment, economy, sociocultural and functional category, technical aspect, process category, and local effects. Each of these categories is defined by a certain number of sub-criteria and indicators reflecting the impact of building and materials used on sustainability. The rating results from weighting categories, criteria, and indicators. The sum of all weighted and completely fulfilled criteria is 100%, whereas the most important elements environment, economy, sociocultural & functional and technical quality are weighted by 22.5%. The process quality is subordinated with 10%. Regarding the building performance, the criteria and indicators in each category form the basis of assessment. The degree of performance is the sum of each sub-criteria result. To reach a holistic assessment, the whole life cycle of the building and related products have to be considered in the assessment.

4 New Sustainability Assessment

Due to the basic understanding of sustainability reflecting the elements environment, economy, society, process, and technology, the sustainability assessment system for steel constructions of renewables is also based on these elements. Each category consists of numerous criteria and indicators describing certain effects of the steel structure. Some indicators of the DGNB or BNB rating system were transferred to evaluate the impact of steel structures of renewables. But indeed most of the indicators are too close to the building concept. Therefore, additional investigations concentrated on establishing criteria reflecting the needs for steel structures of renewables. Due to this, additional criteria describing the sustainability for steel constructions of renewables were created. In the first step, proven indicators originating from the building industry and characteristics reported in literature were used to determine new criteria. Subsequently, 200 possible criteria were analysed regarding their applicability to steel constructions for renewables. Special attention was paid to wind energy converters and biogas plants. Finally, 35 criteria were identified to be best-fit for the sustainability approach regarding renewables.

Focussing on environmental aspects, ten criteria were taken from the standardized life cycle assessment acc. to DIN EN 14040 (2009) and combined with four new criteria resulting in 14 criteria defining the environmental characteristics within the new assessment. Three criteria cover economical effects such as life cycle costs acc. to DIN EN 15643-4 (2012) and expenditures for research & development. The social performance is mainly reflected by company-related criteria as e.g. family friendliness, social engagement, work safety, and advanced training. In total, seven criteria represent the social part within the sustainability assessment. Technical and process elements are described by product-related criteria reflecting technical and logistical solutions. Five technical and six process criteria complete the sustainability assessment method. For each of these criteria, a profile was written to convey necessary information about the criteria and relevance to the user of the method. In combination with a detailed method description for each criterion, decisive sustainability effects for steel construction of OWT can be evaluated.

Additionally, a tool in Microsoft Excel was established enabling a practical application for the user. The impact criteria values are included in a polar diagram visualizing the results (see Figure 3). For each category, a polar diagram can be calculated with the single criteria values plotted on the axis of the diagram. The centre of the diagram displays the value zero as basis. Hence, applying the values for different constructional solutions leads to different spanned areas showing the sustainability impact. In the end, the sustainability for different steel structure solutions can be depicted and compared by five diagrams for the sustainability characteristics economy, ecology, social, technical and process.

For all categories and criteria, the assessment has to encompass the decisive life cycle stages A0 planning, A1–3 product, A4–5 construction, B usage, and C end of lifetime in terms of removal, which is followed by stage D, the life-time exceeding stage, including benefits resulting e.g. from recycling of the material. These life cycle stages were defined in reference to DIN EN 15978 (2012).

5 Steel Constructions of Offshore Wind Turbines

The support structure of an Offshore Wind Turbine consists of the tower and the substructures, whereas the substructure includes all structural components below the tower including the foundation. Depending on the water depth, turbine size, and local conditions, different types of substructures have been developed. Even though the Monopile is the most common solution in Europe, for Germany large water depths require lattice structures like Jacket or Tripod (Figure 2). Detailed information on steel structures for Offshore Wind Turbines can be found in Schaumann et al. (2011b).

Nowadays, tower production is already a highly automated process; submerged-arc welding is used to connect the steel tube segments by robot, bending machines are used for the forming process of round plates. Even though not many employees are needed for the fabrication process, the quality control needs to be done by highly trained employees. These affect the social and process quality regarding sustainability aspects.

Steel tube segments are brought to a location close to the sea where assembling and final manufacturing of segments take place. For the final assembling of the tubes, large factory halls are needed. Special lifting equipment is needed to handle the heavy weight steel constructions, not only in the installation halls, but also dockside to load the segments to the installation vessels. In addition, high logistic effort results from storing before shipping. Small weather windows for installation influence the installation at the offshore location and consequently the amount of stored segments and steel structures dockside. Furthermore, a perfect coordination of different technical crews is needed for the final work on the steel structures, such as e.g. welding processes at Jackets and application of corrosion protection.

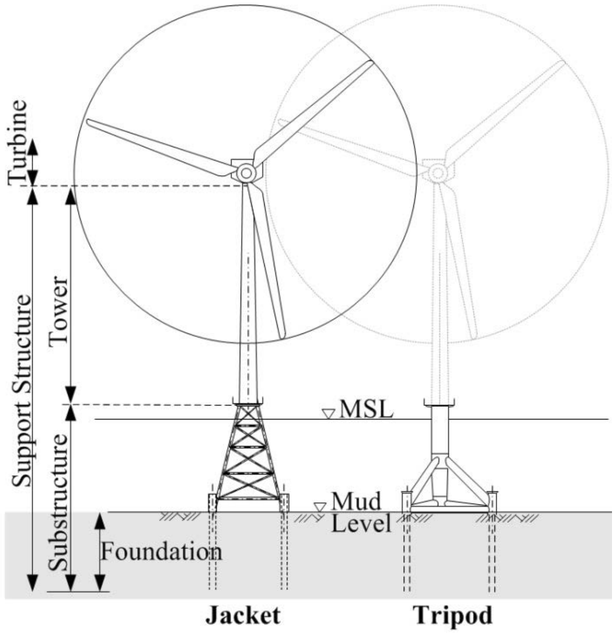

Figure 2: Offshore Wind Turbine with Jacket (left) and Tripod (right) substructure

The installation process of Offshore Wind Turbines includes effects from but also on the environment. The piles are driven into the seabed by a hydraulic hammer, producing noise that influences the fauna and flora, especially whales as e.g. in the German Exclusive Economic Zone. As shown by Wagner et al. (2010), one of the decisive components of OWT regarding ecological sustainability criteria is the substructure. Depending on the substructure type and pile length, the substructure requires up to five-times more steel than the tower. Hence, for a first comparison of results, the focus is set to example substructures “Jacket” and “Tripod” (Figure 2), which have been analyzed in a Life Cycle Assessment (LCA). The applied ecological indicators are shown in Table 1.

Table 1: Ecology impact criteria used for the life cycle assessment

Ecology Impact Criteria	
Cumulative energy demand (CED)	TJ
Ozone depletion potential (ODP)	kg R11-Eq.
Ozone depletion potential (ODP)	t PO_4-Eq.
Photochemical ozone creation potential (POCP)	t C_2H_4-Eq.
Global warming potential (GWP)	t CO_2-Eq.
Acidification potential (AP)	t SO_2-Eq.

Besides material masses, special elements such as welds and corrosion protection were taken into account, reflecting a holistic view. Table 2 summarizes the system parameters used for the LCA of the substructures for a service-life of 20 years. The steel material used for the primary structure is a S355. The corrosion protection for both substructures consists of a coating system in the splash zone and anodes underwater. Regarding the assessment, it was assumed that both substructures are coated by the same corrosion protection system. Therefore, the systems differ only regarding the material masses caused by the different surface area.

Table 2: Parameters of the investigated substructures Jacket and Tripod

Substructure	Tripod	Jacket
Water depth	~ 30m	~ 30m
Pile length	~ 50m	~ 30–45m
Steel mass	~ 1300 t	~ 830 t
Corrosion protection	anodes & coating	anodes & coating
Pile recycling	left in seabed	left in seabed

6 Results

The LCAs of the aforementioned substructures were analyzed regarding the named life cycle stages and the listed criteria (Table 1). The global warming potential (GWP) measured in tons of CO_2-equivalent and the cumulative energy demand (CED) measured in tera joule demonstrate the common parameters describing the influence to the environment.

To indicate the influence of different life cycle stages, the environmental effects are analyzed for each life cycle stage. The main life cycle stages are the construction stage and the service time, reflecting operation and disposal of the construction after 20 years. A comparison of the common ecological impact indicators, the GWP and CED, reveals that the construction stage is the decisive stage for Jacket and Tripod.

During the construction, the energy demand is quite high due to manufacturing and construction. In addition, the productive procedure releases the most CO_2-emissions so that consequently the construction stage displays the life cycle stage with the largest opportunity for optimization. The stage "operation" has only a small impact on ecological factors. Due to the almost hundred percent recyclability of steel, the disposal stage has a negative output, impacting the holistic evaluation positively by a reduction of the total greenhouse emissions.

The investigation did reveal the ecological effect of the substructure types Jacket and Tripod. Regarding GWP and CED, the total results are higher for the Tripod than for the Jacket. This can be traced back to the required steel mass, because each Tripod requires nearly 500 tons of steel more than the Jacket leading to a greater environmental impact. Detailed consideration of the results reflects that the material mass difference effects the disposal and the construction stage. The operational stage comprising monitoring and maintenance is almost identical for both structures. The effect of the steel mass is clearly shown by values for the disposal stage. The Tripod has – due to the larger amount of steel – a larger recycling potential and therefore a greater negative GWP and CED with regards to the disposal stage. However, the construction stage of the Tripod releases more CO_2 and requires more energy. Due to the high production effort of the Jacket structure, the difference of the indicator values is not as large as the mass difference.

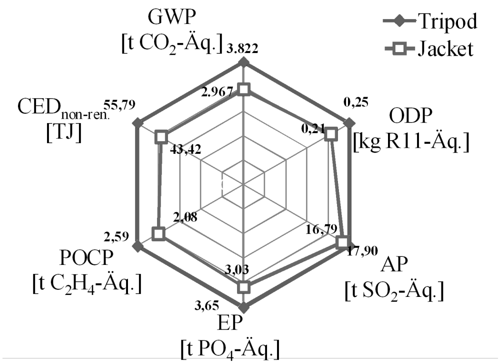

Figure 3: Polar-diagram reflecting ecological impact of Tripod and Jacket

Additional environmental effects of Tripod and Jacket structures are shown in Figure 3 by means of a polar diagram. The impact indicator values for Tripod and Jacket are included in the diagram, whereas the diagram centre displays the value zero as basis. Hence, applying the values for Tripod and Jacket leads to different spanned areas. Complementary to the results in Figure 3, these spanned areas show that the Tripod has a worse ecological impact than the Jacket due to the larger amount of steel.

Besides GWP and CED, the ozone depletion potential (ODP), the acidification potential (AP), the eutrophication potential (EP), and the photochemical ozone creation potential (POCP) are included in the study. Except for the AP, all indicators reflect an approximate similar difference in Tripod and Jacket results. The divergence regarding the AP results from the larger transportation distance of the Jacket components. The indicators integrated in the polar diagram are not weighted. Future holistic assessment concepts to evaluate the sustainability of steel structures for renewables may include weighting to consider the importance of different sustainable aspects. In the given example, the Tripod has a bigger impact on the environment than the Jacket. For both, the influence of the structures to the ODP is quite small.

7 Conclusion

The newly developed sustainability assessment containing the five important sustainability characteristics social, environmental, economical, technical, and process has been introduced. The effects of steel structure for Offshore Wind Turbines on the sustainability evaluation have been shown. Detailed investigations regarding a life cycle assessment of the substructures Jacket and Tripod showed the influence of steel mass and production location as well as transportation distance and manufacturing intensity. It could be shown that the steel mass of the Tripod has a bigger influence to the environment than the Jacket. For both structures, the evaluation for the individual life cycle stages indicated that the construction stage influences the ecological impact indicators significantly. As a result the, most decisive indicators cumulative energy demand, acidification potential, and global warming potential were evaluated.

Future investigations will concentrate on optimization potential for Offshore Wind Turbines regarding sustainability characteristics.

Literature

BNB (2010). *Assessment System Sustainable Building for Federal Buildings*, Federal Ministry of Transport, Building and Urban Development, Berlin, Germany (in German).

DGNB (2011). *Sustainable Building with System.* German Sustainable Building Council (DGNB), Stuttgart, Germany (in German).

DIN EN 14040 (2009). *Environmental management – Life cycle assessment – Principles and framework*, 11/2009, Berlin, Beuth press (in German).

DIN EN 15643-4 (2012). *Sustainability of construction works – Assessment of building – Part4: Framework for the assessment of economic performance*, German version, 04/2012, Berlin, Beuth press (in German).

DIN EN 15978 (2012). *Sustainability of construction works – Assessment of environmental performance of buildings – Calculation methods.* 01/2012, Berlin, Beuth press (in German).

Schaumann, P., Bechtel, A., Wagner, H.-J., Baack, C., Lohmann, J., Stranghöner, N., Berg, J. (2011a). Sustainability of Steel Constructions for Renewables, *Stahlbau*, 10/2011. p. 711–719, Berlin, Ernst & Sohn press (in German).

Schaumann, P., Böker, C., Bechtel, A., Lochte-Holtgreven, S. (2011b). Support Structures of Wind Energy Converters, *CISM Course and Lectures vol. 531 Environmental Wind Engineering and Design of Wind Energy Structures*, 2011: p. 191–253, Udine, Italy, Springer press.

Wagner, H.-J., Baack, C. Eickelkamp, T., Epe, A., Kloske, K., Lohmann, J., Troy, S. (2010). *Life Cycle Assessment of the offshore wind farm alpha ventus*, Münster LIT-press (in German).

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Onshore Wind Energy Development in China and its Implications on Natural Resources

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1 Introduction

Given the abundant potential of economically exploitable wind energy as well as its environmental friendliness and cost efficiency, the installed capacity of wind energy has grown rapidly globally as well as in China (Greenpeace and CREIA, 2011; IEA and ERI, 2011). Large-scale development of wind energy in China began in 2003 and has grown rapidly since then (IEA and ERI, 2011). From 2006 to 2010, China's total installed capacity of wind energy has doubled each year, and the largest part of this new capacity consists on onshore installations. By the end of 2011, the total installed capacity already reached 62 GW (CWEA, 2012). To achieve the national target of a 15% share of non-fossil fuels in primary energy consumption by 2020 (REF), wind energy will need to play an increasingly important role in China. The International Energy Agency (IEA) in collaboration with the China Energy Research Institute (ERI) developed a technology roadmap for wind energy in China, which claims that by the end of 2020 wind energy would contribute up to 5% of total electricity demand in China: 400,000 GWh (IEA and ERI, 2011).

Along with its globally increasing role in electricity supply, assessments of the sustainability of wind energy have drawn increasing attention. For example, its lifecycle-wide mitigation potential has been extensively assessed. However, a sole focus on its climate mitigation potential that overlooks the trade-off with natural resources is not sufficient to assess the environmental-friendliness, because the rapid global growth of wind energy required and will require significant amounts of mineral resources, amongst others critical metals.

Against this background, this study aims to address the lifecycle-wide material requirements of the middle-term onshore wind energy[1] development in China by: 1) exploring the development of the total abiotic material use of the onshore wind energy installation from the *start* of large scale development to 2020; 2) assessing the metal demand pressure of onshore wind energy development from 2009[2] to 2020.

2 Methodology

2.1 Assessing abiotic material use and metal demand pressure

To assess the abiotic material use of wind energy, i.e. the amount of industrial minerals, ores, and fuels extracted from the geosphere, a bottom-up input-oriented lifecycle approach was used in this study. The advantage of an input-oriented method is that all the material inputs that are extracted from the geosphere into the technosphere are measured, and thus indicate the potential impacts of all outputs on the geosphere. By definition, it does not provide an indicator for environmental impacts, but a proxy indicator of environmental pressures resulting from resource use. In contrast, output-oriented approaches can only assess a set of output indicators that are known, but disregard any other types of indicators (Schmidt-Bleek, 1997; Ritthoff et al., 2002).

The theoretical system boundary is between the technosphere and the geosphere. The abiotic material use includes all abiotic materials extracted for the direct and indirect[3] inputs required for the manufacturing, transport, installation, and operation & maintenance (O&M) of wind turbines as well as energy transmission[4].

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1 This study focuses on onshore wind energy, given its expected dominant role in Chinese wind energy installation until 2020 (IEA and ERI, 2011).

2 The start year 2009 is mainly attributed to the data availability of the share of different turbine technologies.

3 Direct inputs refer to those directly used in the wind turbine manufacturing. Indirect inputs refer to those inputs to the whole pre-process chain

4 In practice, cut-off rules are set up. Given the long lifetime of the networks and the large amount of energy they transmit throughout their lifetime, raw material inputs for constructing energy distribution infrastructures were not included. The inclusion of energy transmission in our model boundary is due to our consideration of the grid curtailment and transmission loss.

The abiotic material input in kg/kWh or kg/MW is calculated by dividing the total lifecycle-wide abiotic material requirement by the total amount of energy generated throughout the lifetime of the wind turbine, or by the turbine capacity, respectively. In fact, the abiotic material input is highly site-specific, because, for example, the dominant production procedure and inputs of steel, a major direct input flow, can vary significantly in different countries and thus require different abiotic material inputs. We calculate the material requirement of input flows as far as possible based on their production in China so that the assessment reflects the regional production conditions in China (Xia, 2011). The remaining input flows were calculated based on the Ecoinvent 2.2 database[5].

Furthermore, the so-called relative pressure on metal supply was assessed, an indicator comparing the total metal demand induced by the expected development of wind energy to the current annual global supply of these metals. These metal inputs cover all metal flows activated by the whole process chain of wind energy generation. The selection of the metals for the analysis is based on the global supply data ready to use.

3 System description and scenarios

Two types of onshore wind turbines were modeled in this paper: gearbox wind turbines and direct-drive wind turbines. The former still has a dominant share in the wind energy installation in China, while the latter has a lower, but growing share. The material assessment represents a combination of these two types of turbines that evolves over time[6]. For 2009, the installed capacity of permanent magnet (PM) direct drive turbines reached 2.4 GW, representing a share of 17% in the annual installed capacity. IEA and ERI (2011) assume a 45% share of PM direct drive turbines in the annual installed capacity in 2020.

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5 The input inventory of the ecoinvent process “ferronickel, 25% Ni, at plant/GLO/kg” was modified as follows:
- 0.4348 kg “Nickel, 1.98% in silicates, 1.04% in crude ore, in ground” (instead of 1.7404 kg)
- 1.3043 kg “Iron, 46% in ore, 25% in crude ore, in ground” (instead of 0 kg) This change was necessary due to erroneous high lifecycle-wide nickel use (due to steel use that in turn requires ferronickel).

6 Among the major two direct drive turbine types, the direct drive turbines based on electrically excited synchronous generators(EESG) have started only in 2012 to enter the Chinese wind energy market at a small scale and are thus disregarded here (MEB, 2012).

The state-of-the-art wind turbines were modeled with the help of manuals and technical reports of three selected Chinese manufacturers and information on installation practice in China (Chen et al., 2011). To explore the material use for wind energy generation in 2020, three scenarios were developed by considering the potential technology improvements that have direct influence on the material inputs as well as the improvements of wind energy grid connection. The scenarios are the baseline scenario, the advanced scenario, and the advanced_grid scenario (Table 1). In the baseline scenario, neither changes to the wind turbine technology nor grid improvements were considered. In the advanced scenario, technology improvements for wind turbines were modeled in terms of the capacity factor, turbine capacity, rotor size and materials, lifetime of the turbine and its components. An important challenge for wind energy development in China is the connection of wind farm to grid (e.g. Greenpeace, 2012; Qiao, 2012). By the end of 2011, 16.2% of electricity generated by wind was curtailed (Qiao, 2012), which was assumed to be the curtailment rate between 2009 and 2011. Given the ambition of the government to drive wind energy generation, we expected improvements would be made to enhance the power grid infrastructure and management. Thus, under the advanced_grid scenario, grid improvements were additionally modeled.

The annual shares of the gearbox turbines and PM direct drive turbines in the annual installed capacity were assumed to be the same under all three scenarios.

Table 1: Parameters used in the baseline scenario, the advanced scenario, and the advanced_ grid scenario

Scenarios		Current and Baseline in 2020	Advanced Scenario in 2020	Advanced_Grid Scenario in 2020
Reference turbines		Gearbox: SYFD 1.5MW PM direct-drive: Goldwind 77/1.5MW		
Turbine Capacity (MW)		1.5	3	
Tower	**Hub height (m)**	80	80	
	Tower Materials	Steel	Steel	
Rotor	**Diameter (m)**	82	100	
	Material	Glass fiber	A blend of carbon fiber and glass fiber (carbon fiber: 3600kg; glass fiber: 13636kg)	
Gearbox	**Lifetime**	Replaced Every 5 years[7]	Replaced Every 10 years	
	Feature	3-stage gearbox		
PM generator in direct-drive turbine		External rotor		
Capacity factor		25 % for gearbox turbine 28 % for direct drive[8]	29 % for gearbox turbine % for direct drive (+15% for each turbine type)	
Grid connection		grid curtailment (16%) grid transmission losses (9%) c		grid curtailment (10 %) and grid transmission losses (-30%)
Lifetime of wind turbine		20 years	25 years	

7 (Qianlong, 2012)

8 derived from IEA and ERI (2011) and GoldWind Science & Technology Co. LTD (2007) which states that the PM direct drive turbine generates 3–5% energy than turbines with double-fed generators

In order to project the abiotic material inputs development (kg/MW) between 2009 and 2020 under the advanced scenario and the advanced_grid scenario, a learning curve approach was applied, given that the material cost is significant for the total cost. In practice, the learning rates under a specific scenario were calculated based on the abiotic material inputs and metal demand of wind turbine (kg/MW) in 2009 and 2020 as well as the projected global cumulative capacity of wind energy in these two years.

Finally, the cumulative abiotic material use of onshore wind energy application from the *start* of large scale development to 2020 was calculated as the sum of the product of the material use (kg/MW) each year and the annual installation in China. The effect of recycling of wind turbines was neglected in the model as most wind turbines installed since 2003 were assumed to be still in use, given the average 20 year lifetime of the current wind turbine.

4 Results

First, our calculation indicates that, under the baseline scenario, a gearbox turbine has noticeably higher (16%) lifecycle abiotic material inputs per wind turbine capacity (kg/MW) than a PM direct drive turbine. Given the increased share of PM direct drive turbines and technology improvements, the lifecycle abiotic material inputs (kg/MW) would decrease between 2009 and 2020 under all scenarios, i.e. by 37% under the advanced and advanced_grid scenario and by 5% under the baseline scenario (Figure 1).

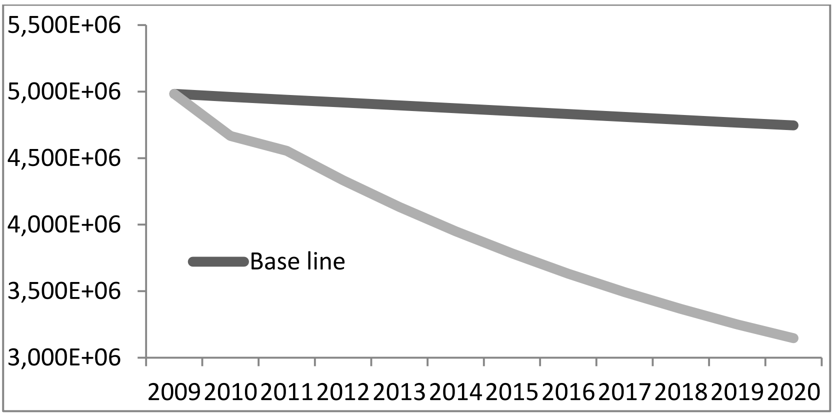

Figure 1: Lifecycle abiotic material inputs per wind turbine capacity (kg/MW) under the three scenarios

Figure 2 shows the cumulative abiotic material use activated by the onshore wind energy development in China between the start of large-scale wind deployment (2003) and 2020 under the three scenarios. Compared to the baseline, the cumulative abiotic material use would be 16% and 22% lower under the advanced scenario and advanced_grid scenario, respectively.

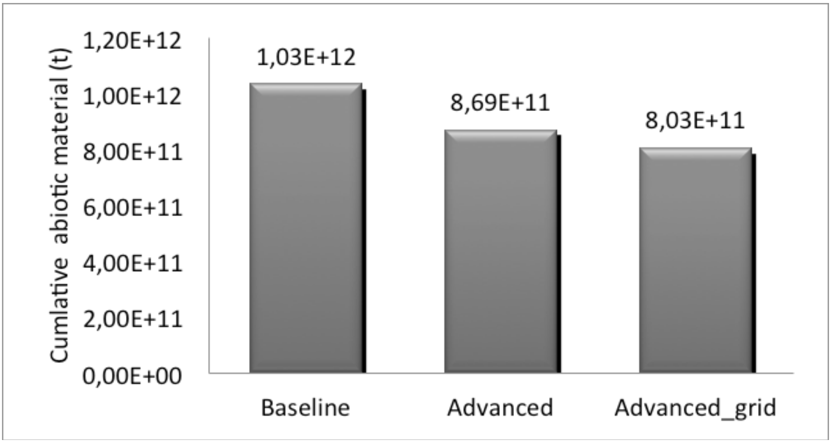

Figure 2: Cumulative abiotic material use activated by the onshore wind energy development in China between 2003 and 2020

Figure 3 to Figure 5 show the development of the annual demand for nine selected metals between 2009 and 2020. Under the baseline scenario (Figure 3), the annual demand of three metals would increase: copper (16%), molybdenum (5%), and neodymium (148%). In contrast, the demand for other metals would decrease. Under the advanced scenario (Figure 4), except for neodymium that would still increase significantly (148%), the demand of all other metals would decrease over time. Under the advanced_grid scenario (Figure 5), although the neodymium would still increase, the increase rate would not be as much as that under the other scenarios (75%) and would start to decrease from 2017.

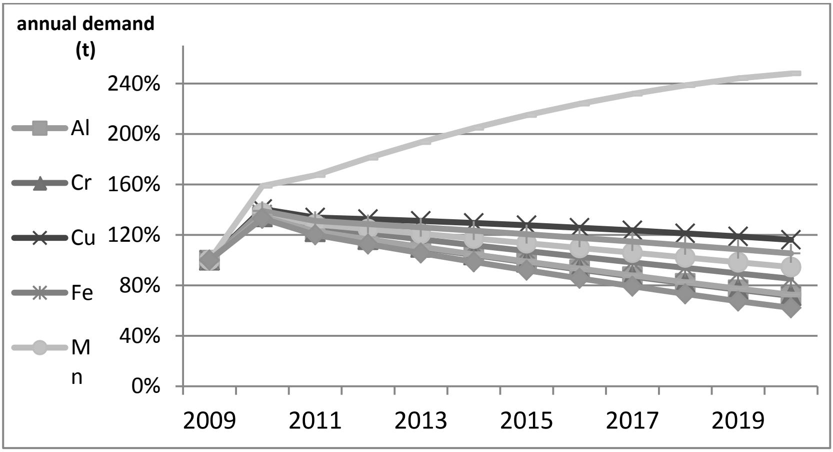

Figure 3: The development of the annual demand for the nine selected metals between 2009 and 2020 under the baseline scenario

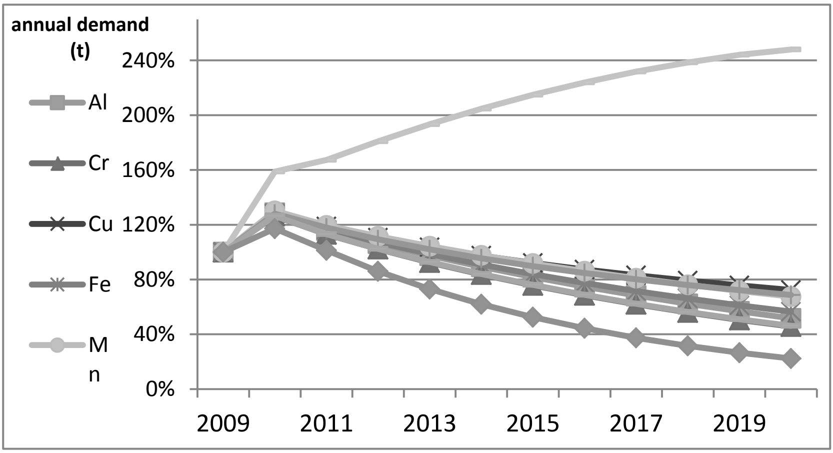

Figure 4: The development of the annual demand for the nine selected metals between 2009 and 2020 under the advanced scenario

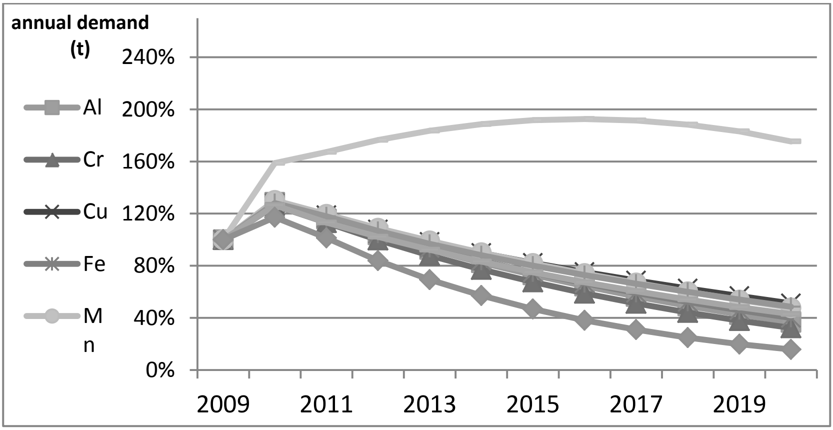

Figure 5: The development of the annual demand for the nine selected metals between 2009 and 2020 under the advanced_grid scenario

The relative pressure of the nine selected metals was calculated to assess the effect of onshore wind energy on metal demand (Figure 6 to Figure 8). Under all three scenarios, the relative pressures of most metals are clearly below 1%. In contrast, the relative pressure of neodymium would reach 6–8% in 2020. In addition, nickel also shows a noticeable relative pressure, i.e. 2–3% in 2020.

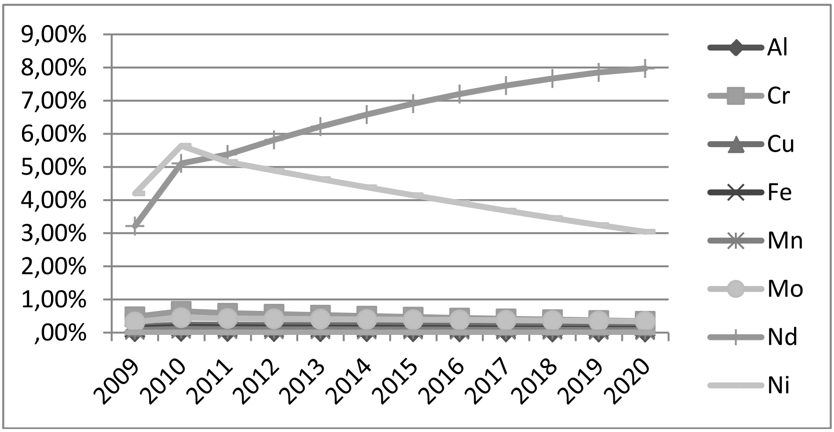

Figure 6: Development of the relative pressure of the nine selected metals between 2009 and 2020 under the baseline scenario

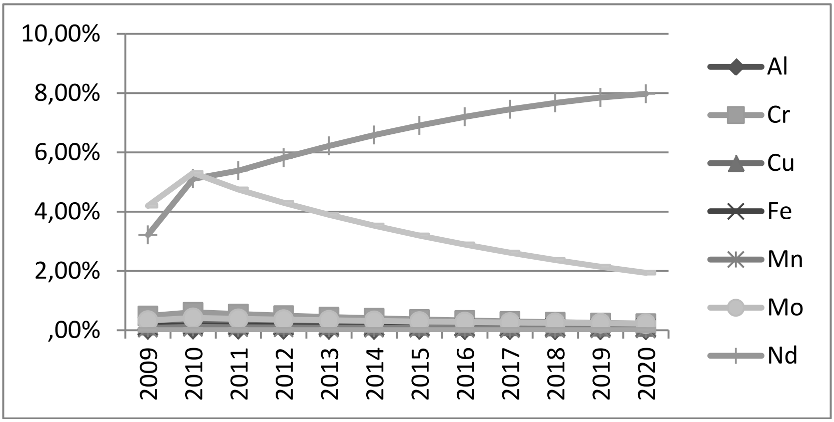

Figure 7: Development of the relative pressure of the nine selected metals between 2009 and 2020 under the advanced scenario

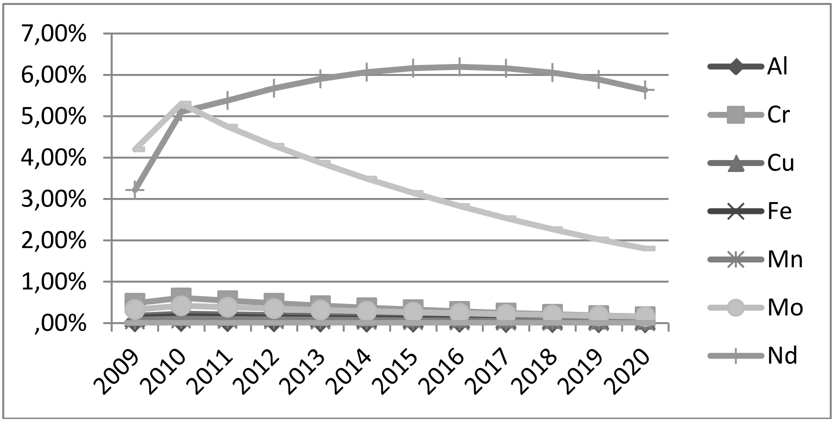

Figure 8: Development of the relative pressure of the nine selected metals between 2009 and 2020 under the advanced_grid scenario

5 Discussion and conclusion

This study explored the life-cycle-wide material requirements of the middle-term onshore wind energy development in China. A contribution of 5% to the total electricity demand by wind energy by 2020, as the IEA roadmap expects, requires significant amounts of abiotic materials. However, given the increasing share of direct-driven turbine technology, the improvements in wind turbine technology, and the improvements in grid connections, the cumulative demand on abiotic material inputs would be significantly lower than that without these improvements.

In terms of metal demand, along with the increasing share of PM direct drive turbines, neodymium demand would increase significantly under all scenarios, in comparison with the current demand. Also, its relative pressure, i.e. its demand against today's global supply, would be significant, reaching 6–8% in 2020. This could potentially pose a bottleneck in the production of PM turbines in China and contribute to the scarcity of neodymium on the world market. Such an impending scarcity could drive the market penetration of direct drive turbines based on the electrically excited synchronous generator (EESG), which is currently at the initial market phase in China. However, it is noteworthy that the EESG development could significantly contribute to an increased demand for copper. In addition, a relative pressure for nickel was also recognized in all scenarios, mainly as a result of chromium steel use. Given that chromium steel is used for numerous purposes, an extra demand for 2–3% of the global supply by the wind energy development in China alone could be significant.

Furthermore, despite the rapid installation of wind energy, the grid problem remains the most serious challenges to wind energy development in China. Our scenario analysis shows that the grid curtailment and grid quality in China can significantly limit the potential of wind energy to contribute to 5% electricity demand in a resource efficient manner. By solving the curtailment issue and improving the power grid infrastructures, the demand of both abiotic materials and different metals would decrease noticeably. For example, the increasing demand of neodymium would be moderated.

Finally, the robustness of the assessment can be enhanced by improved data on the manufacturing of wind turbines (e.g. PM direct drive turbine). The use of secondary materials also needs to be considered in the future study. In addition, the assessment will benefit from a more systematic uncertainty analysis, considering different types of uncertainties (e.g. parameter, model structure, etc.). Although the current analysis of the relative pressure of the selected metals has shown some basic patterns, the results should be further checked for their robustness. In particular, the quality of the assessment could be enhanced by considering scenarios for the future global and Chinese metal supply, due to the general dynamics of the supply of metals. For certain metals that face supply risks, projected Chinese supply could serve as an alternative reference measure.

For further research, a longer-term assessment of the impacts of wind turbine development on natural resources, including the recycling and reuse of existing turbine components and materials, would be interesting. To sum up, this study linked the life-cycle-wide environmental impact of single turbines and the wind energy development trend at the macro level to develop mid-term scenarios of the resource demand of large-scale wind energy application (in terms of abiotic materials and certain metals) in China. Despite the existence of uncertainties, the study provides decision-makers insights into potential impacts of the current middle-term renewable energy strategy on natural resources.

Literature

Chen, G.Q. (2011). Renewability of wind power in China: A case study of nonrenewable energy cost and greenhouse gas emission by a plant in Guangxi. Renewable and Sustainable Energy Reviews 15 (2011) 2322–2329.

CWEA (China wind energy association) (2012). Installed capacity of wind power in 2011.

Greenpeace (2012). China Wind Power Outlook 2012.

IEA (International Energy Agency) and ERI (Energy Research Institute) (2011). Technology Roadmaps: China Wind Energy Development Roadmap 2050.

MEB (2012). PM direct drive will experience market examination. Retrieved from: http://www.meb.com.cn/news/2012_02/20/560.shtml (in Chinese).

Qianlong (2012). Goldwind blow the new wind. Retrieved from: http://report.qianlong.com/33378/2012/03/26/1520@7816616.htm (in Chinese).

Qiao, L.M. (2012). China's Wind Development: Experiences Gained and Lessons Learnt. IRENA workshop, Copenhagen.

Ritthoff, M., Rohn, H.and Liedtke, C. (2002).Calculating MIPS. Wuppertal Spezial 27e. Retrieved from www.wupperinst.org/uploads/tx_wibeitrag/ws27e.pdf

Schmidt-Bleek, F. (1997).Wieviel Umwelt braucht der Mensch? : Faktor 10 – das Maß für ökologisches Wirtschaften.Munich: Deutscher Taschenbuch-Verlag.

Xia, C. (2011): Assessment of synergies between the potential for climate change mitigation and resource efficiency of the implementation of low carbon energy technology innovations in Wuxi, China. Master thesis. Freiburg University and Wuppertal Institute.

Resource Use of two Offshore Wind Farms in the German North Sea

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1 Introduction

This paper analyses the lifecycle-wide resource use of two offshore wind farms in the German North Sea. The first wind farm, pioneer project “Alpha Ventus” (WFAV), is Germany’s first deep-sea offshore farm. The second wind farm, “Bard Offshore 1” (WFBO1), will be the country’s first commercial deep-sea wind farm, scheduled to be fully operational by the beginning of 2014. Both wind farms are equipped with similar 5 MW wind turbines, but differ regarding their overall amount of turbines and their grid connection.

WFAV consists of six turbines of the type “Areva Multibrid M5000” and six “Repower 5M” turbines, both types with a rated power of 5 MW. Since the Multibrid M5000 material inventories were not available, it is accounted for with twelve Repower 5M turbines. The wind farm is connected to the inland high voltage grid by a 66 km long high-voltage rotating alternating current (HVAC) transmission.

WFBO1 represents a 400 MW offshore wind farm with 80 turbines of the type “BARD 5.0” (5 MW), connected by a 200 km high-voltage direct current (HVDC) transmission.

The paper on hand intends to illustrate the resource efficiency of recent and future wind farm technologies and, in particular, of their grid connection. Table 1 outlines the data of the two offshore wind farms used in the analysis.

Table 1: Outline data of analyzed wind parks

Scenario	WFAV	WFBO1
Rated power	60 MW	400 MW
Water depth	ca. 30 m	ca. 40 m
Middle full load hours (net)	3,667 h/a	4,250 h/a
Energy yield (net)	220 GWh/a	1,700 GWh/a
Blade diameter	126 m	122 m
Hub height	92 m over sea	90 m over sea
Foundation	Jacket	Tripile
Grid connection	110 kV AC	150 kV DC

2 Method

To measure the lifecycle-wide resource use, the method “material footprint” (“Material Input Per Service unit”, MIPS) is applied (Schmidt Bleek 1998; Ritthoff et al. 2002, Lettenmeier et al. 2009). The material footprint allows us to estimate the input-oriented consumption of natural resources (material input) of goods used to provide a specific service or benefit, and is measured in kilograms or tons of natural resources. The material inputs are divided into five resource categories:

- Abiotic resources (e.g. minerals and fossil fuels)
- Biotic resources (e.g. from agriculture)
- Water (surface, ground and deep ground water)
- Air (e.g. chemically changed parts)
- Soil movements in agriculture and silviculture

The material input is related to a use, which can be a good or a service, that makes up a “service unit”. In this study, the material input (in kg) refers to the generated electricity at grid connection point. Accordingly, the provided service unit is “MWh.”

To consider all data life cycle wide, material intensity factors (MIT-factors) are used. MIT-factors for different types of materials, modules and services are available online, published by the Wuppertal Institute (Wuppertal Institute, 2011).

3 Scope

3.1 System boundaries

The system boundaries include wind farm (wind turbines and internal cables) and grid connection (offshore platform(s), external cables). System border is the particular point of connection to the high voltage power grid inland. Regarding the WFBO1, parts of the onshore converter station "Diele" are also considered, as the construction of a second AC/DC converter is necessary to establish a HVDC transmission. The lifetime of turbines is assumed to be 20 years. Within this period, all components are accounted for. The exchange of components with a shorter life-time in the use phase is incorporated. Transports of components usually start at assembly point and they are transported via sea vessels, train or lorry.

3.2 Assumptions and limitations

In cases where there was no primary data available on the energy demand for the production and assembly of components, the energy demand is estimated with the help of blanket addition (Tryfonidou, 2006), based on data for the primary energy demand in different industrial sectors. In doing so, this procedure is subject to the assumption that all assembly and wrought material processes use 100% electrical energy from the national energy production mix. In this study, an overall majority of all assembly processes are assessed this way.

Production spill over incurred in the process of manufacturing wrought materials and components is evaluated using blanket material utilization grades of wrought material classes. A selection of these grades can be found in Pick and Wagner 1998, which is based on supplier data. While assumed to be accurate enough for usage in a MIPS analysis, the data might be outdated (1998) in terms of today's material efficiency in the supply chain of wind turbine components, and thus overrated.

The middle full load hours are a significant factor for the overall resource use of wind farms or any kind of energy production plants. As in this study, they are based on projections that might cause uncertainties in the results. In 2011, WFAV exceeded the prognoses, achieving 4,450 full load hours, which is about 15% more than projected (Krux 2012). Hence, the projected middle full load hours might be a conservative estimate.

The cut-off criteria for all assessments in this study accounts for 1% of the overall mass of the bill of materials, as well as the material inventories of each single component.

4 Material inventory

Data for the wind farms are mainly based on the studies Wiesen 2010 and Teubler 2011. However, in the case of WFAV, the length of the external cables has been adjusted from 80 km, which is a conservative estimate, to 66 km (Transpower, 2010). For WFBO1, the basic assumptions on the exchange of spare parts have been aligned to WFAV´s. Table 2 shows the wind farms' weight specifications. For the calculation, additional production spill over during assembly of components is included.

Table 2: Wind farm component weights (rounded)

Structure	WFAV	WFBO1
Wind turbine	1,520 t / turbine	2,590 t / turbine
Internal cables	400 t (25 t/km)	3,500 t (29 t/km)
Transformer / converter platforms	1,580 t	7,410 t / 4,970 t
External cables (marine / land)	5,180 t (85 t/km / 13 t/km)	9,520 t (60 t/km / 22 t/km)
Mass per MW_{rated}	420 t / MW	580 t / MW

4.1 Wind farm

In the case of the turbine Repower 5M, there was a high availability of primary data: Type and weight of components are based on data from the manufacturer Repower (Repower 2005). Because very few data were available for the BARD 5.0 turbine, it is assumed that – considering the similar technical specifications – main components like the gearbox, generator, and transformer are identical. Material compositions of components in general derive from either assumptions of the specific manufacturer, literature data, or expert appraisements.

4.1.1 Rotor and nacelle

The Repower 5M rotor blade is a 19 t fibre reinforced epoxy construction that is 61.5 m in length. In contrast, the BARD 5.0 blade is heavier (28.5 t and 60.0 m in length) and its reinforced fibre design is furnished with a PU core, in which the bonding epoxy is injected by VARTM[1]. The data on the nacelle components of the Repower 5M are mainly based on manufacturer specifications (Wiesen, 2010). The BARD 5.0 Generator, its frame, the bearing, as well as the azimuth-system are predominantly analogue to the 5M turbines of WFAV.

4.1.2 Tower and foundation

WFAV's specific tower weight (4.7 t/m length) is distinctly higher than WFBO1's (4.1 t/m length). However, the estimated weight of the Repower 5M tower is based on the tower of a prototype, while specifications of WFBO1 were published in a press release (Bard, 2010). The tower material composition (more than 90% of it is low alloyed steel) is based on an assumption validated by the manufacturer (Ambau, 2009).

The foundations in WFAV are conventional jacket foundations on four 33–44 m long foundation piles, weighing 766 t overall (Wiese 2009, Weser-Wind 2009), while the WFBO1 uses newly constructed tripile foundations. A Tripile foundation is consists of a massive (495 t)[2] support cross standing on three 85–105 m long foundation piles (up to 450 t each). Both foundations consist mainly of low-alloyed steel (CSC GmbH, 2011).

4.2 Grid connection

Wind turbines of WFAV are linked to a step-up transformer platform (30/110 kV, 75 MVA), which on its part connects the wind farm to the 380 kV AC grid inland via 60 km of submarine cables and 6 km of land cables. WFBO1 is equipped with a similar transformer platform (33/154 kV / 2x208 MVA) and a converter platform, connected to the mainland via a 150 kV HVDC cable link, separated into 125 km submarine cables and 75 km land cables. On the mainland, a converter station converts HVDC back to HVAC. Weight specifications and material composition of the transformer platform from WFAV is mainly taken from a component list of the manufacturer (Areva, 2009a and Areva, 2009b). For WFBO1, masses of the platform substructure and topside are based on H&W 2010, while for the transformer equipment data from WFAV were scaled up. The weight specification

1 VARTM: Vacuum Assisted Transfer Moulding
2 about 450 t in a new re-design (CSC GmbH, 2011)

of the HVDC platform is derived from manufacturer data (ABB, 2010), whereas the composition of key components like the transformer was mainly assessed using genuine EPD's[3] of ABB AG (e.g. ABB, 2003). The jacket substructures of the platforms are assumed to be of the same kind as jacket foundations in WFAV. Weight and composition of submarine HVAC and HVDC cables is based on a cable manufacturer (NSW, 2009) and literature data (Worzyk, 2009). While submarine cables have a copper core with a lead coat, land cables consist of an aluminium core with a plastic coat.

The inventory of the land-based equipment for the DC/AC-switch is assumed to be the same as the switch in the offshore station.

4.3 Recycling and end of life

As defined in the convention of the MIPS concept (Schmidt-Bleek et al. 1998), recycling of materials after the use phase is not considered within the system but shifted into the system in which the recycled material is used as secondary raw material. Regarding the deconstruction phase of the wind farms, the same resource consumption (component transportation) as that of the construction phase is accounted for.

5 Findings

The results of this study show that WFAV has a significantly higher resource use per MWh generated as WFBO1 in terms of abiotic resources, but not in water and air use (s. Fig. 1 and 2). The higher abiotic resource use of WFAV is caused by the external submarine cables. Due to their high content of resource intensive copper in the core, they alone account for 58% of the overall abiotic material input.

In case of WFBO1, the resource use for the production of the wind turbines (head mass, tower, foundation) has a major share exceeding that of the grid connection in all three categories. However, BARD 5.0 foundations and towers outweigh the Repower 5M's by two times resulting in a 50 to 60% higher resource use depending on the resource category.

3 EDP: Environmental Product Declaration (EDP's contain data on specific weight and material composition of HV generators, transformer or switchgear)

The comparison of resource use for grid connection (platforms and external cable) in all categories shows that the HVDC transmission is more resource efficient than the HVAC systems. This can be attributed mainly to the higher specific copper demand of HVAC three phase submarine cables in terms of length and power transmission. As wind farms in Germany are mostly located large-scale over 50 km from the coasts (Dena, 2012), HVDC transmission allowing less power loss and smaller cable cross sections could be economically and ecologically advisable. However, the HVAC cable connecting WFAV is presumably overdimensioned in relation to the transmitted power, since the cable seems not to be designed for the wind farm specifications.

Regarding the resource use of the German power mix (Table 3) it can be said that both offshore wind farms are a resource efficient option to generate electricity. The resource use for grid extension should certainly also be considered, and further research is necessary in this area.

Table 3: Resource use of wind energy and the German Power Mix 2008

Power plants	Abiotic Resources	Water	Air
WFBO1 (2012)	103	837	8
WFAV (2012)	162	948	9
German Power Mix 2008 (Wiesen 2010)	3,150	57,640	510

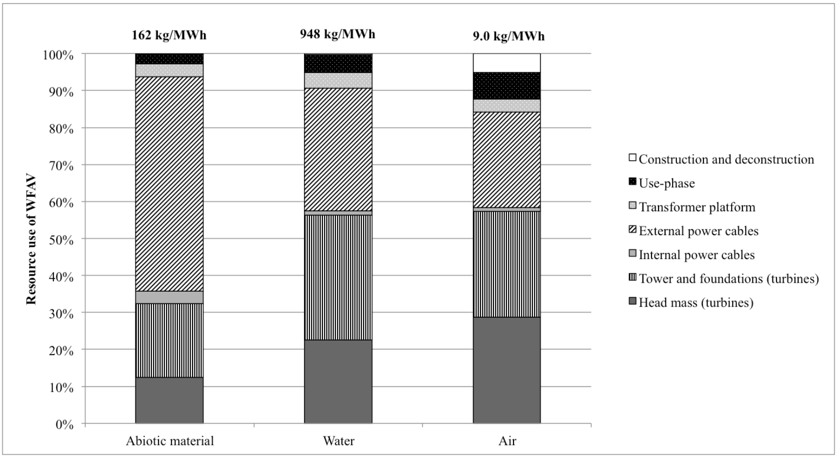

Figure 1: Resource use of WFAV for the subsystems wind farm (turbines, internal cables), grid connection (transformer platform, external cables), use phase, construction and deconstruction

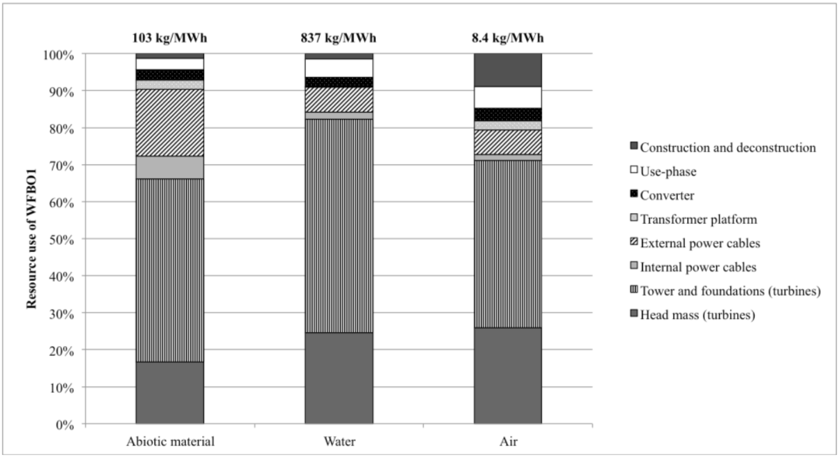

Figure 2: Resource use of WFBO1 for the subsystems wind farm (turbines, internal cables), grid connection (transformer platform and converter, external cables), use phase, construction and deconstruction

Literature

ABB (2010). Langstreckentransport von Offshore-Strom – Technische Lösungen und wirtschaftliche Betrachtungen. ABB AG presentation by Waldhofer, T.

ABB (2003). Environmental Product Declaration – Power Transformer 250 MVA. ABB Transmissione & Distribuzione S.p.A.

Ambau (2009). E-Mail communication. D. Bethke , 28.09.2009, AMBAU GmbH Stahl- und Anlagenbau, Werk Bremen.

Areva (2009a). E-mail communication. F. Zschoge, Projektabwicklung, AREVA Energietechnik GmbH. T&D Systems, Dresden. 13.11.2009.

Areva (2009b). E-mail communication .J. Harthun, Leiter Entwicklung und Konstruktion, Areva Werk Transformatoren, Mönchengladbach.

BARD (2010). Gute Nachbarschaft in Cuxhaven. BARD Magazin, Ausgabe 12. BARD Engineering GmbH. Emden.

BARD (2008). Aerodynamisch ideal – BARD-Rotorblätter sind auf maximalen Ertrag ausgelegt. BARD Magazin 6. BARD Engineering GmbH. Emden, 2008.

Birem, S. et al. (2004). Lebenszyklusanalysen ausgewählter zukünftiger Stromerzeugungstechniken, chapter: Windenergie. VDI, Düsseldorf.

CSC GmbH (2011). E-mail communication. Moeller, M. Teamleader Assembly and Construction at Cuxhaven Steel Construction GmbH.

Dena (2012). Website of Deutsche Energie-Agentur GmbH. http://www.offshore-wind.de/page/index.php?id=4761, accessed 05.08.2012

H&W (2010). BARD Offshore Transformer Completed. Press release January, 2010.

Krux (2012). alpha ventus: Forschung und Industrie präsentieren gemeinsame Erfolge. In: Kooperation international. VDI Technologiezentrum GmbH.

Lettenmeier, M., Rohn, H., Liedtke, C., Schmidt-Bleek, F. (2009). Resource Productivity in 7 Steps: How to Develop Eco-Innovative Products and Services and Improve their Material Footprint. Wuppertal Institute for Climate, Environment and Energy.

NSW (2009). Personal communication. Dr.-Ing. Michael Beigert, Norddeutsche Seekabelwerke GmbH, Nodenham. 19.10.2009.

Pick, E.; Wagner, H.-J. (1998). Beitrag zum kumulierten Energieaufwand ausgewählter Windenergiekonverter. In: Ökologisch verträgliche Energiewirtschaft. Arbeitsbericht. University GH Essen. Juli, 1998.

Repower (2005). RE5M, Massenübersicht: Zusammenfassung 2005-08-03, Repower Systems AG (confidential).

Ritthoff, M., Rohn, H., Liedtke, C. (2002). Calculating MIPS – Resource productivity of products and services. Wuppertal Institute for Climate, Environment and Energy.

Schmidt-Bleek, F. et al. (1998). Materialintensitätsanalyse. Hirzel, Stuttgart.

Teubler, J. (2011). Ökologische Betrachtung eines Offshore-Windparks unter Berücksichtigung der Netzintegration mit einer Hochspannungsgleichstromübertragung. Diploma thesis, 2011.

Transpower (2010). Erfahrungen bei der Planung und dem Bau des Netzanschlusses alphaventus. Transpower Stromübetragungs GmbH. Husum 2010.

Tryfonidou, R. (2006). Energetische Analyse eines Offshore-Windparks unter Berücksichtigung der Netzintegration, Dissertation, Ruhr-Universität Bochum.

WeserWind (2009). E-Mail commcunication. T. Braun, Projektleiter F&E, WeserWind GmbH Offshore. 20.09.2009.

Wiese, Lutz (2009). Informationen 04/2009. Press release, April 2009. Deutsche Offshore-Testfeld und Infrastruktur GmbH & Co. KG.

Wiesen, K. (2010). Ermittlung von Ressourceneffizienzpotenzialen der regenerativen Stromerzeugung durch Windenergie und Biomasse in Deutschland. Master thesis.

Worzyk, T. (2009). Submarine Power Cables – Design, Installation, Repair, Environmental Aspects. Springer.

Wuppertal Institute (2012): MIT Factors. Download at http://www.wupperinst.org/.accessed 05.08.2012

Rotor Blade Production – Resource Efficiency through Material Handling with Robotics

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1 Rotor blade production

Rotor blades consist of the following components (Figure 1): the root section (1), the aerodynamic surface of the blade (8), bars (2, 4), compression and tension spars (3, 5) and the platform (6). All these components are fibre reinforced polymer (FRP) composites with different requirements that have to be considered during the production processes.

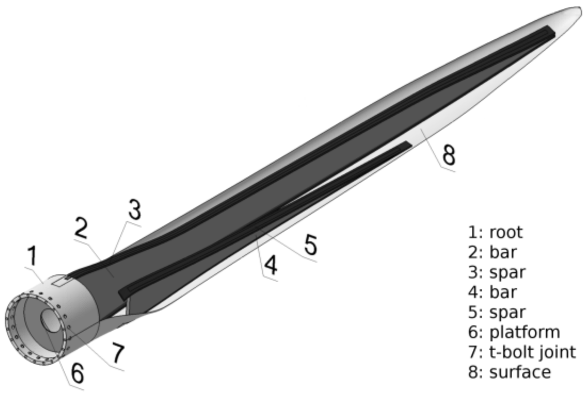

Figure 1: Schematic assembly of a modern rotor blade (according to [1, 2])

In recent years, liquid composite moulding (LCM) has been established for the manufacturing of fibre-reinforced plastic composites. One of these is the vacuum assisted resin infusion (VARI), which is particularly suitable for extensive construction parts and thus proves favourable for the manufacturing of rotor blades.

This process starts with the production of the semi-finished goods, the textiles, resin and auxiliary materials. Through a logistics process, these materials are brought to the production line. In a preforming process, dry fibre textiles are laid up into stacks followed by the LCM. During this procedure the textile preform is placed into a moulding tool, the release film and distribution layer is inserted and aired for the infusion process by means of a flexible counterplate, e. g., vacuum foil. A special resin hardening system is pressed into the ply construction due to the difference in pressure. This is followed by the annealing procedure, which gels and hardens the reactants. The annealing procedure can take place in a heated moulding tool. After curing, the components are assembled and finished (Figure 2).

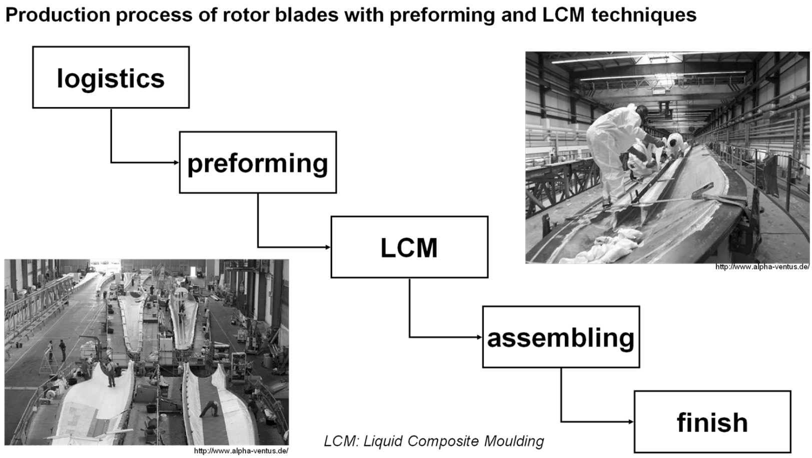

Figure 2: Production process of rotor blades with preforming and LCM techniques (pictures from http://www.alpha-ventus.de/)

The main focus of this analysis is the preforming process and especially the handling of dry fibre textiles. This process has a significant influence on the quality and production cost of the rotor blade.

2 Challenges in material handling during production process of rotor blades

During the production process of rotor blades, a large number of various materials need to be handled. Handling in terms of the production of composites can be divided into gripping, transport, positioning and lay-up of materials and semi-finished goads. Consequently, two groups of material types can be differentiated; “bending resistant materials” (BRM) and “dimensionally instable materials” (DIM). This diversification is necessary to categorize the specifications for handling systems, especially in terms of automation (Figure 3).

The group of BRM contains materials such as textile sheet goods that are on a material roll, or semi finished components such as composites. In comparison to this, dimensionally instable materials (DIM) are complicated in the handling process. One of the challenges in the production of composites is the handling of dimensionally instable non-crimp fabrics in the preforming process. Concerning the manufacturing method, the handling of dimensionally instable textiles becomes more essential for the production of large scaled composite structures such as rotor blades for wind turbines. During the handling process, the sensitive textiles can be damaged irreversibly. Textile damage caused by manual gripping processes leads to textile buckling or fibre displacement. These negative effects remain in the textile and in the preform. After vacuum infusion and curing, the described textile damages remain in the composite and reduce the quality of the component.

Process chain	bending resistant materials (BRM)	dimensionally instable materials (DIM)
Logistics	• textile sheet goods • auxiliary materials • resin + hardener	
preforming	• semi finished components	• textile pre-cuts • core materials • fixing materials
LCM	• resin + hardener	• vacuum-bag • auxiliary materials
assembling	• finished shells • adhesive	
finish	• paint • components	

Figure 3: Handling of materials in the production of rotor blades

Automation can help to reduce textile damage, increase the quality of composites and reduce the amount of material [3]. The automated build up of accurate and precise preforms is determined by the cutting system, the handling and in particular the placement of the textile material. As a consequence of a precise lay-up of textiles, and therefore higher process stability, safety factors defined by the design can be reduced. In this way, the total amount of material can be lowered. This leads to lighter components, less material cost and higher performance of the wind turbine.

3 Resource efficiency through material handling with robotics

Robotics in the production of rotor blades leads to a higher resource efficiency through material-adapted processes. This is based on different cases shown in the following paragraphs.

3.1 Material saving

By using automated systems in the production of rotor blades, textile cut-off waste can be reduced significantly. This is possible because of the precise cutting position of an automated system. Furthermore, tolerances in the overlapping layers, which are between 50 mm and 300 mm in manual processes, can be reduced. This leads to a reduction of material of approximately 0.31 m² per overlap (Reduction from 300 mm to 50 mm per overlap; layer width of 1270 mm = 0.31 m²).

Reduction of production waste is also possible through an innovative material management system specialised for the automated production process. This leads to a decreasing number of textile types (triax vs. ud+biax vs. ud+ud+ud) and of textile and roll width. Additionally, with the knowledge of the material use and material storage, which is only effectively usable with automated production processes, the material savings can be significantly increased.

The third approach is to reduce the fixing area of textiles outside the mould. Especially areas positioned at a 90° angle in relation to gravity, such as the root section, are affected. In this case, automatically applicable binder technology leads to noticeable material savings. For example with 300 mm width of the fixing area, a component length of 10 m and 50 layers (root section) 150 m^2 of textiles can be saved.

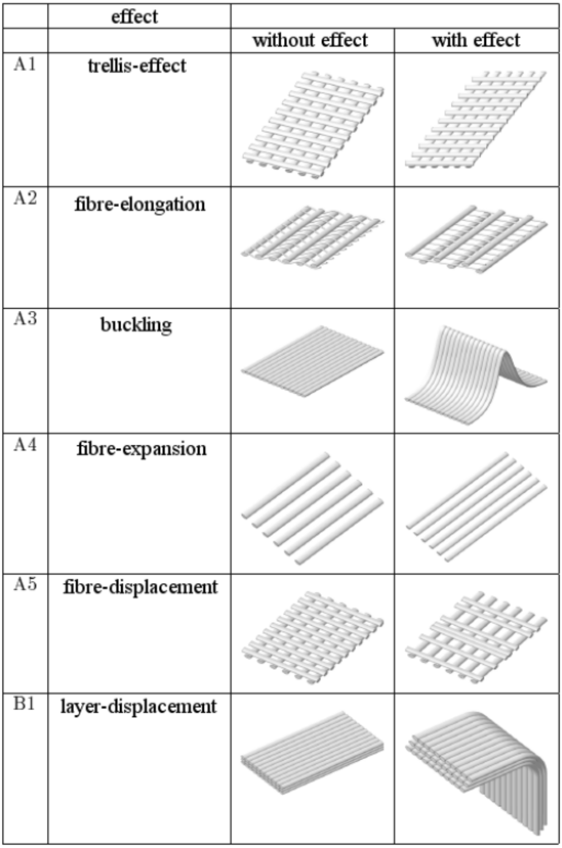

Figure 4: Different failure modes of fabrics and textiles [6]

3.2 Avoiding production waste

The production waste of technical textiles is decisively based on undesired textile, fabrics and handling effects. Handling of technical textiles can lead to different failure modes in the textile structure (Figure 4) like buckling or displacement.

These failures decrease the mechanical properties of final composites. Because of this radical influence on composite properties, the handling process is vital in the composite production process.

The damageable structure of textiles for high performance composite parts requires sensitive application of textile pre-cut parts in the mould [7]. The automated handling of these limp technical textiles is an effective tool with height reproducibility.

3.3 Design of rotor blade

Normally the design of actual rotor blades for wind turbines is affected by fluidic characteristics and technical strength. Due to the manual production processes, higher safety factors are necessary. This also results in additional textile plies and a higher weight of each rotor blade. The automation of the production processes decreases these safety factors and results in lower weight and higher quality. By approximate estimate, the reduction of 10% of the technical textiles (approx. 1,000 kg per rotor blade) is possible.

4 Realised automation

Various automation approaches have been developed by the BIK. Beginning with the rotor blade root section, an automated system for thick preforms was developed (project “preblade”). This system is able to cut textiles and build up stacks with 150 layers and different materials [4, 5].

Using the example of compression and tension spars, the direct placement of dry fiber textile pre-cuts was tested in the project “Large Area Robot.” The essential flexibility of the production of these components can be achieved with a mobile robot concept with innovative controlling systems. Both sensor technology and programming enable this system to react autonomously to material and process defects [8].

Further work for the research activities of the Institute will include the automation of textile handling for the rotor blade surface.

Literature

[1] Hau, E.: *Windkraftanlagen – Grundlagen, Technik, Einsatz, Wirtschaftlichkeit.* 4., vollständig neu bearbeitete Auflage. Berlin – Heidelberg – New York : Springer Verlag, 2008

[2] Weigel, L.: Fertigung von Rotorblättern für Windenergieanlagen im Vakuuminfusionsverfahren. In: *8. Internationale AVK-TV Tagung*. Baden Baden, 2005

[3] Gebauer, I.; Müller, D. H.; Ohlendorf, J.-H.; Kochmann, M.; Weigel, L.: Quality Improvement of Rotor Blades. In: *8th German Wind Energy Conference (DEWEK)*. Bremen, 2006

[4] Dörsch, C.; Ohlendorf, J.-H.; Gebauer, I.; Müller, D. H.; Weigel, L.: Teilautomatisiertes preforming zur Qualitätssicherung und Verkürzung von Fertigungszeiten von Windenergieanlagen. In: *Materialwissenschaften und Werkstofftechnik* 38 (2007), Nr. 11, S. 915–921

[5] Müller, D. H.; Weigel, L.: Gemeinsamer Technischer Abschlussbericht für das vom Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) geförderte Verbundprojekt „preblade" / Universität Bremen und Abeking & Rasmussen Rotec GmbH & Co. KG. 2008 – Forschungsbericht

[6] Ermanni, P.: *Composites Technologien*, Skriptum zur Vorlesung. Eidgenössische Technische Hochschule Zürich, Institut für mechanische Systeme, 2004

[7] Eberth, U.; Herrmann, A. S.; Meyn, T.: Stringerversteifte Schalen in der Textiltechnologie, In: *10. Chemnitzer Textilmaschinentagung*. Chemnitz, 2005

[8] Rolbiecki. M (Vortr.); Thoben, K.-D.; Müller, D. H.: Large Area Robot – Automated Production of Rotor Blade Tension and Compression Spars. In: *WIND ENERGY & ENVIRONMENT FORUM, JEC Asia.* Singapore, 2010

Recycling of Rotor Blades from Wind Turbines

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1 Introduction

Renewable energies and especially wind energy technologies have been implemented in modern power generation systems over the last few years. In parallel, the thoughts and concepts about sustainability play a major role in technology development. Concerning onshore wind energy, wind turbine size and technology status have been developed over the past few years. This development started a period in which not only new wind turbines have been built, but old wind turbines have also been dismantled. Concerning the sustainability of wind energy, it is important to consider the material flow, waste treatment possibilities and capacities of these replaced machines.

2 Waste treatment situation in 2012

The processes of recycling the material starts with the dismantling of wind turbines. Concerning the different units of a standard wind turbine, it can be divided into the following parts:

1. Foundation
2. Tower
3. Gearbox
4. Generator
5. Electronic Components
6. Rotor blades / Nacelle

The dismantling of foundations and towers is not a problem, and these parts are crushed or fragmented on site. The concrete used for the foundation will be treated and afterwards it can be used for construction, e.g. in road construction. One common material for the tower is steel with an epoxy resin coating. After the dismantling on site, a material recovery is possible and the steel can be used as scrap in the steel industry.

The gearbox consists of cast iron, lubricants and oil. The oil can be reprocessed and the rest of the gearbox can be separated into metal fractions or parts of it can be refurbished. After a refurbishment, a re-use is possible. For other metal parts, a material recovery is possible.

The generator is made of cast iron, copper and electronic devices. It is possible to separate the different materials and – depending on the condition – to refurbish some parts for re-use or to choose the material recovery pathway.

The rotor blades and the nacelle are the problem when it comes to dismantling and handling the material afterwards. The rotor blades are made of fibre-glass reinforced plastics, and after dismantling, it is possible to cut down the material on site. In Germany, combustion is the only solution afterwards. Disposal in landfills is not possible in Germany as the material contains around 30% organic material. It exceeds the threshold limits of the German landfills regulation act. Figure 1 shows the possibilities for the waste flow according to German legislation. It can be seen that disposal in a landfill is no longer an option. But the paths of recovery with either recycling or energy use provide options for the treatment of rotor blades.

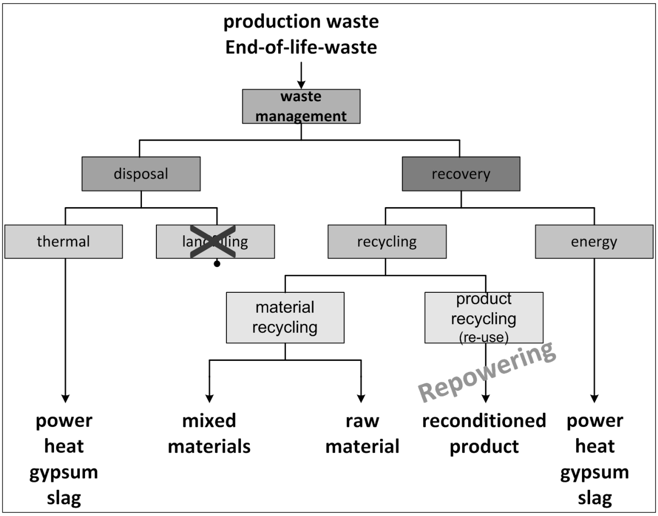

Figure 1: Waste flow scheme in Germany

3 Treatment Technologies for FRP

After the dismantling of the wind turbine and cutting down the rotor blades, the material can be taken to an incineration plant. The capacities of incineration plants for crushed rotor blades are limited. The other way is an energy recovery and material recycling by using the crushed rotor blades in a cement plant. In Germany, HOLCIM is applying this technology in full scale. At the moment, there is no large scale plant for FRP recycling. Companies like ERCOM, Seawolf Design Inc. or ReFiber Aps tried to implement large scale material recovery but so far none of them have had enough success to operate in an economical way [Albers et al, 2009].

4 Treatment capacity forecast

Full scale technology developments have to look for treatment capacities as a main influencing factor. First, a traditional approach was used for the treatment capacity forecast. As can be seen in Figure 2, the basis for the traditional approach was the amount of installed wind turbine capacity per year. According to a 20 year life cycle of wind turbines, the amount of installed capacity was shifted 20 years with the assumption that the material used in the construction needs to be treated at the end [Albers et al, 2008]. As the average composition of a wind turbine is known, it was possible to determine the amount of waste for different fractions. For a start, this approach was good as it presented a first impression of the material flow over the next few decades. For a more detailed consideration of other influencing factors, a more advanced approach was needed.

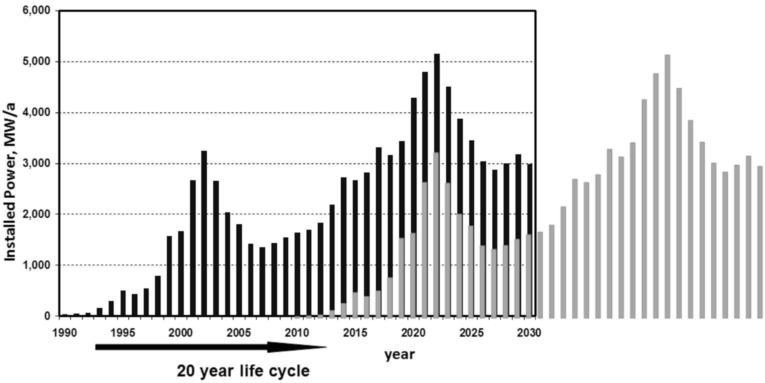

Figure 2: Traditional approach for material flow prediction

This advanced approach also takes into account that larger wind turbines are built nowadays. The resulting increase of performance is reached by less or the same or more specific material input. The point in time at which wind turbines are dismantled is also influenced by reuse or repowering actions of old wind turbines. With the Renewable Energies Act (EEG), an incentive for repowering is offered to operators under certain conditions, and therefore the wind turbines may be dismantled before they have been operating for 20 years [Wessels, 2011]. The material of these plants needs to be treated earlier. A reuse of wind turbines can also decrease the material that needs to be treated. By means of a study, a conversion factor was determined. According to the study and our own calculations, this conversion factor is assumed to be 10 kg of rotor blade material per kW of installed capacity of a wind turbine.

The main factors influencing repowering and reuse actions are the age of the turbine, relevant legislation, performance class, hub height, rotor diameter, market value, condition, and maintenance status. Age, performance, class, and brand have been identified as driving factors [Wessels, 2011].

With the advanced approach, a prediction tool was developed. Figure 3 shows the basic assumption. In each year, an already existing quantity of wind turbines is available. Each year, old wind turbines are dismantled, re-used, or repowered, and new wind turbines also come into operation. At the end of one year, a new quantity of wind turbines is the basis for the next year. According to Wessels's approach [Wessels, 2011] there is a distinction between the different performance classes in Figure 3.

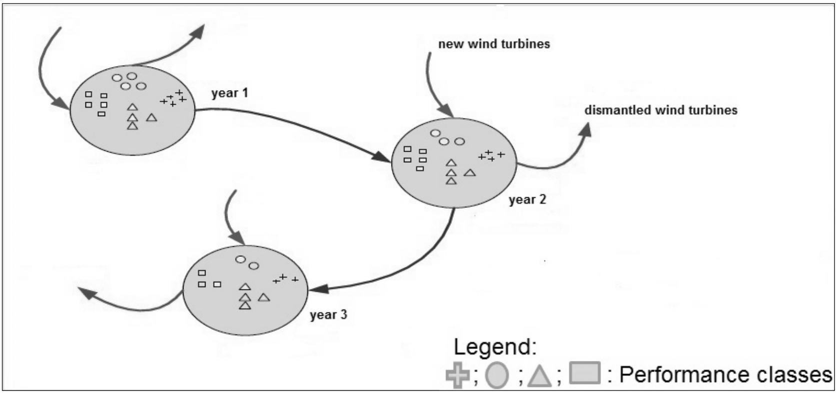

Figure 3: Model of the prediction tool

Figure 3 describes the basis for the changing numbers of wind turbines over the years. Market observations show that many factors influence the numbers of wind turbines dismantled in one particular year. As a consequence, different scenarios have been set up. These scenarios are shown in Figure 4. These different scenarios are the basis of the advanced approach for materials and mass calculations. Wessels [Wessel, 2011] started with scenario C1 and C2 looking at the masses available for recycling and reuse in a particular period. The other scenarios include the regular running time as well as an extended running time, in the case that the operator has the possibility to run the wind turbine longer than 20 years. Other scenarios include the change of large components prior to lifetime end, irreparable damage followed by re-cycling of the material, or the use of the components as replacement parts, and the dismantling of wind turbines due to elemental damage before the end of the running time.

The results of Wessels's work for the scenarios C1 and C2 will be described in the following.

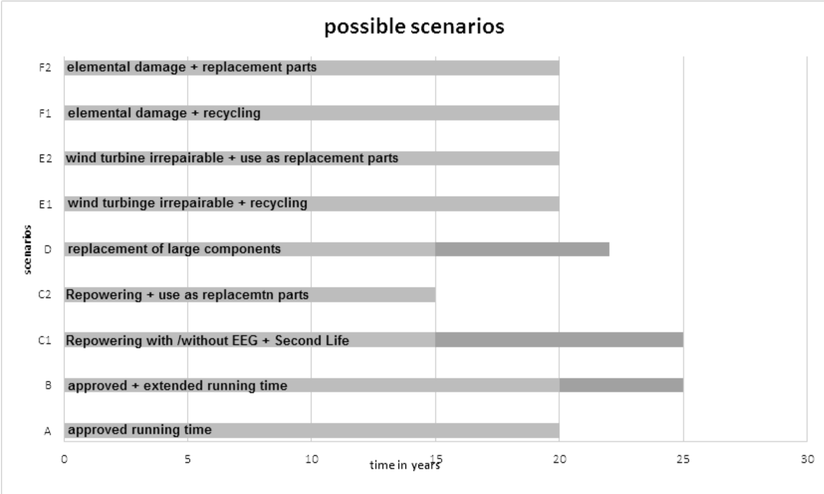

Figure 4: Possible scenarios of the advanced approach

Wessels [Wessels, 2011] used the basis of the advanced approach for a forecast. He divided wind turbines into four performance classes:

- up to 500kW
- 501 to 1,000kW
- 1001 to 2,000kW
- more than 2,001 kW

The early repowering is meant for the repowering of wind turbines after 10 to 15 years. The second scenario is based on the late repowering after 15 to 20 years.

For both scenarios, Wessels modeled the reuse and the recycling potential until 2020. The results are shown in Figure 5.

The prediction tool considers factors for repowering and material composition of the wind turbine.

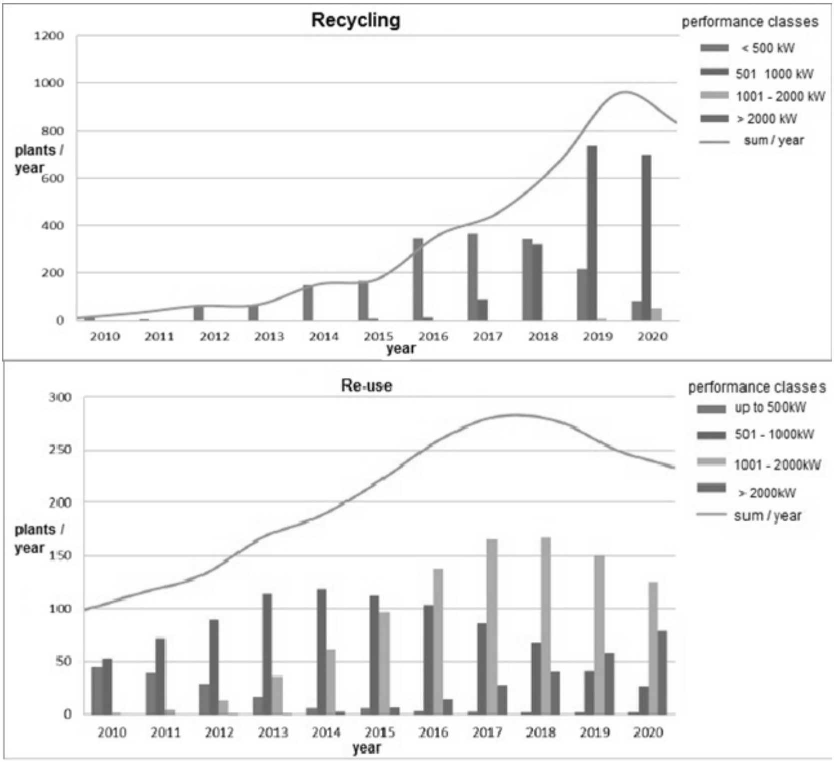

Figure 5: Scenario with late repowering after 15 to 20 years lifetime

The results for the scenario referring to late repowering are shown in Figure 5. The late repowering is expected to be the most probable scenario, and therefore the peak of material available for recycling and reuse will be around the year 2018. This prediction only concerns the potential for re-use; re-use could take the form of a second life. The market for previously used wind turbines may have much capacity, but in order to make a valid statement, this scenario needs further investigation.

With the identification of the scenario with the late repowering as the most probable one, it is possible to make a prognosis on the material composition available for recycling. This prognosis is shown in

Figure 6. According to this figure, the amount of available FRP in particular will increase within the next few years. The other materials available for

recycling like copper, aluminium, electronic waste and liquids are also increasing in the same ratio. Concerning the statement of Figure 6, it can be said that the share of FRP is increasing from around 200 tons in 2010 up to almost 7,000 tons in 2019 and 2020. Now it is important to put these numbers into relation with the available capacities and the waste flow of other materials. So far with the HOLCIM treatment pathway, it is possible to recycle around 6,000 tons per year. In addition, a thermal waste treatment capacity of around 19 millions of metric tons [UBA, 2012] is available in Germany. Therefore, the capacity is not the problem at the moment. According to Kranert et al. (2010), the amount of residual waste per person and year is 204 kg. This means that 40,000 people generate 8,160 kg of residual waste, and that is more than the amount of FRP that can possibly be in 2019. It has to be said that the amount of FRP available for recycling is a prognosis. With increasing re-use, less FRP needs to be treated, and with less re-use, more FRP have to be treated. The other uncertainty is the amount of repowering. With increasing repowering, more rotor blade material will be available either for re-use or recycling. An interesting mechanism could be a second life market in the future when wind turbines that have not been in use for too long or which are in a very good condition are dismantled.

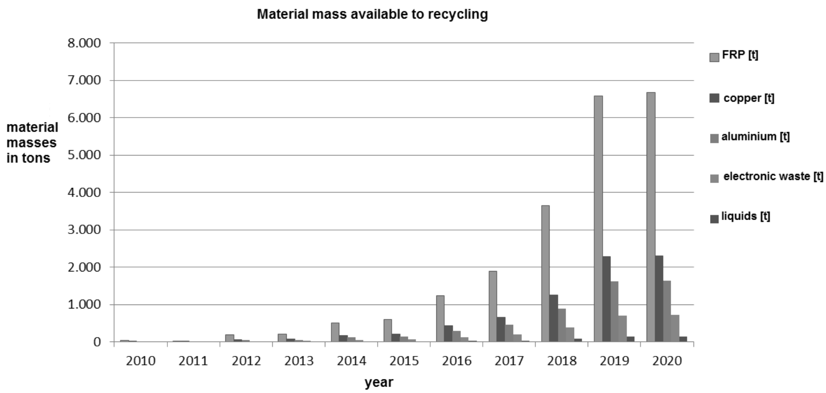

Figure 6: Material mass available for recycling in the scenario of late repowering

5 Conclusion

In conclusion, it can be said that the FRP waste flow will strongly influence treatment technology capacity building. At the moment, the market is assumed to be a small one with high mass flow fluctuations and poor forecast data. Repowering actions, changes in waste and energy regulations and international second life market mechanisms will play a major role as input factors to further technology developments. But overall, the mass flow of rotor blade material is due to increase within the next decade.

Literature

Wessels, D. (2011). *Recycling von Rotorblättern – Potenziale und Möglichkeiten*. Master Thesis Bremen, Hochschule Bremen – University of Applied Sciences.

Albers, H. et. al. (2009). *Recycling of Wind Turbines Rotor blades – Fact or Fiction?*. Albers, H., Greiner, S., Seifert, H., Kühne, U., DEWI Magazin Nr. 34, S. 32–41, 2009

Albers, H. et al, (2008). *Recycling of Fibre-Glass Reinforced Plastics*, Albers H., Greiner, S., Kühne, U., Seifert, H., 11.AVK Tagung Essen, 23.09.2008

Kranert, M. et al. (2010). Einführung in die Abfallwirtschaft, Kranert M., Cord-Landwehr K., Vieweg + Teubner, Wiesbaden, 2010

UBA, 2012: Umweltbundesamt, Wörlitzer Platz 106844 Dessau-Roßlau http://www.umweltbundesamt-daten-zur-umwelt.de/umweltdaten/public/theme.do?nodeIdent=2307 (last access: 29.10.2012, 19:06 o'clock)

Designing a Synchronised Material and Information Flow within the Logistics Network of the Offshore Wind Industry

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1 Introduction

The concept of sustainability has the aim to develop material, products and processes which are future-orientated, cost-saving as well as material-saving. Using this concept within an emerging industry, the leading question for this contribution is: "How can concepts of sustainability be applied to logistic processes of the offshore-wind industry?" To pursue this question, processes and technologies that support the basic aims of sustainability have to be adapted and further developed. A significant step regarding these aspects will be discussed in the following contribution. The logistics network can be improved by automatically synchronising the flows of material and the associated pieces of information. To achieve these improvements, specific technical equipment is needed to identify objects and process information.

This article shows the design of the logistics network of offshore wind industry including its processes and actors. Based on this network, the concept of synchronising information and material flow will be developed. Additionally, the technical aspects will be presented.

2 The Logistics Network of the Offshore Wind Industry

The main processes within the network of the offshore wind industry are production, transport over land and sea, storage, handling and installation on the offshore site. The main components of an offshore wind energy plant are the foundation structure, the tower sections, the nacelle and a set of three rotor blades. Pre-assembly of these components can be performed at intermediate steps within the network. Every process that is implemented on a logistical object within the network can be summed up as material flow. A material flow causes new information. The pieces of information also have to be assembled and documented as they are passed on to other actors in the logistics network. At present, this information flow is mainly organised manually. An automation of the information flow can decrease time, delays and errors and thus helps to establish efficient logistical processes. Figure 1 shows the described logistics network that results from a comprehensive study of offshore-wind farm projects (Schweizer et. al 2011).

Three tasks have to be performed to achieve the synchronised logistics material and information flow:

- Development of standardised logistics processes
- Design of information flows for the logistics network
- Implementing information- and communication technology within the network

These tasks will be specified subsequently.

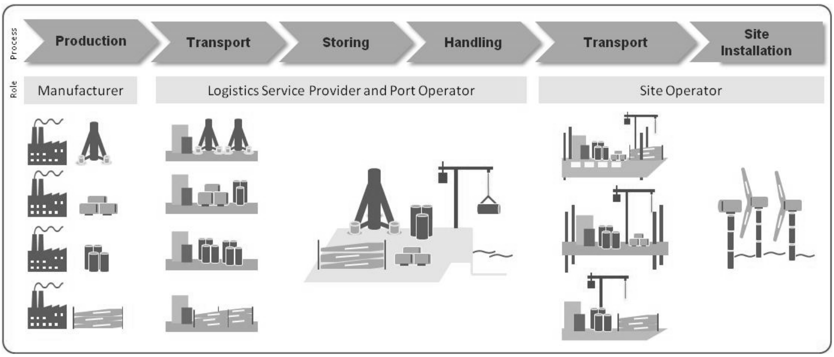

Figure 1: The logistics network of the offshore-wind industry (Schweizer et. al, 2011)

3 Development of standardised Logistics Processes

The installation of an offshore-wind farm can be organised as a project (see Gerdes et. al, 2005). Standardised logistic processes within the project need allocated resources for transport, storage and installation. This task is complex due to the amount of different strategies used for the installation of an offshore wind farm. These include the selection of a suitable vessel concept for the installation, a port concept and a transport concept for the offshore material supply.

Regarding the selection of an installation vessel, four different ship designs are used in offshore wind energy logistics. Pontoons, heavy duty crane ships, and jack-up platforms have to be towed by a tugboat. The jack-up vessel is equipped with its own marine engine. The installation of offshore foundations can only be achieved with the crane of the jack-up vessel. The remaining components can, however, be installed using the cranes of heavy-duty crane ships and jack-up platforms. (EON, 2010). Only one vessel can perform the material transport from the port to the offshore site. It is called the mono vessel concept. The ship is also used to install the components with its own equipment and resources. The feeder vessel concept consists of at least two ships. One vessel always stays at the construction site to install components while the other(s) supply(ies) components. (IFF, 2010).

The selection of a port concept is based on the integration of ports into the logistical network. Three different concepts can be differentiated here: the first is the "consolidation concept." It uses one port for all manufacturers where all of the main components can be supplied and loaded. The second concept is called "bus concept." This is implemented if every manufacturer uses a different port, and the vessel that is responsible for the picking-up calls into the various ports for the loading of the components. The third concept is a combination of these two concepts. (ZDS, 2010).

In Schweizer et al. (2011) the authors present the wide range of dynamic and controllable disturbances that can occur within the network. Logistic processes need to be designed to react to these disturbances. The greatest disturbance, which is also presented by the authors, is called backward-push. If a logistical object is not installed the right way at an offshore site, it causes logistics handling effort, because it cannot be stored temporarily anywhere on the site. It is usually performed at onshore sites. These challenges have to be compensated for by the logistics network.

<table>
<tr><th rowspan="3">Concept</th><th rowspan="3">Components</th><th colspan="8">Liftings</th><th rowspan="3">Liftings Total</th></tr>
<tr><th colspan="3">Tower</th><th rowspan="2">Nacelle</th><th rowspan="2">Hub</th><th colspan="3">Blade</th></tr>
<tr><th>below = s3</th><th>middle = s2</th><th>top = s1</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td>1</td><td>single components</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>8</td></tr>
<tr><td>2</td><td>bunny ears, seperate installation of tower components</td><td>|</td><td>|</td><td>|</td><td colspan="4">|</td><td>|</td><td>5</td></tr>
<tr><td>3</td><td>bunny ears, s2 and s1-section pre-assembled, s3 seperate</td><td colspan="2">|</td><td>|</td><td colspan="4">|</td><td>|</td><td>4</td></tr>
<tr><td>4</td><td>bunny ears, pre-assembled tower componentes</td><td colspan="3">|</td><td colspan="4">|</td><td>|</td><td>3</td></tr>
<tr><td>5</td><td>blade star, seperate installation of tower components</td><td>|</td><td>|</td><td>|</td><td>|</td><td colspan="4">|</td><td>5</td></tr>
<tr><td>6</td><td>blade star, s2 and s1-section pre-assembled, s3 seperate</td><td colspan="2">|</td><td>|</td><td>|</td><td colspan="4">|</td><td>4</td></tr>
<tr><td>7</td><td>blade star, pre-assembled tower components</td><td colspan="3">|</td><td>|</td><td colspan="4">|</td><td>3</td></tr>
<tr><td>8</td><td>completely pre-assembled offshore wind turbine (without foundation)</td><td colspan="8">|</td><td>1</td></tr>
</table>

Figure 2: Installation concepts of offshore wind turbines (Hermann, S.A., 2002)

As an offshore wind turbine mainly consists of nine major components, it is essential to analyse how they are assembled. Besides the foundation, offshore wind turbines consist of three tower segments; nacelle, hub and three blades. Figure 2 shows eight different concepts of installation ranging from single component installations up to a completely pre-assembled wind turbine and the associated number of liftings.

4 Design of Information Flows for the Logistics Network

As the offshore wind industry is emerging and standards are lacking, the information flow also has to be developed. We propose to apply the concept of awareness. Awareness helps the actors in the logistics network to be aware of the status of a specific logistics object or another actor. As we are focusing on the logistical objects, we present the concept to automatically generate information regarding an object. This is achieved by the integration of identification and communication technology. The concept also addresses the idea of sustainability. The components of an offshore wind turbine can be subsumed as logistics objects. Most of the logistics objects are transported on load carriers; they will be equipped by an identification and localisation box, which generates data for the tracking and tracing of the object. The current load carrier cycle of the logistics network of the offshore wind industry uses three pools of load carriers.

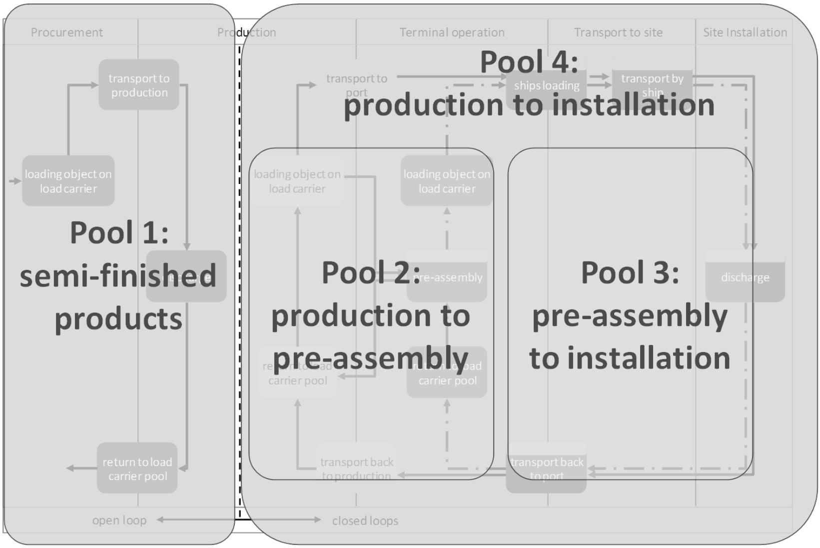

Figure 3: Current load carrier cycle including three pools within the offshore wind industry (following Beinke et. al 2012)

Load carriers for semi-finished products are subsumed in pool 1. Most components are transported by using load carriers from pool 2 and 3. Pool 2 uses load carriers from within the production to a pre-assembly at the port of shipment. Load carriers of pool 3 are used to transport pre-assembled components from the port of shipment to the installation site. It is necessary to reload and secure the components when changing load carriers. If one central pool of load carriers – like pool 4 – can be established for all components, the aim of sustainability and process security will be accomplished.

Load carriers that are used during and after production are mostly organised in different pools, although it is a central goal to avoid reloading. After unloading, the load carrier is transported to the process step during which it was initially inserted into the cycle. One aim when considering the different load carrier pools and different components is to reduce the amount of pools. The overall objective is to develop one standardised load carrier and therefore one pool of load carriers for a specific component. Furthermore, technology can be equipped to implement the requirements regarding information flow.

5 Technology

- Different technologies can be applied to design an intelligent load carrier.
- Sensors: temperature, moisture, orientation etc. – the information can be used for product assurance
- Identification: The identification of a logistics object will be relevant to optimise the organisation of the logistics network, as components are individually managed
- Localisation: Using GPS helps to track & trace the components during transport. The concept of virtual planks (described below) can be implemented by the technology
- Communication: As information is gathered by the logistics object, the information needs to be transferred to other objects or control stations within the logistics network
- Data processes: The logistics network itself needs a specific infrastructure to distribute the generated data within the logistics network

The benefits resulting from an integration of technology into the load carrier pools and handling divide as follows: the implementation of a logistics cycle will be achieved by using standardised load carriers during production, transport and assembly. Damages can be significantly reduced, as reloading will not be necessary. The logistics operations can be improved by virtual planks for planning and controlling of processes. This approach is also used in (Scholz-Reiter, 2008). The virtual planks help to identify disturbances within intermediate process steps of the network by matching the current local position of a logistics object to a pre-defined area. Furthermore, automatically generated information which implements the requirements of standardised information flows and processes can be used to design robust processes.

6 Results

The proposed concept combines standardised logistics processes of the project's specific logistics network and automatically generated and distributed information. This information flow is based on a standardised process concept that has to be defined with the participation of all actors in the logistics network. The information regarding location and status of a specific logistics object helps to plan and control the processes within the network, especially under dynamic disturbances such as weather conditions or damaged components. Figure 4 shows the general idea of the concept by focussing on load carriers for the rotor blades. During every single process step from production through transport, storing, and transport to offshore site, the identification device sends information to a database, which is accessable by every network-partner using a customised IT-system. The system can be used to plan, control, and simulate the logistics processes based on real-time information.

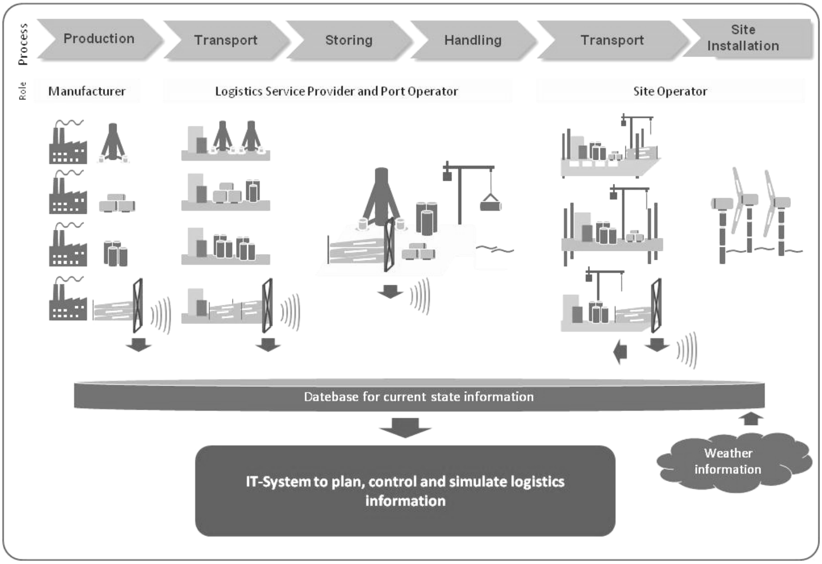

Figure 4: Automatic generated information within the logistics network

7 Conclusion

The concept presented here points to a synchronised material and information flow that uses automatically generated information from communication devices applied to load carriers within the logistics network of the offshore wind industry. The concept helps to apply fundamental ideas of sustainability for example by reducing efforts within the logistics network through the design of standardised processes and information flows.

Literature

Beinke, T.; Quandt, M.; Schweizer, A.: Offshore-Windenergielogistik: Supply Chain Event Management und Tracking and Tracing Technologien für ein stabiles Logistiknetzwerk. Chemnitz, Germany. Symposium „Vernetzt Planen und Produzieren 2012 & Symposium Wissenschaft und Praxis“. To appear in proceedings 12/2012.

EON Climates and Renewables GmbH: E.ON Offshore-Windenergie Factbook. Online available. 2010.

Gerdes; Tiedemann; Zeelenberg: European Offshore Wind Farms. A survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms. Case Study. Online available. 2005.

Hermann, S.A.: Offshore Wind Farms. Analysis of Transport and Installation Costs. ECN. Study. Retrieved from http://www.ecn.nl/docs/library/report/2002/i02002.pdf (last access: 21.09.2012).

IFF Magdeburg, ISL Bremen: Verbesserung der Planungsgrundlagen für kampagnengeprägte Supply Chains (SC) am Beispiel von Offshore-Windenergieanlagen (OWEA). Available online. 2010.

Schweizer, A.; Beinke, T.; Scholz-Reiter, B.: Das Logistiknetzwerk der Offshore-Windenergie. Bewältigung dynamischer Einflüsse. In: Industrie Management 06, 2011 S. 9–12.

Scholz-Reiter, B.; Toonen, C.; Virnich, A.: e-Logistik im Umfeld der Logistikdienstleistungen. Industrie Management 24 (2008), S. 13–16.

ZDS – Zentralverband der Deutschen Seehafenbetriebe e.V.: Offshore-Windenergie: Lastenheft Hafenwirtschaft. Online available. 2010.

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Posters

How Critical is Wind Energy?

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1 Introduction

Wind energy is experiencing high importance not only in the EU but in the whole world, as the Global Wind Energy Council (GWEC, 2010) indicates in its report of 2010. The growing trend of wind energy markets around the world in the next twenty years is evident, with a higher growth in North America, Europe, China, and India.

Due to the fact that wind energy is renewable, we want to achieve that most materials needed for wind turbines shall be sustainable from the beginning until the end of their lifecycle. As the tower or other components are made of steel, aluminium, or recyclable materials, most of the whole wind turbine could be considered as sustainable. An average life span of wind turbines is expected to be twenty years, but due to repowering, the life time is reduced to ten years. After ten years of generating wind energy in Western Europe, wind turbines are often exported to Eastern Europe for energy generation.

In this paper we are going to focus on resource needs of a wind turbine and if there will be any shortages of resources in the coming years.

2 State of the Art in the Development of Wind Energy

Wind energy has grown rapidly in recent years. Despite the economic crisis of several countries, Europe's wind energy sector is still growing to achieve the environmental goal established by the EU's new Renewable Energy Directive (2009/28/EC), setting an EU renewable energy target of at least 20% of final energy consumption by 2020 (GWEC, 2011).

However, several countries such as Spain and Germany go beyond this goal; both of these countries belong to the top 5 in terms of wind power capacity installed worldwide. Spain established a 22.7% energy consumption (IDAE & IDAE, 2012) on its National Renewable Energy Action Plan (NREAP) 2011–2020. The Spanish employer association, Asociación Empresarial Eólica (AEE), comments that the plan is “not ambitious but reasonable given the economic situation” (McGovern, 2011).

According to a political decision by the German government, atomic energy will no longer be tolerated, and there is a strong focus on renewable energy. Therefore, there is a sustained effort in Germany to expand renewable energies and especially wind energy. The percentage of renewable energy of the gross end energy consumption should increase to 60% by 2050, according to the goal of the German government, which is an even more ambitious goal than that of Spain. This will be achieved by an increase to 18% in 2020. Due to the fact that available land is scarce in Germany, onshore wind energy plants will be repowered, and offshore wind energy parks are going to be installed in the North Sea (Alpha Ventus Park for example).

Nowadays, the total installed power of wind turbines in the European Union amounted to almost 94 Gigawatts (GW) in 2011 with a percentage of 4.04 from offshore turbines (EWEA, 2012). In the same year, the sum of worldwide wind power installation equalled 238 GW with a percentage of 1.72 from offshore turbines (REN21, 2012).

The European Wind Energy Association (EWEA) as the voice of the wind industry estimates that the development of wind energy plants will equal up to 735 GW installed power by the year 2050, which corresponds to 50% of the European power needs (Arapogianni, 2011) as shown in Figure 1. Worldwide, power generated by wind turbines will increase to an estimated 3000 GW.

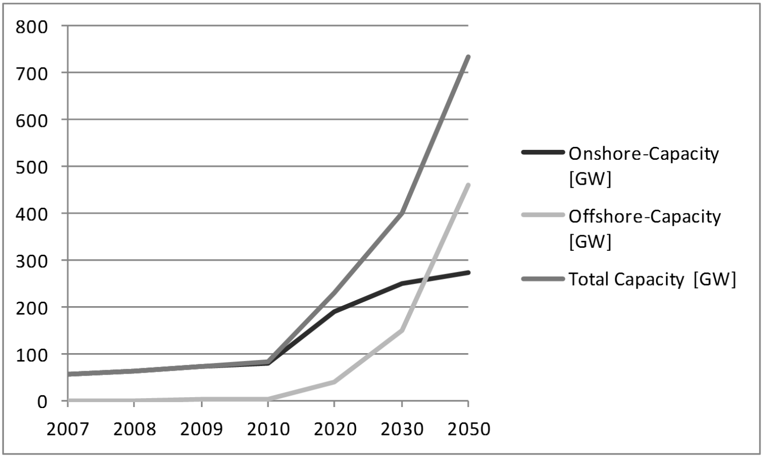

Figure 1: Forecast of installed power of wind turbines in Europe until 2050 (Arapogianni, 2011)

3 Components of Wind Turbines and their Life-Cycle

Considering the whole life-cycle of wind turbines from the material point of view, several general phases are identified relating to material and information needs. The phases identified are research & development, production, logistics, construction, operations & maintenance, and end-of-life. From the materials point of view, all these phases are parts of a chain that nowadays is partly linear. It would be beneficial if it were to become a closed-loop in the near future, which is already the tendency in the wind industry sector.

Strictly speaking, the research & development phase does not involve any bulk materials. However, this is the crucial phase to take into account the kind of materials employed as well as the quantity of them involved in the "posterior" phases, when wind turbines are developed and manufactured. Further work on this area will yield innovative and more sustainable solutions.

The production phase is the starting point of a wind power plant life-cycle with regards to materials that are needed as raw materials or feedstock and have to be extracted and transported to the manufacturing plant beforehand. The materials involved in the production phase include steel and cast iron (towers, nacelles, rotors, etc.), pre-stressed concrete (towers), magnetic materials (gearboxes), aluminium (nacelles), copper (nacelles), wood epoxy (rotor blades), Glass Fibre Compound (GFK) (rotor blades), and Carbon Fibre Compound (CFK) (rotor blades). In the future, the use of composites of GFK, CFK and steel will likely increase due to increasing numbers of wind power plants (Jacobson & Delucchi, 2010).

The amounts of materials needed to produce a wind power plant, as well as the costs related to them are shown by percentage in
Figure 2.

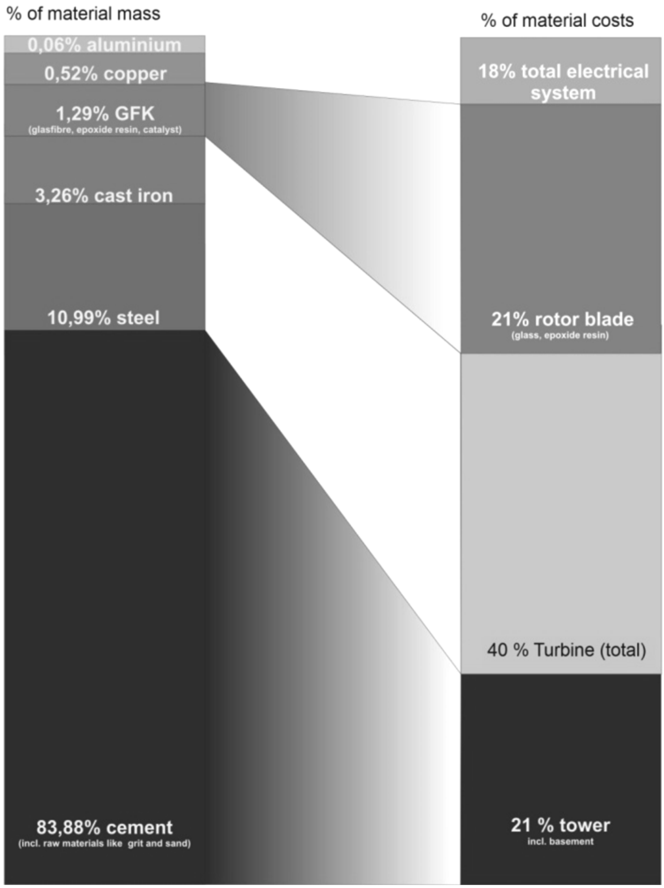

Figure 2: General material and cost composition of a wind power plant

Big challenges apply to the logistics and construction phases due to the size and the final location of the wind power plants, but there is no extra need of materials for the wind power plants apart from what was already planned in the production phase.

Every sector in the operations & maintenance phase applies to preventive maintenance to maximize the operation effectiveness of the machine, or in this case, the wind power plant. However, other maintenance strategies can be useful to minimize the amount of material needs for the proper operation of a wind power plant. Possible maintenance strategies could include predictive maintenance, which measures variables directly from the equipment, or proactive maintenance, which involves directly corrective actions aimed at addressing the root causes of failure. Maintenance monitoring is possible with a reliability centered maintenance (RCM) approach, which is the main tool for improving the cost-effectiveness and control of maintenance, hence improving availability and safety (Hameed, Vatn, & Heggset, 2011). New materials used in maintenance approaches for monitoring are being researched, as a smart pint developed by Scottish researchers made of recycled materials that can detect microscopic faults in wind turbines before structural damage occurs (Daily, 2012). The combination of the RCM tool and different maintenance strategies is going to increase the reliability of wind turbine components, which is reflected in increasing the environmental performance of the wind turbine due to longer life times, as well as reducing unexpected failure that could mean the need of a replacement part and its associated material requirement. By increasing the reliability of products – here the components of wind turbines – we increase the environmental performance of the wind turbine due to longer life times. Longer life times save resources for new products and are always the best environmental solution.

An ideal end-of-life would be that the whole wind power plant's bulk could be recycled or reused to produce a new wind power plant or other kind of product. A comparison of the materials involved for production and construction of wind power plants with the percentage of these materials that can be recycled indicates that the industry is on the right track to achieving a fully closed-loop. In order to be able to generalize, as far as possible, we have made the following assumptions for this comparison:

- The wind turbines selected are on-shore wind turbines. The foundation of the wind turbines play an important role in the amount of material used, and in the case of off-shore wind turbines, there is no unique technique for the foundation with an important variety of steel involved in the different current solutions like Tripod and Jacket (see Schaumann et al. 2012, page 25).

– The materials involved are just the ones used in the wind turbine, not other peripheral materials like the ones involved in the electrical network, for instance.
– The rotor blades are recycled as a substitute fuel in cement plants; this process is explained in detail in the rotor blade sub-chapter.

Table 1: Recycling percentage of the materials used in the production of a wind power plant

Material	Recycling %
Aluminium	100
Copper	97
GFK(Glass Fibre Compound)	100
Cast iron	98
Steel	100
Cement	80

More than 90% of the wind turbine can be recycled. An unknown figure represents the total recovered cement of the foundation onshore and especially the steel removed from the sea. The tripods, for example, are mounted in the sea, and after a life expectancy of 20, 30 or 40 years, we will be curious to see the decommissioning process.

Furthermore, we have to look at the materials involved for production and installation of a wind turbine and estimate the percentage of these materials that can be recycled in a realistic manner. It cannot be a sustainable solution to invest more resources into recycling efforts than the recycled resource itself.

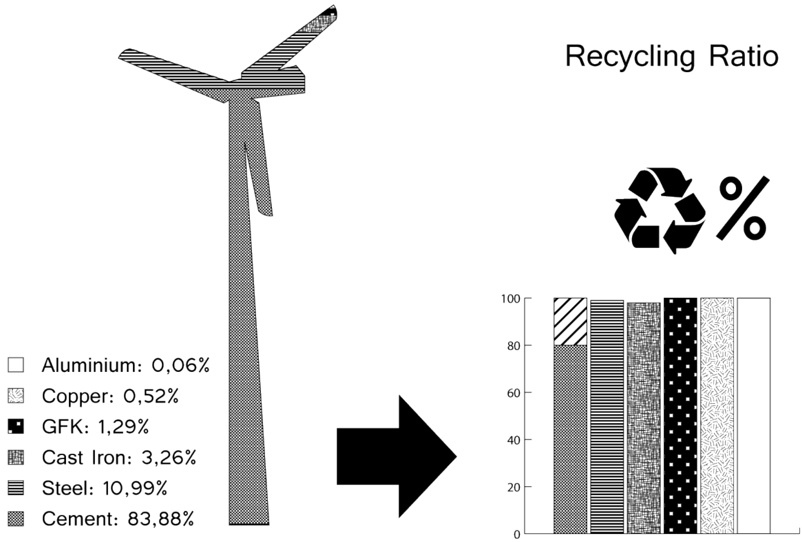

Figure 3: Recycling percentage of the materials used in the production of a wind turbine

In the following chapters some parts of the wind turbine are presented in detail.

3.1 Nacelle

The nacelle contains most of the electrical equipment of the turbine and therefore contains the most metals. The casing is either made of cast iron or of thermoplastics or GFK, respectively. The electrical equipment is composed of cast iron (generator, drive, etc), aluminum, copper, and other metals that are considered critical within the European Union.

Seven critical metals are used in the wind energy sector. Dysprosium, neodymium, and terbium are used in the permanent magnets of a generator, the remaining metals chromium, manganese, molybdenum, and niobium are typically used in the nacelle of a wind turbine as stainless steel type 316 and as high-grade steel 18NiCrMo7 (Kleine, 2012). These metals can also be found in other alloys. It can be observed that there is a trend towards an increased use of critical metals in permanent magnets (Michel, 2010) due to the advantage that the generators operate more effectively through less weight.

Table 2: Composition of permanent magnets [Buchert, 2011 and Kooroshy, 2011]

Source	Fe	Nd	Dy	B	Tb
Öko-Institut (Buchert, 2011)	65%	30%[1]	3%	1%	<1%
Shin Etsu Chemical (Kooroshy, 2011)	66%	29%	3%	1%	n.a.
Great Western Minerals Group (Kooroshy, 2011)	68%	31%		1%	n.a.
Technology Metals Research (Kooroshy, 2011)	69%	28%	2%	1%	n.a.
Avalon Rare Metals (Kooroshy, 2011)	n.a.	30%	n.a.	n.a.	n.a.
Average Composition	67%	29.25%	2.67%	1%	0.08%[2]

These permanent magnets are suitable for use in synchronous generators with or without gear. In literature, the composition for permanent magnets in gear-less turbines varies between 533.5 kg und 850 kg per Megawatt.

Table 3: Permanent magnets (PM) in kg per MW of gearless wind turbines (Buchert, 2011, US Department, 2011 and Kooroshy, 2011)]

Source	Kg PM / MW
Öko-Institut (Buchert, 2011)	533.00[3]
US Department of Energy (US Department, 2011)	600.00
Shin Etsu Chemical (Kooroshy, 2011)	625.00
Great Western Minerals Group (Kooroshy, 2011)	670.00
Technology Metals Research (Kooroshy, 2011)	800.00
Avalon Rare Metals (Kooroshy, 2011)	850.00
Average mass of permanent magnet PM [kg/MW]	679.75

Based on the value of 679.75 kg permanent magnet per Megawatt wind turbine power and comparison with the values of Table 2, we are able to

1 Contains unspecified mass of Praseodym
2 Calculated by the difference of 100% minus the sum of the other materials
3 Calculated by the mean value of the MIN value of 400kg and MAX value of 667kg PM/MW

calculate the mass of dysprosium, neodymium, and terbium for a gearless wind power plant as shown in Table 4.

Table 4: Critical metals in permanent magnet generators of a wind turbine (Kleine, 2012)

Critical Metal	Kg / MW
Dysprosium Dy	18.15
Neodymium Nd	198.83
Terbium Tb	0.54

The required raw materials for the worldwide expansion of wind power (+2800 GW plant capacity) cannot be provided from the available raw material reserves except for molybdenum and dysprosium. Therefore, the exploitation of further resources or the recovery of raw materials from scrap metal is of high importance. Only the metals chrome, manganese or niobium have sufficient resources.

The raw materials dysprosium and terbium have the strongest indications for possible supply bottlenecks by the year 2050.
Depending on the resource, it is possible that there are losses of at least 60 per cent during the recovery process. It can even be a complete loss of raw materials if we look at the critical metals which are needed for permanent magnets due to the current lack of recycling technologies.

3.2 Rotor Blades

As mentioned in the beginning of the chapter, most rotor blades are manufactured with Glass Fibre Compound (GFK) and only a few with Carbon Fibre Compound (CFK). Due to the high costs of CFK, it is used only in parts where rotor blades have to cope with the highest stress. In the other parts with less stress load, GFK is used. CFK has also the advantage of less weight compared to GFK if both have to deal with the same stress. Considering the total weight of one single rotor blade (7 tons for a 40 m GFK rotor blade), the reduction of weight is of great interest to the manufacturers.

An estimate of the expected amount of rotor blades used is difficult at this moment. Rotor blades are the only part of the wind turbine where there is no proper recycling established. There are already efforts to use crushed rotor blade materials as substitute fuel in cement plants. Geocycle is already per-forming the energy and material recovery of rotor blades in Germany (Schmidl et al, 2010). A life time expectancy of rotor blades is estimated at 20 years or more, but they are often replaced earlier (after 10 years) because of repowering issues and better rotor blade design.

The manufacturing of rotor blades can be compared to the manufacturing of passenger car tires because there is a competitive market and no manufacturer publishes its procedure for rotor blade production, as it is their competitive advantage. Every rotor blade manufacturing company has a different way of building rotor blades that makes their product different, because even the materials involved in production are the same ones, but in different proportions to get the desired properties. In addition, on-shore and off-shore rotor blades have a similar material composition, just varying in size and design.

The main component consists of GFK or CFK layers (up to 30 layers) with thermoset resin infusion and bonding agents (Brøndsted, 2005). This compound is designed to never separate by itself in order to cope with the high stress (like passenger tires in use on the road). Due to the length of rotor blades, there are variances in mass and material and an estimate of an average is difficult to make. The fk-wind institute and the University of Applied Science in Bremen have published their research findings on the recycling of rotor blades (Albers et al. 2007). Through interviews with industry partners for rotor blades manufacturing and use, they were able to identify a correlation between the installed power and the mass of the rotor blades: 1 kW installed power refers to 10 kg materials (Albers et al. 2007).

However, the disposed material that is related to rotor blades consists of more components than just the old rotor blades from wind farms. Because rotor blades are primarily produced by hand and not by an automated process, the cut-offs and the waste produced during the production process consists of a certain amount of different and mixed materials. Furthermore, there are semi-finished rotor blades that need to be disposed of due to failures in the production process. A solution for these problems would be beneficial from the point of view of resource efficiency as well as the economic interest of producers.. The reduction of waste during the production process of rotor blades and a proper system for waste collection could make it possible to reuse or recycle some waste materials, resulting in an improvement of the over all sustainability of these parts of the wind turbine.

Some solutions for dismantling old rotor blades currently exist, but are they environmentally sustainable? One popular possibility in recent years in the EU is repowering wind power plants so the rotor blades from Western Europe are replaced with new and more energy efficient ones after around half of their life-cycle. The old rotor blades are then sold to other countries that will have the problem of final dismantling in the future. This solution is an energy strategy followed by some wind parks, but strictly speaking, cannot be considered to be a dismantling option.

The routes followed until now to dismantle rotor blades are a) landfill, b) incineration, and c) recycling. A): Landfill disposal is the easiest solution, but not an environmental sustainable one; it is no longer allowed in the EU due to the high (30%) organic content of rotor blades (Larsen, 2009). B): The incineration route is also called combined heat and power (CHP) plants where the heat of the incineration is used to create electricity, but there is also a negative side to this solution, since 60% of the input is left behind as ash after incineration. C): In the recycling options we find two approaches; the old one is material recycling, in which only 30% of GFK can be re-used to form new GFK, with most going to the cement industry as filler material (Larsen, 2009). A new recycling possibility has been developed in Germany and has been working since May 2010; this solution is a new process that guarantees the complete thermal and materials recycling of GFK. In this solution, the ashes from used rotor blades are used as a corrective in clinker composition in cement production; the substitution of fossil fuels contributes to the protection of natural resources (Hinrichs, 2012).

This is the current situation with rotor blade materials and production, but is this the most sustainable solution that we can offer? Some manufacturers are beginning to study the possibility of using thermoplastic composites in the production of rotor blades (Gardiner, 2008). Furthermore, Delft University Wind Energy Research Institute (Bersee, Teuwen, & Rasool, 2010) are looking into the appropriateness of this solution, paying attention to composite properties, and they have developed a 1 meter prototype. Moreover, the company Éire Composites sited in Ireland is leading a research project called GreenBlade to produce glass-fibre reinforced polypropylene (Twintex®) thermoplastic wind turbine blades for 15kW and 6kW machines. For the production of these blades, they use the patented MechTool tooling system, which can be used for rapid and cost-effective production of rotor blades. The current phase of the project is developing 12.6 meter long prototype blade in thermoplastic composites (Composites, 2012). The use of this material has certain advantages and poses some challenges, but the most attractive advantage is that it could be easier to recycle the whole rotor blade at the end of life, as well as the possible manufacturing waste and cut-offs from the production process. Is this solution applicable for larger rotor blades? Is it economically sustainable for producers?

4 Conclusion and Outlook

This paper intends to raise the awareness of materials used in wind turbines during their whole life cycle, including recycling. There are still many questions open during the wind turbine's life time. We presented an overview on the resources commonly used for the operation of wind energy power plants. Cement, steel and cast iron make up the largest share in turbine composition, representing more than 95 mass percent of the total. From an economical point of view, rotor blades increase to more than 21% of the total share.

We identify no shortage of bulk materials for wind turbines like cement, steel, cast iron, copper, and aluminium. These materials are considered to be easily recycled. It is just a question if all materials are recycled or just left in the ground, as might be the case with some cement from the foundation for example. It would make no economic sense to retrieve all cement from deep in the ground. The ecological impact has to be assessed for each turbine dependent on the location.

Looking at electronic and mechanical parts, there is a shortage of critical metals. Seven critical metals are used in the wind energy sector. Dysprosium, neodymium, and terbium are used in the permanent magnets of a generator, and the remaining metals chromium, manganese, molybdenum, and niobium are typically used in the nacelle of a wind turbine as stainless steel type 316 and as high-grade steel 18NiCrMo7. The required raw materials for the worldwide expansion of wind power (+2800 GW plant capacity) cannot be provided from the available raw material reserves except for molybdenum and dysprosium. Only the metals chrome, manganese, and niobium have sufficient resources available.

The raw materials dysprosium and terbium have the strongest indications for possible supply bottlenecks until the year 2050. Engineering efforts should focus on the long-term availability of critical resources, or else find substitutes to guarantee the survival of the technology.

In the end, the question "How critical is wind energy?" cannot be answered due to lack of information and due to the fact that wind energy is still a young technology. However, we are working on ensuring that wind energy plants stay environmentally sustainable during their whole life time, and even at the end-of-life stage.

Literature

Albers, H., Greiner, S., Kühne, U., Brahms, T., Seifert, H. (2007) Recycling von Rotorblättern – Fakt oder Fiktion?, HUSUMwind 2007, WIND-STÄRKE-FORUM, Germany

Arapogianni, A.; Moccia, J. (2011) European Wind Energy Association: Pure Power – Wind energy targets for 2020 and 2030, www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Pure_Power_III.pdf, consulted 21.02.2012

Bersee, H., Teuwen, J., & Rasool, S. (October 2010). Dutch Wind Workshops. Consulted August 2012 http://dww.wmc.eu/pdf/3c-05%20TUD-DPCS-DWW2010.pdf

Buchert, M.; Dittrich, S.; Liu, R.; Merz, C.; Schüler, D.; Oeko-Institut e.V. (2012) Study on Rare Earths and Their Recycling, www.oeko.de , consulted 15.01.2012

Brøndsted, P., Lilholt, H. and Lystrup, A. (2005) Composite materials for wind power turbine blades, Annual Review of Materials Research, Vol. 35 – 2005 (doi: 10.1146/annurev.matsci.35.100303.110641)

Composites, É. (2012). WIND ENERGY. Consulted 13. September 2012. Éires Composites: http://www.eirecomposites.com/wind-energy-composites-materials-manufacturing-and-prototyping.html

Daily, S. (30. January 2012). Science Daily. Accessed May 2012 http://www.sciencedaily.com/releases/2012/01/120130131505.htm

d'Souza N, Gbegbaje-Das E, Shonfield P (2011) Life Cycle Assessment of Electricity Production from a V112 Turbine Wind Plant, Copenhagen

Elsam Engineering A/S (2004) Life Cycle Assessment of offshore and onshore sited wind farms.

Geuder M (2004) Energetische Bewertung von WEA. Was man über Stoff- und Energiebilanz von erneuerbaren Energien wissen muss. Erneuerbare Energien(8): 25–29

EWEA, T. E. (2012). Thirty years growing together. EWEA.

Gardiner, G. (2008). Wind Blade Manufacturing, Part II: Are thermoplastic composites the future? High-Performance Composites .

Global Wind Report "Annual Market update 2010" (2010) available on: http://www.gwec.net/fileadmin/documents/Publications/Global_Wind_2007_report/GWEC%20Global%20Wind%20Report%202010%20low%20res.pdf, consulted 12.03.2012

Guezuraga, B., Zauner, R., Pölz, W. (2011) Life cycle assessment of two different 2 MW class wind turbines. Renewable Energy 37(1): 37–44. doi: 10.1016/j.renene.2011.05.008

GWEC. (2011). Consulted 14. April 2011 in http://www.gwec.net/index.php?id=127

Hameed, Z., Vatn, J., & Heggset, J. (2011). Challenges in the reliability and maintainability data collection for offshore wind turbines. Renewable Energy , 2154–2165.

Hinrichs, S. (2012). Sustainable Material usage for Rotor Blades in Cement Plants. Hanse-Wissenschaftskolleg „Nachhaltige Materiallebenszyklen in der Windenergie". Delmenhorst, Germany.

IDAE, & IDAE. (2012). IDAE- Instituto para la Diversificación y Ahorro de la Energía. Consulted 03. September 2012 http://www.idae.es/index.php/id.501/lang.uk/relcategoria.1153/relmenu.12/mod.pags/mem.detalle

Jacobson, M. Z., & Delucchi, M. A. (2010). Providing all global energy with wind, water and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure and materials. Energy Policy , doi:10.1016/j.enpol.2010.11.040.

Kabir MR, Rooke B, Dassanayake GM, Fleck BA (2012) Comparative life cycle energy, emission, and economic analysis of 100 kW nameplate wind power generation. Renewable Energy 37(1): 133–141. doi: 10.1016/j.renene.2011.06.003

Kleine, M. (2012) Bedeutung und Analyse von strategischen Metallen in der Windenergie, Student Thesis at Bremen University, Institute for Integrated Product Engineering, Germany

Kooroshy, J.; Kara, H.; Moss, R.; Willis, P.; Tzimas, E.; (2011) JRC – Institute for Energy and Transport; Oakdene Hollins Ltd; The Hague Centre for Strategic Studies: Critical Metals in Strategic Energy Technologies – Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies, doi: 10.2790/35600

Larsen, K. (2009). Recycling wind. ReinforcedPlastics January/February 2009 , 20–25.

McGovern, M. (16. May 2011). Wind Power Monthly. Consulted 03. September 2012 http://www.windpowermonthly.com/news/1070125/Costs-force-Spain-cut-2020-offshore-projection/?DCMP=ILC-SEARCH

Michel, S.; Permanentmagnete im Trend (2010) Vogel Business Media, www.windkraftkonstruktion.vogel.de/triebstrang/articles/289412/,consulted 21.02.2012

Martínez E, Sanz F, Pellegrini S, Jiménez E, Blanco J (2009) Life cycle assessment of a multi-megawatt wind turbine. Renewable Energy 34(3): 667–673. doi: 10.1016/j.renene.2008.05.020

Pehlken, A.; Zimmermann, T, (2012); Material Flows in Wind Energy Plants; International Conference on Mechanical Engineering and Mechatronics ICMEM 2012, Ottawa, Canada

REN21, R. E. (2012). Renewables 2012. Paris: REN 21.

Schleisner, L, (2000) Life cycle assessment of a wind farm and related externalities. Renewable Energy(20): 279–288

Schmidl, E., Hinrichs, S. (2010), Geocycle Provides Sustainable Recycling of Rotor Blades in Cement Plant, DEWI Magazin No. 36, February 2010, pp. 6–14

Seiler E (2010) Recycling von Windkraftanlagen. Internal Study, Pfinztal

Tremeac B, Meunier F (2009) Life cycle analysis of 4.5MW and 250W wind turbines. Renewable and Sustainable Energy Reviews 13(8): 2104–2110. doi: 10.1016/j.rser.2009.01.001

U.S. Department of Energy: Critical Materials Strategy, energy.gov/sites/prod/files/DOE_CMS2011_FINAL_Full.pdf, consulted 15.01.2012

Vestas Wind Systems A/S (2006a) Life cycle assessment of electricity produced from onshore sited wind power plants based on Vestas V82-1.65 MW turbines, Randers, Denmark

Vestas Wind Systems A/S (2006b) Life cycle assessment of offshore and onshore sited wind power plants based on Vestas V90-3.0 MW turbines, 2nd edn., Randers, Denmark

Ziegahn, KF; Schubert, H.; Reichert, T.; Braunmiller, U. (2007) Lebensdauer von Windkraftanlagen – Überlegungen zur Umweltsituation, In: Umwelteinflüsse erfassen, simulieren, bewerten. 33. Jahrestagung der GUS 2004, Fraunhofer ICT, Pfinztal

Zimmermann T (2011) Fully parameterized LCA tool for wind energy converters. LCM 2011 Conference, Berlin

Prospects for Raising Awareness in Material Efficiency: Context-Sensitive Support for Technicians and Engineers Using ICT

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1 Introduction

Material efficiency describes the ratio between product output and material input, which leads to a characterization of the environmental impact of production processes. A higher level of material efficiency would be reached through the production of the same amount of product output with less material input (Allwood et al., 2011; Söderholm and Tilton, 2012). Among the expected operational savings in a production process, further recent developments increase the pressure to gain a higher degree of efficiency. These is for instance the global demand for engineering materials that has risen dramatically in recent years, as well as the possible impact on climate change or further environmental impacts on air, water and land (Allwood et al., 2011).

From the microeconomic and the macroeconomic perspectives, gaining a higher degree of material efficiency is a present challenge that has already led to economic development schemes in certain countries (compare Deutsche Materialeffizienzagentur and VDI/VDE Innovation + Technik GmbH, 2012 for instance). Extrapolating the demand of materials as well as the respective prices for their procurement, the need for simple and effective measures that increase the material efficiency in production processes becomes clear.

However, in general the awareness of the topic is present, so that different measures must be fulfilled in order to meet a standard in sustainable economic management. This range of measures covers component re-use, repair or recycling, through property and yield improvements, up to holistic concepts like special design paradigms (Allwood et al., 2011). Designing a more environmentally friendly business, production or process is currently a challenge. Special regards have to be given to a rising number of ecology-minded customers who base their purchasing decision on a company's degree of sustainability.

Regarding the case of renewable energy systems like wind energy or solar energy, a precarious situation is a given. Nowadays the human population is consuming more and more energy every day. Due to this increasing consumption of energy and the recent eco-friendly attitude people are looking for renewable energies, which allows using energy without wasting resources or damaging our environment. Solutions such as renewable energies are becoming more popular, and sustainability is crucial from the environmental, economic and social points of view. While renewable energy sources possess the image of being environmental friendly and green, considering the consumption of limited resources, this generally affects only the production of electricity itself. But what about the sustainability of production processes? A life-cycle assessment of objects related to renewable energy, i.e. wind turbines or photovoltaic systems, shows that there is still the capability to optimize the handling of limited resources during the whole life-cycle. (Albers et al., 2009; Jungbluth et al., 2005)

To tap this further potential, the state of qualification regarding topics like material efficiency and sustainability is critical with respect to engineers and technicians in the field of renewable energy. While sustainability does play a role in the higher education of engineers, pragmatic approaches helping to transfer this knowledge into practice are missing. Moreover, as in the wind energy sector, there is a booming industry with an expected job increase of 250,000 during the next decade (EWEA – The European Wind energy association, 2009). As illustrated in the following Figure 1, the expected development of total job opportunities tentatively shows that suitable education and qualification for the issues of the wind energy sector is a challenge. A high fluctuation of employees, high degree of recent graduates, as well as still pioneering work and processes complicate the problem of addressing topics like sustainability and material efficiency during the everyday workload.

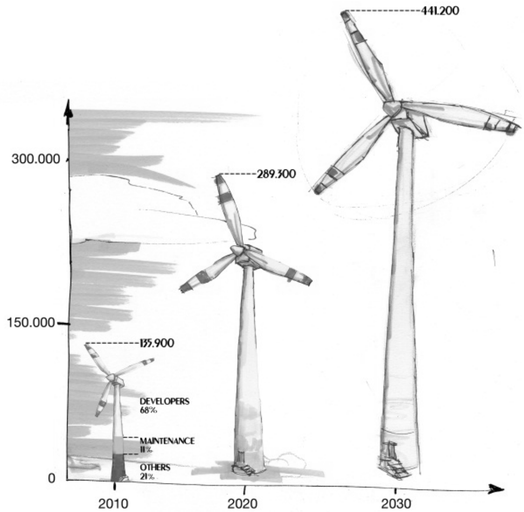

Figure 1: Expected development of jobs related to wind energy (based on EWEA – The European Wind energy association, 2009)

2 Research Question

Addressing the challenge of raising the attention of process improvements that reduce useless material output, one changing parameter could be better support for engineers and technicians. Gaining knowledge and raising awareness about sustainability aspects should be integrated seamlessly into daily work.

The hypothesis of this research paper is that awareness of material efficiency can by supported on the one hand by ICT, which integrates seamlessly into the working processes of technicians and engineers, and on the other hand, through specific learning scenarios using realistic business games.

In the following, the parameters to adjust material efficiency are clarified and possible effects using ICT are discussed. Furthermore, concrete tools are proposed and compared with theoretical considerations.

3 Material efficiency options

According to Worrell et al. (1995) material efficiency improvement is present if the considered product allows fulfilling the same function with a reduction of the material used. In general, it is possible to apply two main strategies in order to improve material efficiency. The first and more sustainable one in a long term perspective is to reduce the material input into the system. The second one is to find or provide a sustainable disposal route for products at the end of their life-cycle.

In the wind energy case, the material used is raw material that is transformed either into the final product or waste. Moreover, maintenance replacements, materials or products used in production and maintenance activities, etc., which are often hidden in corresponding assessments, have to be considered. Based on this, material efficiency options for the wind energy sector are allocated along the whole life-cycle of the product as shown in Figure 2. To achieve improvements in material efficiency, it is necessary to apply different measures in the life-cycle phases of a product. Often these measures are applied in one of the phases of the life-cycle, but have their repercussions and influence in or by another phase.

Based on the two main strategies for material efficiency, general measures which can be proposed are as follows (based on Allwood et al., 2011; Worrell et al., 1995).

Reduce material input into the system:

- Material-efficient product design: designing lightweight products
- Decreasing production waste: changes in production processes can allow a better use of resources, reducing production waste
- Decreasing maintenance replacements: designing of products with minimal needs of maintenance replacements
- Increase Life-cycle: using products more intensely, designing products for longer life-cycle or providing means to repair, upgrade or remanufacture products.

Sustainable disposal route:

- Material substitution: replacement of the original material by another more sustainable one in terms of energy and end of life.
- Product designed for re-use: designing products with focus on re-use after their main life-cycle.

– Product designed for recycling: designing products with focus on recycling after their life-cycle.

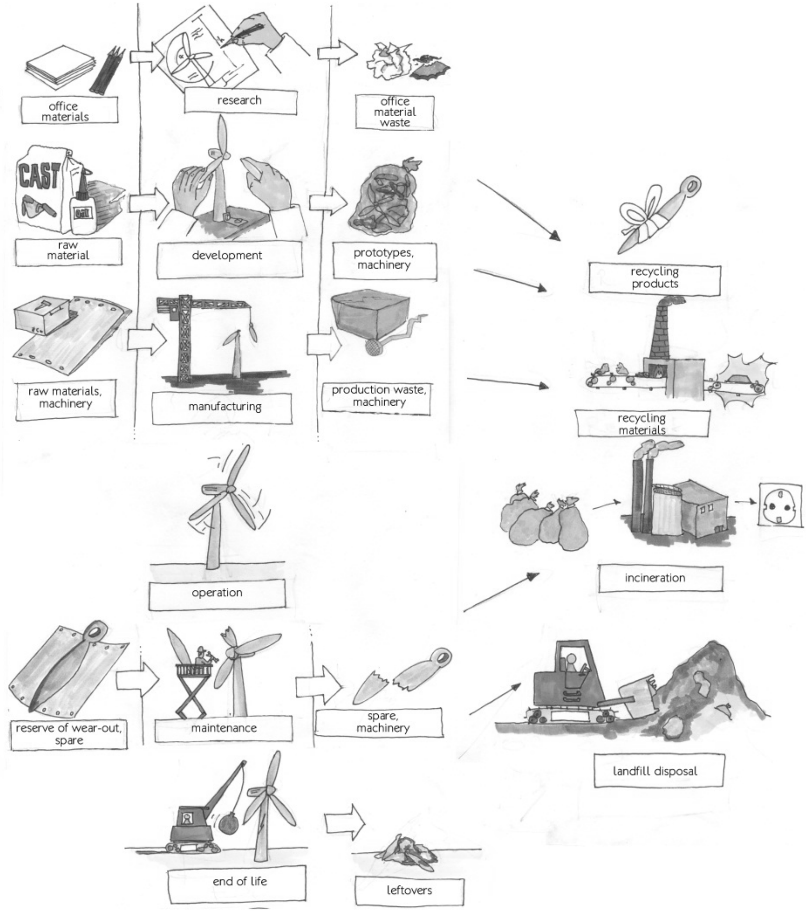

Figure 2: Hidden material output (waste) considering the total life-cycle of wind turbines

Theoretically, the measures proposed are applicable to the wind energy sector. But are all of them appropriate? The wind energy sector is still a young sector in which technology is continuously improving and the energy yield obtained by wind turbines is still increasing. Also, new materials have been tested. Based on these facts and economic reasons, it is probably an early stage to apply measures like increasing the life-cycle of the product in the case of wind turbines, for instance.

In the first place, measures like material substitution or decreasing production waste are aimed to improve material efficiency or environmental issues, but also have impacts in a short or long timeframe on the economical and technological perspectives (e.g. Halme et al., 2007; DeSimone and Popoff, 1997).

Until now, there has been no regulation for disposal in the wind energy sector, but there are already restrictions in several countries regarding the disposal of wind turbine parts in a landfill (Larsen, 2009). Measures like designing for re-use or recycling will help companies to be more competitive in the sector and prepared for future regulation.

In any case, the application of these measures is not possible without qualified engineers and technicians. ICT-based tools are proposed to support technicians and engineers in the field of material efficiency.

4 Concrete proposal of ICT-based tools to support technicians and engineers

There are different ICT-based tools that can support technicians and engineers in their daily work to achieve material efficiency improvements. But material efficiency is not just an extended approach; first there is a need to convince engineers and technicians about the necessity and benefits of implementing material efficiency strategies. Through this, they get the ability to implement such strategies while developing new products, processes or services.

An approach that can support awareness of professionals is a Serious Game on material efficiency for the wind energy sector. Serious games have been used for conveying skills on complex systems for several decades in the area of military education. They offer a risk free training environment, which allows raising awareness on this specific topic (Hays and Singer, 1989). The game will cover all life-cycle phases of a wind turbine, from development/design until disposal. During the different phases, the player will have to make decisions related to materials that are needed, as well as measures that can be applied. The decision of choosing one or another material in the designing phase as well as changes in the production processes to enable the decrease of the material used have repercussions on the material efficiency ratio, which is shown during the whole game. The measures applied to the different phases have associated costs and benefits, so that the player has to decide which measures can be applied with regards to his budget. The game ends after 25 years, with the result of the material efficiency ratio, turnover, and energy production compared with the best case scenario. Feedback for improvements is also provided.

Once the professionals are aware of how to apply material efficiency measures, these measures have to be developed and applied. Supporting professionals in the designing phase would be possible through a data base with a large catalogue of materials, including information about the end of life of these materials. This information will cover recycling possibilities for materials, the percentage of material recovery of each possible recycling route, use of energy in the recycling process per kg, as well as CO_2 emissions during the recycling process. This tool will provide designers information for end of life of the materials to connect the designing and end of life phases of a product. Designers can use this information to choose materials that will be involved in the production phase, with a focus on material efficiency for the whole life-cycle.

A monitoring system for the usage of materials, with established ratios in the different processes and for all the materials is involved in the production phase. This monitoring system establishes an objective for the technicians, as well as making it possible to follow-up the work for engineers.

In order to support end of life of the different part of the wind turbine, it would be helpful to know the exact materials that the parts of the wind turbine consist of. A possible solution is the inclusion of a RFID code printed or included in each of the parts where the materials used for the production and construction of this part are included as well as their proportions.

5 Conclusion and Outlook

This paper presented the current specific requirements and constraints of renewable energy companies as they decide to enhance the sustainability of the products in terms of increasing the material efficiency along the life-cycle. Moreover, due to the green image of renewable energies, it is necessary to engage in the material efficiency of the products.

While general possibilities and measures to reach this aim can be adopted from other industries, the renewable energy industry sector is characterized by a high degree of fluctuation of employees, degree large number of recent graduates, above-average growth in the number of employees, etc. While handling the challenges of everyday working tasks, it seems hard to concentrate on further tasks like sustainable designs, products and processes. Regarding the hypothesis that seamlessly integrated ICT support could improve this situation, several ICT-based measures were proposed, including serious games and knowledge management applications that share information along the life-cycle.

For future work, further ICT-based methods and technologies like knowledge management, decision support, simulation, and wearable computing could prepare the ground for ICT-applications that improve sustainability management in the field of renewable energy.

Literature

Albers, H., Greiner, S., Seifert, H., Seifert, U. (2009). Recycling of Wind Turbine Rotor Blades – Fact or Fiction? *DEWI Magazine*, 34, 32–41.

Allwood, Julian M., Ashby, Michael F., Gutowski, Timothy G., Worrell, Ernst (2011). Material efficiency: A white paper. *Resources, Conservation and Recycling*, 3, 362–381.

DeSimone, L. D.; Popoff, F. (1997). *Eco-efficiency. The business link to sustainable development*. Cambridge, Mass: MIT Press.

Deutsche Materialeffizienzagentur; VDI/VDE Innovation + Technik GmbH (Eds.) (2012). Förderung: go-effizient. Available online at http://www.demea.de/foerderung/go-effizient, updated on 15/10/2012, checked on 28/11/2012.

EWEA – The European Wind energy association (2009). Wind at Work. *Wind energy and job creation in the EU*. Available online at http://www.ewea.org/fileadmin/ewea_documents/documents/publications/Wind_at_work_FINAL.pdf, checked on 8/11/2012.

Halme, Minna, Anttonen, Markku, Kuisma, Mika, Kontoniemi, Nea, Heino, Erja (2007). Business models for material efficiency services: Conceptualization and application. *Ecological Economics*, 1, 126–137.

Hays, R. T.; Singer, M. J. (1989). *Simulation fidelity in training system design. Bridging the gap between reality and training*. New York: Springer-Verlag.

Jungbluth, Niels, Bauer, Christian, Dones, Roberto, Frischknecht, Rolf (2005). Life Cycle Assessment for Emerging Technologies. *Case Studies for Photovoltaic and Wind Power*. *The International Journal of Life Cycle Assessment*, 1, 24–34.

Larsen, Kari (2009). Recycling wind turbine blades. *Renewable Energy Focus*, 7, 70–73.

Söderholm, Patrik, Tilton, John E. (2012). Material efficiency: An economic perspective. *Resources, Conservation and Recycling*, 0, 75–82.

Worrell, E., Faaij, A. P. C., Phylipsen, G. J. M., Blok, K. (1995). An approach for analysing the potential for material efficiency improvement. *Resources, Conservation and Recycling*, 3–4, 215–232.

Program

Tuesday, June 19 (Day 1)

11:00	*Welcome*

Session: Material Flows and Sustainability

11:15–11:45	Material Stock and Material Flows of Onshore Wind Turbines in Germany (Sören Steger, Wuppertal Institut)
11:45–12:15	Material Flow of Strategic Resources for the Future Wind Energy in Germany (Beatrix Becker, TU Darmstadt)
12:15–12:45	Sustainability Assessment of Steel Constructions for Offshore Wind Turbines (Anne Bechtel, Leibniz Universität Hannover)
12:45–14:00	*Lunch Break*

Session: International Developments

14:00–14:45	Keynote Lecture (Jeetendra Bisht, Suzlon Energy Ltd., India)
14:45–15:15	Implication of Onshore Wind Energy Development by 2020 in China on Natural Resources (Chun Xia, Wuppertal Institut)
15:15–15:45	*Coffee Break*

Session: Life Cycle Approach

15:45–16:15	Resource Use of Two Offshore Wind Farms in the German North Sea (Jens Teubler, Wuppertal Institut)
16:15–16:45	LCA Tool for Wind Energy Converters (Stefan Gößling-Reisemann, Universität Bremen) Article published by Till Zimmermann: “Parameterized tool for site specific LCAs of wind energy converters” in: *The International Journal of Life Cycle Assessment* (6 July 2012), pp. 1–12 doi:10.1007/s11367-012-0467-y
16:45–17:15	Logistics in Offshore Wind Parks (Nils Giese, Universität Oldenburg)
17:30–18:30	Poster and Industry Session
18:30–22:00	*Dinner Reception*

Wednesday, June 20 (Day 2)

09:00	*Welcome and Summary of Day 1* *(Alexandra Pehlken, Universität Bremen)*
09:15–10:00	Keynote Lecture: Development in Wind Energy in Europe (Athanasia Arapogianni, EWEA, Brussels)
10:00–10:30	Synchronisation of Material and Information Flows in the Logistics Network of Offshore Wind Energy (Thies Beinke, Anne Schweizer, Universität Bremen)
10:30–11:00	*Coffee Break*

Session: Rotor Blade

11:00–11:30	Rotor Blade Production – Resource Efficiency through Material Handling with Robotics (Jan-Hendrick Ohlendorf / Martin Rolbiecki, Universität Bremen)
11:30–12:00	Recycling of Rotor Blades from Wind Turbines (Henning Albers, Hochschule Bremen)
12:00–12:30	Sustainable Material Usage of Rotor Blades in Cement Plants (Stephan Hinrichs, Holcim AG, Hamburg)
12:30–13:15	Discussion and summary of the conference (Alexandra Pehlken, Universität Bremen)
13:15–14:45	*Lunch and Departures*