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An Empirical Investigation of Interorganizational Learning, Knowledge Bridging and the Role of Boundary Objects in Heterogeneous Collaborations

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Knowledge Integration in Innovative Smart Grid Projects -

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Table of Contents

List of Figures

List of Tables

Abbreviations

AMPQ	Advanced Message Queuing Protocol
CGMES	Common Grid Model Exchange Standard
CIM	Common Information Model
DSO	Distribution System Operator
EA	Enterprise Architect
EC	European Commission
e.g.	for example
ed.	edited; edition
et al.	et alteris
etc.	et cetera
EU	European Union
GDPR	General Data Protection Regulation
H1	Hypothesis 1
H2	Hypothesis 2
H3	Hypothesis 3
HV	High Voltage
ICCP	Inter-Control Center Communication
ICT	Information and Communication Technology
IT	Information Technology
LV	Low Voltage
MQTT	Message Queuing Telemetry Transport
NIST	National Institute of Standards and Technology
RCT	Randomized Controlled Trials
REST	Representational State Transfer
R&D	Research and Development
SOA	Service-oriented Architecture
SoS	System of System
TSO	Transmission System Operator
vs.	versus
WP	work package
XML	Extensible Markup Language

Abstract

Today's energy system is facing a major transformation to feed renewable energies into the system and to develop new digital business models. While a few years ago the grid operators dominated the energy system and implemented innovations rather slowly, today innovation cycles are shortening due to advancing digitization and the appearance of new players in the market. Not only are new organizations capturing the market, but the roles of established players are shifting as well. Dwelling on these changes, the future Smart Grid is evolving into a socio-technical system that increasingly connects humans with technologies. There is no doubt that these socio-technical innovations are particularly dependent on the exchange of interdisciplinary knowledge in the international arena. Although Smart Grid projects are a common way for exchanging heterogeneous knowledge, they often pose challenges for the actors involved that have not yet been adequately addressed. My research therefore contributes to the scientific debate on the integration of heterogeneous knowledge and collaborative innovations in Smart Grids

The dissertation analyzes the knowledge integration in innovative Smart Grid projects. Collaborative projects in the energy system have become an important part for creating intelligent solutions. At the same time, Smart Grid projects are becoming increasingly challenging due to more intertwined and heterogeneous relations, a growing knowledge-intensive environment or the application of big data. Smart Grid projects also depend on the different knowledge backgrounds of the partners involved, as individual organizations are unable to cover all the expertise needed for Smart Grid innovations. From this angle, Smart Grid project partners rely on knowledge integration among themselves and are therefore forced to enter into cooperative ventures. Although heterogeneity in Smart Grid project holds the potential for more possibilities of knowledge combination, this might also lead to a lack of common understanding as well as trust between organizations. Consequently, my research does not take efficient collaboration for granted and considers it fundamentally challenging.

To disentangle the knowledge integration process, my dissertation addresses different social science concepts, such as knowledge integration (Tell 2011), proximities (Boschma 2005), knowledge boundaries (Carlile 2004), interorganizational learning (e.g. Ellström 2010), knowledge bridging (Mattes 2010; Schmickl and Kieser 2008), boundary objects (Star and Griesemer 1989), and innovation development (e.g. Kodama 2009). Based on these strands of research, my dissertation sheds light on how and to what extent heterogeneous project partners integrate knowledge from each other to develop innovation in the energy system. By using the

respective concepts, it is possible to investigate different facets of knowledge integration and to combine them in a novel way. While the proximity concept identifies how closely aligned project partners are at an organizational, institutional, social, cognitive and geographical level, the concept of knowledge boundaries analyzes the syntactic, semantic and pragmatic difficulties that arise in Smart Grid projects. The dissertation also evaluates to what extent experts need to bridge complementary knowledge and where learning processes take place in the project. Building on these investigations, the dissertation tackles the question whether and how boundary objects develop in the knowledge integration process. This concept describes how diverse actors can be involved in a cooperation project, although they have different and, in many cases, conflicting interests.

Insights into the knowledge integration in Smart Grid projects are gained through an empirical case study. For this study, I conducted 32 qualitative interviews with experts from an EU Smart Grid project. Due to the open-ended questionnaire, I was able to discover many new aspects for the knowledge integration process and could draw new patterns and conclusions to the existing theoretical concepts.

My research revealed that knowledge integration is not only complex and multi-faceted, but also confronts diverse knowledge boundaries resulting from increasing heterogeneity. To deal with these challenges, interorganizational learning takes place in the investigated case study in the area of common method and tool knowledge in order to create a shared knowledge base. In this process of interorganizational learning, knowledge boundaries become particularly prominent as it requires intensive common work. Conversely, the more complex expertise in the form of domain-specific knowledge is thereby bridged between the organizations of the Smart Grid project. In order to use this expertise properly, the case study showed that it is particularly important to identify common interfaces between the project partners. My research discovered that the method and tools learned are the basis for creating a common foundation through which the domain-specific knowledge can be integrated and bridged between the disciplines. The two processes of interorganizational learning and knowledge bridging are therefore interrelated. Finally, different boundary objects develop in the investigated Smart Grid project, enabling collaboration among diverse and conflicting partners.

Zusammenfassung

Das heutige Energiesystem steht vor einer großen Transformation, um erneuerbare Energien in das System einzuspeisen und neue digitale Geschäftsmodelle zu entwickeln. Während noch vor einigen Jahren die Netzbetreiber das Energiesystem dominierten und Innovationen eher langsam umsetzten, verkürzen sich heute die Innovationszyklen durch die fortschreitende Digitalisierung und das Auftreten neuer Akteure auf dem Markt. Nicht nur neue Organisationen erobern den Markt, sondern auch die Rollen der etablierten Akteure verschieben sich. Ausgehend von diesen Veränderungen entwickelt sich das künftige Smart Grid zu einem sozio-technischen System, das zunehmend Menschen mit Technologien verbindet. Es bestehen keine Zweifel daran, dass diese sozio-technischen Innovationen in besonderem Maße auf den Austausch von interdisziplinärem Wissen im internationalen Umfeld angewiesen sind. Smart Grid Projekte sind zwar ein gängiger Weg, um heterogenes Wissen auszutauschen, stellen die beteiligten Akteure aber oft vor Herausforderungen, die noch nicht hinreichend geklärt sind. Meine Forschung leistet daher einen Beitrag zur wissenschaftlichen Debatte über die Integration von heterogenem Wissen und kollaborativen Innovationen in Smart Grids.

Die Dissertation analysiert die Wissensintegration in innovativen Smart Grid Projekten. Kollaborative Projekte im Energiesystem sind zu einem wichtigen Bestandteil für die Schaffung intelligenter Lösungen geworden. Gleichzeitig werden Smart Grid Projekte durch die zunehmende Verflechtung und Heterogenität der Beziehungen, ein immer wissensintensiveres Umfeld oder die Anwendung von Big Data immer anspruchsvoller. Smart Grid Projekte hängen auch von den unterschiedlichen Wissenshintergründen der beteiligten Partner ab, da einzelne Organisationen die für Smart Grid Innovationen erforderlichen Kompetenzen nicht allein abdecken können. Unter diesem Gesichtspunkt sind Smart Grid Projektpartner auf die Wissensintegration untereinander angewiesen und daher gezwungen, Kooperationen einzugehen. Obwohl die Heterogenität in Smart Grid Projekten das Potenzial für mehr Möglichkeiten der Wissenskombination birgt, kann dies auch zu einem Mangel an gemeinsamem Verständnis und Vertrauen zwischen den Organisationen führen. Folglich sieht meine Forschung eine effiziente Zusammenarbeit nicht als selbstverständlich an und betrachtet sie als grundsätzliche Herausforderung.

Um den Prozess der Wissensintegration zu entflechten, greift meine Dissertation auf verschiedene sozialwissenschaftliche Konzepte zurück, wie Wissensintegration (Tell 2011), Proximitäten (Boschma 2005), Wissensgrenzen (Carlile 2004), interorganisationales Lernen

(z.B. Ellström 2010), Wissensüberbrückung (Mattes 2010; Schmickl und Kieser 2008), Boundary Objects (Star und Griesemer 1989) und Innovationsentwicklung (z.B. Kodama 2009). Basierend auf diesen Forschungssträngen beleuchtet meine Dissertation, wie und in welchem Umfang heterogene Projektpartner Wissen voneinander integrieren, um Innovationen im Energiesystem zu entwickeln. Durch die Verwendung der jeweiligen Konzepte ist es möglich, verschiedene Facetten der Wissensintegration zu untersuchen und diese auf neuartige Weise zu kombinieren. Während das Proximity-Konzept aufzeigt, wie eng die Projektpartner auf organisatorischer, institutioneller, sozialer, kognitiver und geografischer Ebene zusammenarbeiten, analysiert das Konzept der Wissensgrenzen die syntaktischen, semantischen und pragmatischen Schwierigkeiten, die in Smart Grid-Projekten auftreten. Die Dissertation evaluiert daneben, inwieweit Experten komplementäres Wissen überbrücken müssen und wo Lernprozesse in der Projektarbeit stattfinden. Aufbauend auf diesen Untersuchungen geht die Dissertation der Frage nach, ob und wie sich Boundary Objects im Wissensintegrationsprozess entwickeln. Dieses Konzept beschreibt, wie verschiedene Akteure an einem Kooperationsprojekt beteiligt sein können, obwohl sie unterschiedliche und in vielen Fällen widersprüchliche Interessen haben.

Einblicke in die Wissensintegration in Smart-Grid-Projekten werden durch eine empirische Fallstudie gewonnen. Für diese Studie habe ich 32 qualitative Interviews mit Experten aus einem europäischen Smart Grid Projekt durchgeführt. Dank des offenen Fragebogens konnte ich viele neue Aspekte für den Wissensintegrationsprozess entdecken und neue Muster und Schlussfolgerungen zu den bestehenden theoretischen Konzepten ziehen. Meine Forschung ergab, dass die Wissensintegration nicht nur komplex und vielschichtig ist, sondern auch mit diversen Wissensgrenzen konfrontiert ist, die sich aus der zunehmenden Heterogenität ergeben. Um diese Herausforderungen zu bewältigen, findet in der untersuchten Fallstudie interorganisationales Lernen im Bereich des gemeinsamen Methoden- und Werkzeugwissens statt, um eine gemeinsame Wissensbasis zu schaffen. In diesem Prozess des interorganisationalen Lernens treten die Wissensgrenzen besonders deutlich hervor, da dieser eine intensive gemeinsame Arbeit erfordert. Umgekehrt wird dadurch das komplexere Fachwissen in Form von domänenspezifischem Wissen zwischen den Organisationen des Smart-Grid-Projekts überbrückt. Um dieses Fachwissen richtig zu nutzen, hat die Fallstudie gezeigt, dass es besonders wichtig ist, gemeinsame Schnittstellen zwischen den Projektpartnern zu identifizieren. Die erlernten Methoden und Werkzeuge sind dabei die Grundlage für die Schaffung einer gemeinsamen Basis, durch die das domänenspezifische Wissen integriert und zwischen den Disziplinen überbrückt werden kann. Die beiden Prozesse des interorganisationalen Lernens und der Wissensüberbrückung sind also eng miteinander verknüpft und verflochten. Schließlich entwickeln sich in dem untersuchten Smart-Grid-Projekt verschiedene Grenzobjekte, die eine Zusammenarbeit zwischen unterschiedlichen und konfliktreichen Partnern ermöglichen.

1. Introduction

In recent years, actors in the energy system are confronted with numerous structural challenges, such as the integration of decentralized and renewable energy, the management of changes to the demand side and the optimal provision of expensive assets with the aim of saving energy to decrease the overall carbon footprint (Farhangi 2010). However, these challenges cannot be solved within the existing energy system because the current power gird already carries a number of deficiencies, such as the unilateral conversion of electricity resulting in energy loss in the grids, as well as frequency and voltage imbalances as a result of an irregular integration of renewable energies (Pong et al. 2020). The grid is also adversely affected by the domino effect due to the hierarchical topology of grid assets (Farhangi 2010) as well as by the problematic integration of renewable energies resulting from their uncertain nature (Neetzow 2020). From this angle, the energy system requires an overarching transformation in every sphere. To address these problems and create intelligent solutions and new business models for the energy system, the so-called Smart Grid should be introduced to improve the efficiency of energy consumption and supply (Lösch and Schneider 2016). According to the National Institute of Standards and Technology (NIST), the Smart Grid can be defined as *"an electric system that uses information, two-way, cyber-secure communication technologies, and computational intelligence in an integrated fashion across the entire spectrum of the energy system from the generation to the end points of consumption. The availability of new technologies such as distributed sensors, two-way secure communications, advanced software for data management, and intelligent and autonomous controllers have opened up new opportunities for changing the energy system"* (NIST 2018).

On the basis of the definition, the digitization of the energy system through an intelligent networking of all actors and components plays a major part for solving current challenges to the system. Information and Communication Technology (ICT), an umbrella term for all types of technologies that facilitate the transmission of information, is increasingly integrated in all energy-related processes (Lubbe and Singh 2009). The Internet plays an important role here in enabling data exchange in the form of sending and receiving information between different systems. Consequently, the Smart Grid consists of the exchange of information through ICT and the transmission of electricity flow between the various systems, resulting in an enhanced two-way information and power exchange between all actors (Giordano et al. 2011).

This transformation points to an increasingly decentralized and highly automated management of energy resources that is changing the current communication and energy distribution structure. By expanding monitoring capabilities, system operators gain comprehensive control over all their assets and services. To eliminate sources of failure, the future energy system aims to be self-healing and resilient to system anomalies (Farhangi 2010). Despite the general agreement on what structural improvements need to be made, the nature, emphasis and models involved of the Smart Grid remain objects of discussion and contention among the respective organizational actors.

The step into the digital energy system also links several organizational actors simultaneously. A few years ago, the system operators that dominated the energy system tended to implement innovations rather slowly. This contrasts with the current innovation cycles, which are becoming shorter as a result of ongoing digitization, but are effected even more by the emergence of new players in the market. This has already left traces- new organizations, such as flexibility suppliers and aggregators, prosumers, or storage operators are entering the market (Boscán and Poudineh 2016). However, not only are new organizations capturing the energy market, but the roles of established players are shifting as well. Dwelling on these changes, the future Smart Grid is evolving into a socio-technical system that increasingly connects together heterogeneous organizations (Köhlke 2019b). Likewise, the pressure from the need for energy transition, as evidenced by the current energy crisis in Europe, requires rapid and efficient action from the various organizations involved. However, the impetus to create innovative solutions and new business models depends on tight cooperation between new and established organizations and the exchange of interdisciplinary knowledge in the international arena. Hence, the future Smart Grid can be seen as an emerging regime involving fundamental reorganization of all social constellations and technical connections (Miller, Richter, and O'Leary 2015).

Actors in the energy system are increasingly entering into innovative collaborations, which often take place in the form of project work. Although Smart Grid projects are a common way for exchanging heterogeneous knowledge, they often pose challenges for the participating organizations that have not yet been adequately addressed. Collaboration is thus, by no means self-evident or free of conflict, as organizations face entirely new fundamental challenges in the international environment. In particular, the increasing interdependent structures combined with heterogeneous experts leads to a greater need for coordination between them. The system is therefore required to find new ways of engaging and conducting operations along the system

(Farhangi 2010). It is expected that technical components cannot be separated from the transition of actor structures in the system, nor from their relations and their hierarchies within which they cooperate (Lösch and Schneider 2016).

1.1. Collaboration in Smart Grid projects: Self-evident yet multi-faceted?

Collaborative projects are generally important sources for creating intelligent solutions. At the same time, collaborative Smart Grid projects are becoming more challenging because of increasing interconnectedness of relationships, a growing knowledge-intensive environment and the application of big data (Köhlke 2019a). Smart Grid projects also depend on the different knowledge backgrounds of the actors, as individual organizations are unable to cover all the areas of expertise needed for Smart Grid innovations (Paustian et al. 2022). From this angle, Smart Grid project partners are forced to integrate knowledge across potentially competing domains and engage in cooperative ventures. Although the heterogeneity in Smart Grid projects has the potential for the synthesis of different knowledge sources and new combination possibilities, it can equally increase the risk of a lack of common understanding as well as trust among the cooperating parties (Köhlke, Hanna, and Schütz 2021). The thinking through the channels of collaboration in terms of integrating knowledge between different partners in the Smart Grid is often dismissed as self-evident. It is precisely this assumption, namely that knowledge integration in innovative Smart Grid projects is self-evident, that this research will challenge, arguing that this process is multi-faceted with interactions forming opaque networks – both socially and epistemologically.

The *liberalization of the energy market* as well as its digitalization is leading to a growing number of new market players, resulting in a more intensive cross-organizational transfer of operational and business-relevant information and data (Brunekreeft et al. 2014). However, new roles and associated responsibilities in the evolving Smart Grid are still being negotiated, particularly in the areas of testing and implementation of new technologies and their accompanying social conditions and requirements (Van Den Oosterkamp et al. 2014). This demands a rearrangement of the relative positions of the organizational actors in the energy system (Lösch and Schneider 2016). Accordingly, new organizations not only take on new tasks and services, but also have different responsibilities in the system. New grid users are emerging, who are physically connected to the grid and participate in the electricity trading, such as suppliers, aggregators or balance responsible parties (Van Den Oosterkamp et al. 2014). Also, technology providers are represented by bodies, such as metering operators, ICT service providers, home appliances vendors, grid communication network providers, ancillary service providers or electric transportation providers (Van Den Oosterkamp et al. 2014). Building on this, the Smart Grid is exposed to other influences and demands from regulators, including European Union (EU) and national legislation authorities, as well as bodies from standardization and the financial sector (Van Den Oosterkamp et al. 2014).

The establishment of various new roles in the energy system leads to *increasing heterogeneity* in the energy system. Especially within Smart Grid projects, these different roles come together for developing intelligent innovation. Accordingly, the knowledge from different scientific fields is required. Not only will computer scientists play an important role, but also engineers, economists, jurists, social scientists and other representatives from knowledge fields will be required to create a comprehensive socio-technical system. However, the knowledge from different disciplines poses the difficulty that it is tied to the organizational actors. Nevertheless, a shared understanding of the Smart Grid functionalities is seen as a prerequisite for its development (Gottschalk, Uslar, and Delfs 2017). In addition to differences in cognitive knowledge, Smart Grid actors often have diverse nationalities and languages, are subject to different regulation and politics, as well as operate under various economic and social conditions (Köhlke 2019b; Paustian et al. 2022). Heterogeneity also arises from organizational disparities. While the established system operators mostly have corporate structures, many organizations that entered the market have start-up structures. This is compounded by a high technical dependency and differing geographical distribution of project partners, one is faceted with a crisscrossing of organizational interests and cultures, differing knowledge structures and virtual communication channels that must be effectively negotiated for any project innovation to work (Gibson and Gibbs 2006). These new circumstances enable a new virtual way of working compared to the previous work at a settled workplace. Nevertheless, it is often the social situations from which good ideas and innovation emerge (Mattes 2015) and which are now exposed to the risks of misunderstanding, misinterpretation, or simple rejection (Majchrzak, More, and Faraj 2012). Heterogeneous projects are, thus, joint ventures of various resources in multiple, complex and potentially conflicting dimensions (Gläser et al. 2004).

Another challenge lies in the *technical complexity of the tasks* involved in Smart Grid projects, which can only be carried out in a collaborative process. Hence, the Smart Grid is a complex system, which is reflected in the integration of new heterogeneous components that need to be introduced in the system (Guérard, Ben Amor, and Bui 2012). Generally speaking, complex systems can be defined as a *"network of elements in mutual interactions, which behaviors and* *properties cannot be deduced from a part"* (Guérard et al. 2012). The complexity is dependent upon the effectiveness of the scale and topology of the system structure as well as the dynamics, determined by the interactions of the system (Ben Amor et al. 2007). To preserve all system functions, complex systems, such as Smart Grids, should be adaptable to internal and external requirements. To handle the complexity in the tasks, Smart Grid actors must understand and be familiar with a wide variety of components of the system. For example, the implementation of sensors, machine learning or measurement tools indicates a complex system that requires different expertise from the project partners (Guérard et al. 2012). All of this shows that the system cosists of small-scale and diverse components and organizations. This complexity relates not only to the regional level, but also at the global level where Smart Grid project partners drive dynamic processes and specific field expertise merge (Gilbert 1995). However, for the establishment of innovations in Smart Grid projects, organizational actors are increasingly confronted with the task of dealing with these new fields of competence. These tasks demand the creation of functional interfaces between different components of the system by means of ICT and related standards in order to produce a uniform exchange of information and standardized interfaces (Gottschalk et al. 2017). This is the only way to minimize redundancies and conflicts between project partners and to share their strategies for integrating renewable energies worldwide (Hadjsaïd and Sabonnadière 2013).

Furthermore, the *increase of data in the energy system* adds yet another facet. Smart Grid projects demand the exchange of information and data between the different actors in the system and are therefore strongly influenced by the emergence of ICT and big data (Chauhan et al. 2017; Köhlke 2019a). Boyd and Crawford (2012) define big data as *"cultural, technological, and scholarly phenomenon"* and add that it *"is about a capacity to search, aggregate, and cross-reference large data sets"*. With regard to the future Smart Grid, large datasets are needed, which can hardly be stored and analyzed with conventional database technology and therefore require new technologies. The development and transmission of big data is not only associated with a high velocity of data processing (Cai and Zhu 2015), but also with a high variety of data types, making the data unstructured for the processing (Lee 2017). However, a loss of trustworthiness and a disorder of data leads to the challenge that big data often consist of lower quality (Cai and Zhu 2015). The rapid growth of big data as well as the demanding use and consumption of such data makes projects even more complex than in the past (Sinha 2014).

Many researchers assume that big data will increasingly shape future project planning, as well as the control and output of projects. This implies that in projects in which big data plays a major role, additional aspects such as semantic adjustments, dynamic real-time analytics, redundancy, visualization or data latency have to be taken into account (Sinha 2014). The data to be exchanged includes not only information on business partners and competitors in the electricity industry, but also specific rules and data standards to lower transaction costs (Brunekreeft et al. 2014). Likewise, ICT facilitates more possibilities for the real-time data monitoring of consumption, generation, transmission and distribution. Devices such as smart meters allow a better assessment of energy consumption, but also risk the misuse of sensitive data from a security and privacy point of view (Cuellar 2013). Therefore, cooperation based on trust is all the more important for the work in Smart Grid projects.

Bringing together different organizational actors in projects is often understood as problematic as *not all project partners are willing to cooperate*. This is based on the general assumption that project partners do not always exchange their knowledge fully, even though this is necessary for overall high project performance (Niedergassel and Leker 2011). Some authors assume that cooperation between independent and competitive organizations is generally unlikely, as these organizations would only be willing to cooperate if no other strategically better options are available (Braczyk and Heidenreich 2000). For example, groups are often accused of opportunism, of formation oligopolies or cartels, and of being inert to innovation. Therefore, cooperation does not always serve as a primary strategy or motivation to open up new markets for the commercial use of new technologies, or for the acquisition of new knowledge. Some authors even assume that cooperation hampers competitive dynamics and associated advantages (e.g. Ricciardi et al. 2022). In developing knowledge outputs, most organizations try to preserve and restrict knowledge within the organization due to the threat of knowledge leakages (Ahmad, Bosua, and Scheepers 2014). Such knowledge leakages to competitors would mean a loss of reputation and productivity as well as the breach of confidential contracts, which could not only cost the company, but could also leads to a loss of competitive advantages (Khelil 2017). Likewise, companies are often afraid of losing property rights (Chesbrough and Teece 1996) or have concerns that more complex innovation processes are not satisfactorily coordinated. Only if these losses of control are controllable or do not damage one's own abilities, a cooperation will be considered. Likewise, companies deviate from the "non-cooperative will" in the face of rapid technological change (Braczyk and Heidenreich 2000). In this case, global groups often rely on strategic alliances or on the purchase of new knowledge through start-ups (Braczyk and Heidenreich 2000). Thus, only when the in-house production of knowledge as well as the acquisition of knowledge through start-ups is no longer sufficient, cooperation with other organizations will be considered.

To sum up, the multi-faceted nature of the economic and knowledge relations in Smart Grid projects increase the *risk of ineffective knowledge integration.* In particular, the different practices associated with the development of the Smart Grid are creating not only new power relations, but also new sources of knowledge (Lösch and Schneider 2016). The emerging transformation of the energy system, therefore, leads to new knowledge constellations (Lösch and Schneider 2016). In these heterogeneous knowledge constellations, not only do new actors emerge, but the use and exchange of big data also plays an important role. Besides, not all organizations are willing to share their specific expertise. All these different aspects not only make project work more difficult, but also carry the risk of inefficient knowledge integration (Okhuysen and Eisenhardt 2002). This means that critical data or knowledge is often missed by members or simply not shared (Strasser and Stewart 1992), because there is a lack of understanding between the partners (Bechky 2003); there is a distinct world of thoughts (Dougherty 1992); there are differences in verbal competences; cooperation is inhibited by poor conflict resolution (Eisenhardt 1989); and discrepancies in status (Gruenfeld et al. 1996); there is a spatial distance between the partners, which is exacerbated by the multi-lingual context of the knowledge generation (Tell et al. 2017b). Togeher, these obstacles can hinder an effective knowledge integration process. Despite these obstacles, knowledge integration still occurs, and new products emerge in projects. The question is, therefore, how knowledge integration takes place *despite* these challenges. However, due to today's fast and complex organizational environment and the fact that organizations alone cannot cover all knowledge, cooperation is indispensable (Mishra and Sarkar 2012). Cross-border projects in the Smart Grid area are particularly important in order to jointly decide on regulations, standardization, policies and to establish business models of mutual benefit (Hadjsaïd and Sabonnadière 2013). The following chapter provides the conceptual design for dealing with the challenges of integration of knowledge in Smart Grid projects.

1.2. Conceptual design and relevance

The investigation of knowledge integration in Smart Grid projects is currently of high pertinence due to an increasing number of actors involved, leading to more intertwined interorganizational relations and a growing knowledge-intensive environment (Tether 2002), but also because of an increasing lack of common understanding and trust between actors in the energy system (NIST 2014). Therefore, there is a growing awareness by organizations that isolated innovation is generally problematic (Tether 2002), why interorganizational projects are increasingly being put at the center of innovation work. Collaborative projects have evolved as a common but difficult method for developing innovation, particularly as the environment of organizations in the energy system is extremely fragile (Köhlke 2019b). The revolutionary process for innovation development in Smart Grid projects takes place in an environment that is undergoing particular change and is, thus, fraught with uncertainties (Engels and Münch 2015). This change requires a closer look at collaborative knowledge integration in Smart Grid projects.

Despite the multi-layered hurdles in Smart Grid projects, theorists, such as Cassiman and Veugelers (1998), argue that future innovation will be mainly based on the integration of external, heterogeneous knowledge in the innovation process. Accordingly, knowledge integration is seen as the basis for the coordination of innovation within projects as well as for driving the energy transition, the importance of which proves the relevance of this research. Without cooperation and the integration of knowledge, the survival of industrial organizations is far from assured (Lundvall and Johnson 1994, p. 25). Intensive knowledge integration within a group of actors is, therefore, decisive for organizational success (Okhuysen and Eisenhardt 2002). In this manner, it is crucial to identify the actual knowledge integration in Smart Grid projects.

While different approaches exist to describe knowledge integration (Tell 2011), they are neither mature nor adapted to today's requirements for new knowledge constellations in the Smart Grid. Although there is an increasing awareness of the need for diverse knowledge, its importance for the development of innovations has so far been underestimated. Consequently, the collaborative character of knowledge integration has been little explored to date. In the face of these considerations, the overall objective of this dissertation is to find out how and to what extent Smart Grid actors need specialized knowledge from the different actors involved in the project in order to develop innovation. In addition to investigating the influence of heterogeneity on the project work in Smart Grids, this research also aims to investigate different formations in the process of knowledge integration. The aim is to create a broad and comprehensive understanding of knowledge integration and to shed light on its specific characteristics in Smart Grid projects. It aims to discover what the knowledge constellations in the development of innovative solutions are, which type of knowledge is inevitably and how organizational actors integrate this knowledge in Smart Grid projects. The leads to the following overall research question:

How and to what extent do heterogeneous Smart Grid actors integrate specialized and distributed knowledge in order to develop innovation in Smart Grid projects?

The general research question can be divided into two sub-questions to better illuminate its different aspects. The first sub-question relates to the primary facet of heterogeneity, which is investigated in terms of the influences of heterogeneity on the challenges in knowledge integration. Here, reference is made to how the influence of heterogeneity on the knowledge integration process is enacted. The challenges of knowledge integration are considered here as boundaries. These knowledge boundaries can be pinpointed by the investigation in that they arise in the process of knowledge integration in Smart Grid projects and have their origins in the heterogeneous nature of innovation projects. The focus here is on the difficulty resulting from the different functions and new roles of organizations within the energy system. The aim of the first sub-question is to systematically address the evolving boundaries to knowledge integration that result from heterogeneity. Thus, heterogeneity shall be conceptualized as forming the basis for identifying possible challenges and obstructions in Smart Grid projects, thereby elucidating first insights into the efficiency of knowledge integration. Consequently, the first sub-question is:

Sub-question 1: Which boundaries of knowledge integration develop in Smart Grid projects due to heterogeneity?

After analyzing the boundaries, it will be explored how knowledge integration takes place in Smart Grid projects. The aim of the second sub-question is to take a closer look at the process of knowledge integration in order to identify the extent to which actors have to integrate knowledge from each other when developing innovation. Hence, the second sub-question refers to the extent of knowledge integration between Smart Grid actors. The degree of knowledge integration becomes especially important, given the new circumstances of interorganizational projects. These take on new organizational forms for collaborating, especially regarding the management of tensions between cooperation and competition. The old view of organizations, which characterizes organizations as independent systems, is therefore, continuously being replaced. This suggests that the integration of knowledge between organizations has also changed, leading to new forms between them. In this context, the new realities of project work should be emphasized far more than current research does. The second-sub question adopts a processual perspective of knowledge integration and aims to analyze the extent of knowledge integration required in Smart Grid projects. This leads to the second research question:

Sub-question 2: To what extent do actors have to integrate expert knowledge from other actors in order to develop Smart Grid innovations?

The extent of knowledge integration is fundamental for not only the overall project planning and its success, but also recognizing how innovations can be developed. The extent of integrating knowledge between experts in Smart Grid projects should provide an indication of the outcome of knowledge integration and hence give an indication of which knowledge is needed to be integrated between the Smart Grid project partners. The question aims to describe how heterogeneous actors can be involved in a cooperating project and achieve consensus, although they are surrounded by boundaries caused by heterogeneity. In these new knowledge constellations in the Smart Grid projects, many heterogeneous actors come together with different opinions and knowledge backgrounds that do not always coincide. As a result, the ultimate purpose of this dissertation is to investigate how Smart Grid actors actually cooperate and to elucidate how strongly heterogeneous knowledge can be integrated in the organizations in order to develop innovation.

1.3. Structure of the dissertation

For answering the research questions, the thesis is structured as follows: Chapter 1 introduces the challenges to Smart Grid collaboration. This will be followed by an explanation of the conceptual design including research questions and their relevance.

Chapter 2 describes the foundations for knowledge integration. The term knowledge is first explained and distinguished from other related terms, such as information and data in order to avoid confusion. This is followed by how the theoretical framework of knowledge integration provides insights into the project environment, its purpose for the innovation development and its process perspective. The three existing approaches to knowledge integration are described, which form the basis for identifying research gaps.

In chapter 3, my own conceptual approach for knowledge integration is presented. My concept theorizes what I mean by “knowledge integration beyond boundaries”. For this purpose, the dilemma of heterogeneity is described in parallel with the theorization of the multi-faceted nature of heterogeneity according to different proximity dimensions between organizations. With this in mind, I further define the concept of knowledge boundaries and elaborate the existing strategies for managing those boundaries. I then elaborate on the different underlying concepts of interorganizational learning and knowledge bridging. Both are illustrated with an overview of the type of knowledge, its process, its influences and its outcome. From my own conceptual approach, the hypotheses are delineated.

Chapter 4 outlines the methodological design for disentangling knowledge integration. The case study approach will be presented, as well as the case study design used to research Smart Grid projects. The chapter evaluates the validity of my conceptualization and operationalization of knowledge integration in heterogeneous Smart Grid projects.

The thesis continues in chapter 5 with the empirical analysis along the theoretical framework I have outlined. After a description of the specification of Smart Grid projects, the emergence of heterogeneity and knowledge boundaries is descriptively characterized and subsequently analyzed to elucidate the first hypothesis. The responses from the interviews to the concepts of interorganizational learning and knowledge bridging are presented next, where the data is used to analyze the second hypothesis. Likewise, the concept of boundary objects and innovation development is descriptively presented and used to enlighten the third hypothesis.

Chapter 6 discusses the various findings of the case study. First, a tabular overview is provided. Based on this, conclusions about the existing theory of knowledge integration are drawn in order to unravel the process. From my empirical findings, a new perspective will be provided giving insights into the new aspects of knowledge integration developed in Smart Grid projects. Finally, implications for the future Smart Grid projects are considered, particularly regarding what can be learned from the study. Chapter 7 ends with the conclusion of my thesis.

2. Knowledge integration in innovative projects

The new knowledge constellations in the Smart Grid are analyzed with respect to the integration of knowledge in heterogeneous collaborations. In this dissertation, knowledge integration is used as a theoretical framework for describing: *How and to what extent Smart Grid project partners integrate specialized and distributed knowledge in order to develop innovation.* This chapter on the concepts of knowledge integration forms the basis for answering the research question of my thesis. Gaps in the existing approaches will be identified through the theoretical elaboration with the view to establishing my own concept for knowledge integration in Smart Grid projects. After a chronological review of the development of knowledge integration, the term knowledge is defined and distinguished from similarly used concepts. Further, the need of knowledge integration for innovation development and its role in projects is highlighted and the process character is presented. Subsequently, the three different approaches of knowledge integration are synthesized, thereby identifying the current theoretical and empirical weaknesses created by the research gaps.

Knowledge integration has been studied from different angles and by several authors, resulting in the emergence of various theoretical approaches (Rakevičius and Auzias 2016). Preliminary considerations on knowledge integration began in 1776, when Smith (1776) observed the need for a new model of knowledge to explain emerging forms of specialized work and its economic advantages. Building on this initial thinking, Hayek (1945) emphasized the need for coordination to integrate knowledge and its role in economic specialization. In the middle of the 1990s, knowledge integration received a boost from strategic management scholarship, which examined the concept in relation to specialized knowledge (Tell et al. 2017b). This period has also witnessed the emergence of new concepts in the field of coordination within organizations, focusing in particular on the knowledge-based view of organization (Grant 2017). This new perspective brought together an opportunity to conciliate the advantages of division of labor with the necessity to integrate the efforts of various experts to formulate common goals. These explanations already addressed constraints on learning, the requirements to ensure that the process of knowledge integration process does not compromise the efficiency of specialization and the character and architecture of organizational capability (Grant 2017).

The interest in knowledge integration also remained present between the late 1990s and early 2000s, influenced in particular by authors such as Nonaka and Takeuchi (1995), Carlile (2002; 2004), Carlile and Rebentisch (2003), and Okhuysen and Eisenhardt (2002). Also later, around the 2010s, authors like Enberg (2007) and Söderlund (2010) or Wahlstedt (2014), Berggren et al. (2011) dealt with knowledge integration and contributed new insights into the concept. These authors not only attempted to determine the influence of knowledge integration on organizational performance within and across organizations, but have also formulated diverse ideas about what knowledge integration actually is and how it is integrated between organizations (Rakevičius and Auzias 2016). Tell (2011) has summarized these different approaches of knowledge integration and differentiated them into the three categories *"sharing and transferring of knowledge"*, the *"use of similar/related knowledge*" and the *"combination of specialized, differentiated but complementary knowledge"*. For my research, it is important to know how these existing approaches can be used as a starting point for describing knowledge integration in Smart Grid projects. To break down the different approaches, it is important to first take a step back and describe the origins of the concept of knowledge and terminological distinctions. Accordingly, it is necessary to develop an understanding of the knowledge term in order to further explore the different definitions of knowledge integration and to gain insights into how it can be used as an organizational source in innovative projects.

2.1. The developments in the term "knowledge"

Before going deeper into the various approaches of knowledge integration, it must be first clarified what is meant by the term "knowledge" in this research. In general, there are many definitions for the term (Grant 1996a), reflecting the differing traditions in areas of the sciences. In this thesis, the definition of knowledge should be placed in the context of innovative project work. The clarification and understanding of the term "knowledge" is particularly important not only due to the change of innovation work in interorganizational projects, but also due to the developments of knowledge sources (Fey and Birkinshaw 2005). In organization studies, knowledge has become an important topic (Kubo and Saka-Helmhout 2002), particularly with regard to how organizations process, create and share knowledge (Lahti and Beyerlein 2000; Ndlela and Du Toit 2001). In fact, knowledge is considered as a critical resource for organizational work, as it is expected to improve an organization's competitive performance (Grant 1996a; Okhuysen and Eisenhardt 2002). According to Grant (1996a), the competitive advantage is created primarily by an organization's ability to integrate the knowledge of individuals within the organization.

There are different definitions and approaches to knowledge as a resource for organizations. The most established definition of knowledge relates to the philosophical thinking of it as *"justified true belief"* (Dalmer 2022). The definition considers knowledge as the dynamic human process towards revealing the truth. Likewise, Nonaka and Takeuchi (1995) characterize knowledge as *"justified beliefs"*. In contrast, they do not try to put knowledge in a formal logic, but take into account the human factors that lead to the knowledge. From this, the authors have derived the definition of knowledge as a *"dynamic human process of justifying personal belief toward the "truth"* (Nonaka and Takeuchi 1995). However, truth as a main characteristic of knowledge is seen as critical, since it always depends on the personal circumstances and interests of specific actors (Dalmer 2022). Another definition derives from Davenport et al. (1998), who defines the term as *"the interconnectedness of experiences, values, contextual information as well as expertise that offers a setting for the evaluation and integration of new information and experiences"*. In this respect, knowledge is seen as context-specific, as it is embedded in documents, repositories as well as in routines, processes, practices and norms of an organization (Huber, Davenport, and King 1998).

Evolutionary philosophers, like Searle and Polanyi, as well as neurologists like Edelman and Damasio emphasize the importance of subsidiary consciousness and tacit consent when defining knowledge (Tell 2017). Polanyi (1966) distinguishes knowledge into the two different types tacit and explicit knowledge. To start with, tacit knowledge can be acquired by an individual especially through experiences (Polanyi 1966). However, the transfer of tacit knowledge is generally considered challenging, since tacit knowledge adheres to a person and has a sticky nature (Bush and Tiwana 2005; Dosi 1988; Hoskisson and Hitt 1994; Polanyi 1966; Rampersad and Rai 1996). Unlike tacit knowledge, explicit knowledge is not depend on one person and their experiences, but can be formalized into a series of rules and procedures that can be written down in books and knowledge libraries (Haddad and Bozdogan 2009). However, researchers distinguish the two types of knowledge differently: some researchers draw a hard line between tacit and explicit knowledge (Nonaka and Takeuchi 1995; Spender 1994), while others argue that knowledge consists of both types (Haddad and Bozdogan 2009; Kogut and Zander 1992; Polanyi 1966). In this respect, Haddad and Bozdogan (2009) assume that tacit knowledge is the specialized and contextual part of knowledge that refers to the subjective context, whereas explicit knowledge is more generic and abstract. The tacit character is also an important source for knowledge creation. In this sense, Polanyi (1958) assumes that knowledge articulation is an asymmetrical process that primarily relies on tacit knowledge. He argues that tacit knowledge is connected to discoveries and the irrevocable development of concepts, which improve the comprehension for problem-solving. Therefore, it is a reversible logical operation of known symbols. In codifying knowledge as an enhancement of articulation, an emphasis must be placed on the linguistic and symbolic character of knowledge formulations, as they establish the links between actions and outcomes (Ancori, Cohendet, and Bureth 2000). Codification thereby enables the storage and transfer of knowledge across time and space as well as the possibility to change and manipulate the transferred knowledge by rearranging it (Foray and Steinmueller 2003; Tell 2017).

Another approach to defining the concept of knowledge originates from Lundvall and Johnson (1994), who propose a differentiation of the term knowledge in the four categories *"know-what", "know-who"*, *"know-why"* as well as *"know-how"*. Their approach to the definition of knowledge is of valuable importance for this work, as it particularly relates specifically to interactive innovation development. The first category *know-what* pertains to facts and therefore refers to the gathering of information. Information of this kind can be divided into small pieces (Lundvall and Johnson 1994). Arguably, some professions, such as doctors or lawyers, require this know-what to fulfil their tasks (Lundvall and Johnson 1994). The next category *know-who* is related to the social relations of actors. The category refers to the importance of whom one knows, not just in terms of professional knowledge, but more importantly, as part of the network of social relations (Lundvall and Johnson 1994). In this sense, know-who is related to an interactive as well as cumulative innovation process (Lundvall and Johnson 1994). Third category is *know-why* relates to the laws and principles of nature in society, which is essential for innovative technological development (Lundvall and Johnson 1994). Lastly, *know-how* is related to the skills of an individual and, therefore, takes place on a practical level. These abilities apply not only to production activities, but also to other activities in the economy (Lundvall and Johnson 1994). Lundvall and Johnson adapt Polanyi's approach of tacit and explicit knowledge, arguing that know-how consists of both. The explicit part of know-how is based on scientific knowledge that is easy to understand and learn (Lundvall and Johnson 1994). Additionally, the tacit part can be seen in the fact that know-how often relates to key functions, which are hidden and cannot be separated from the social context of the individual. Know-how is reflected in many interorganizational relationships and is made accessible in them (Lundvall and Johnson 1994).

It can be seen that knowledge plays an increasingly important role in the economy and is traded as a valuable resource for the development of innovations and competitive advantages (Nonaka and Takeuchi 1995, p. 6). However, the differentiation of knowledge to information and data is often vague in the literature (Yolles 2006). In order to create a clear demarcation between the terms, it is essential to further discuss and distinguish the concepts in the following chapter 2.2.

2.2. Differentiation of knowledge from other terminologies

In everyday vocabulary, the term knowledge is often equated with other expressions, such as information or data (Dalmer 2022). A distinction between these terms is especially relevant as Smart Grid projects are significantly influenced by ICT, why a mix-up between knowledge, data and information is possible to occur. By distinguishing the terms, knowledge should be used in its most concrete of meaning in this thesis.

To start with, the term knowledge often goes along with the term *data* (Ajmal and Koskinen 2008). In general, data is objective and relates to discrete facts or statistics that can be collected for analytical purpose using a variety of methods (Davenport and Prusak 1998; Tarantino 2022). These include, for example, measurements, interviews or experiments. Likewise, data can be stored and used by organizations in specific systems. However, data alone often has little meaning, which is why it must be gathered, processed and interpreted (Dalmer 2022). Only when data is put into the right context can it make a difference and ultimately become information (Davenport and Prusak 1998).

As pointed out earlier, the term knowledge is also often confused with the term *information* (Rakevičius and Auzias 2016). In this sense, knowledge is often associated with the ability and skills of organizations to exchange information, which are built up within certain methods and strategies (Simon 1973). Many authors differentiate their definition from the origin of knowledge from information. Liebeskind (1996, p. 94), for example, defines knowledge as "*information, whose validity has been established through tests of proofs"* and, therefore, refers to information developed from test data as knowledge. Similarly, Johannessen and Stokvik (2018) define the term as the process of *"systematizing and structuring information for one or more goals or purposes"*. These definitions suggest that information is often a component of knowledge. In a similar way, Bateson (1979) argues that information offers a perspective on the interpretation of objects and events, rendering previously invisible meanings visible or revealing unexpected connections. Information is consequently used to construct knowledge by adding or restructuring aspects (Bateson 1979).

According to Nonaka and Takeuchi, however, the concept of knowledge goes beyond that. While information is indeed a part of the process, knowledge is *"essentially related to human* *action"* (Nonaka and Takeuchi 1995, p. 59). To further develop the consideration, the authors distinguish information from knowledge by three observations. First, they argue that *"information is a flow of messages, while knowledge is created and organized by the very flow of information"* (Nonaka and Takeuchi 1995, p.15). Thus, knowledge is, in comparison with information, about an action *"to some end"*. Second, the authors observe that knowledge connects beliefs as well as commitment, which is not the case for information (Nonaka and Takeuchi 1995, p. 58). Accordingly, knowledge is characterized as a function of a specific attitude, viewpoint or purpose (Nonaka and Takeuchi 1995). Third, knowledge is a matter of meaning, in other words, knowledge is relational and grounded in a specific context (Nonaka and Takeuchi 1995). From Nonaka and Takeuchi's point of view, information can only be viewed from the two perspectives of *"syntactic"* and *"semantic"*. While semantic information is the volume of information, syntactic information is its meaning. Nonaka and Takeuchi (1995) attribute a particularly important role to semantic information for knowledge creation as it is needed to convey meaning. Similarities of information and knowledge, besides the meaningfulness of both, can only be seen in their context specification and in their relationality, since they emerge dynamically and are situation-dependent (Nonaka and Takeuchi 1995).

The Data, Information, Knowledge and Wisdom (DIKW) pyramid developed by Ackoff (1989) distinguishes between the terms data, information, knowledge and wisdom and explains the transitions between them. Figure 1 reveals the concept, which defines data as all kind of signals, words and numeric values. In this sense, data only takes on meaning when it is located within a context. This turns data into information, which is expected to be organized, useful and structured (Ackoff 1989). By giving information meaning, information can become knowledge, which is synthesized, as well as integrated through the process of learning. The highest level is the transformation from knowledge to wisdom, which can be achieved by putting knowledge into practice (Ackoff 1989). According to the knowledge pyramid, data and information can be represented as explicit knowledge, while it can become tacit knowledge with increasing context know-how and skills (Haddad and Bozdogan 2009).

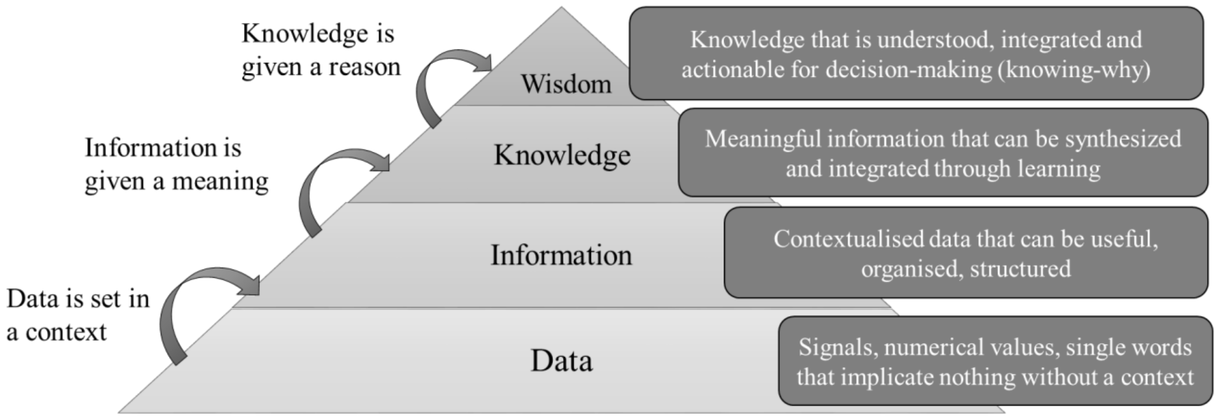

Figure 1 Knowledge in the DIKW pyramid according to Ackoff 1989 (Köhlke 2019a)

The distinction makes it clear that while the concepts of data, information and knowledge are related, the concept of knowledge often goes beyond that and includes human actions. Only when data becomes information in the right context and the information is given a meaning, can knowledge evolve. Chapters 2.1 and 2.2 have laid the foundations for the concept of knowledge. Finally, the next chapter elaborates the prerequisites for knowledge integration in an innovative project context and highlights its process character.

2.3. Knowledge integration as a prerequisite for innovation development in projects

In order to research knowledge integration in Smart Grids, it is first necessary to identify the surroundings and specific circumstances. Since the focus is placed on project work, it is necessary to explore the theoretical foundation of projects and to reflect knowledge integration in their environment. Next to the project-based setting, an overview on knowledge integration and innovation is elaborated in order to explore how and why multi-faceted challenges, such as those found in the energy system, require new solutions in the form of innovations. Innovation and its dynamics and processes are inherently complex and, thus, can be applied and defined in many ways. Accordingly, it is necessary to point out the theoretical basis of innovation in terms of knowledge integration.

2.3.1. Knowledge integration in a project-based context

Smart Grid projects constitute the operational framework for knowledge integration in this dissertation. In recent years, projects have evolved into dominant forms of organization (Taylor and Asheim 2001) and are considered as significant resources for organizational learning (Brady and Davies 2004). Since projects often feature an interorganizational dimension, they are commonly embedded in the context of networks or ecologies (Sydow and Braun 2017). In general, projects can be defined by *four fundamental characteristics* (Grabher 2002). Firstly, projects rest on a specific task. Secondly, due to its complexity, the task is solved in an interactive process. Thirdly, a project manager is responsible for bringing together the different parts of the work to be done. Fourthly, the manager's function reflects the consequent balance of power. In order to solve certain interrelated tasks, different project partners are allocated to a project for bundling needed capabilities (Grabher 2002).

In general, projects can be seen as *temporary social systems* that integrate expert knowledge from various organizations (Bakker 2010; Bechky 2006; Jones and Lichtenstein 2008; Sydow, Schüßler, and Müller-Seitz 2016). For example, Cleland and Kerzner (1985) define projects as *"a combination of human and non-human resources pulled together into a temporary organization to achieve a specific purpose"*. Accordingly, projects are not only a temporary organization, but also a production of functions and the merging of different resources (Turner and Müller 2003). As has been pointed out, projects are temporary mergers that are confronted by an increasing complexity and a higher demand of mobility when integrating new knowledge (Söderlund and Bredin 2011). Mobility can be seen in the fact that research and especially engineering projects are often performed by mobile engineering experts who are deployed flexibly within the projects. The working context of engineers in projects is therefore subject to high mobility and flexibility due to changing circumstances and geographical distances between organizations (Söderlund and Bredin 2011).

Turner and Müller (2003, p. 7) introduce another *innovation-based perspective* of projects. They describe projects as *"temporary organizations to which resources are assigned to undertake a unique, novel and transient endeavor managing the inherent uncertainty and need for integration in order to deliver beneficial objectives of change"*. The authors highlight the importance of projects for dealing with current uncertainties and developing innovations. Projects, as a form of cooperation between organizations, are predominantly established to gain new knowledge and insights, which cannot be achieved by their own (Abbas et al. 2019). Usually, projects consist of several organizations that aim to cooperate by contributing their resources and skills (Dussauge and Garrette 2000, p.99). To reach their full economic potential, organizations rarely work autonomously and are, thus, dependent on the integration of complementary knowledge of other companies (Johansson et al. 2011; Mu et al. 2021).

As a systematic form of knowledge management and as an instrument of organizational learning, projects are proposed to improve the integration of knowledge (Brady and Davies

2004). Despite these positive effects of projects, the integration of knowledge within project work is often perceived as a *demanding task* due to two main factors (Lawrence et al. 2022). Firstly, the characteristic of knowledge itself is very complicated as a result of the tacit nature, especially if the knowledge cannot made explicit by communication alone (Cohen and Levinthal 1990), but also due to the differentiation, uncertainty and interdependencies of knowledge. Projects are, thus, challenged by interdependencies and the development of solution strategies to deal with different knowledge disciplines and technologies, which pose a major challenge to the success of the project innovation (Granstrand, Patel, and Pavitt 1997). In the past, these aspects have led researchers to focus more on the skills required of project members need in order to work with relatively unfamiliar partners and to quickly build relationships in order to define work roles and establish partnership in the process of knowledge integration (Bredin and Söderlund 2011). Accordingly, project members require the capacity to work with experts from different background in order to understand how to use external knowledge and how to incorporate one's own unique knowledge in the problem solving process of projects (Söderlund and Bredin 2011). Secondly, the circumstances of the cooperation between organizations determine knowledge integration in projects. These circumstances include the aforementioned temporality, flexibility, complexity and mobility of projects (Söderlund and Bredin 2011), but also assert specificity, uncertainty and conflicts of interests (Johansson et al. 2011). Also, a difficulty of knowledge integration in projects stems from the need to create general knowledge for communication within a group, such as in the form of common knowledge (Carlile 2004). For this purpose, project oriented settings require a low level of common understanding (Söderlund and Bredin 2011). Moreover, due to the temporal limitation and the changing character of projects, additional effort and resources have to be invested to build trust between the members (Grabher 2002).

Project environments require a fast socialization, but also rapid deliveries and tight deadlines (Söderlund and Bredin 2011). Previously, project partners understood their role to be solving problems or performing a predefined and technically demanding task within tight time and cost constraints (Lindkvist 2005), whereas now, the interactional basis of project work is much more complex as a result of the temporary setting and the coping with opposing and conflicting interests (Tell 2011). In this sense, the organizational fluidity within interorganizational projects requires a more complex form of knowledge integration, contrary to the traditional project culture and team structure in well-established businesses (Söderlund and Bredin 2011). To conclude, project partners require more skills related to the integration of knowledge in a project-based as well as fluid economy (Söderlund and Bredin 2011). The knowledge integration process is now characterized by high dynamics, mobility and temporary characteristics, which is why project members have to deal with different expert knowledge, time difficulties and conflicts of interests (Söderlund and Bredin 2011).

2.3.2. Correlation of knowledge integration and innovation development

Developing innovations is one of the main objectives in today's project work between different organizations. The theoretical debate on the concept of innovation is generally extensive and spans many disciplines, including many of researchers in the community (Fagerberg and Verspagen 2009). The widespread use of the innovation term is leading to diversification and thus less established and consensual definitions. Looking at the more general discussion on the innovation concept, most authors investigate innovation development in terms of new processes, products, organizational practices, or markets (Carboni and Russu 2018). From this perspective, Baregheh et al. (2009) define innovation as the *"multi-stage process whereby organizations transform ideas into new/improved products, services or processes, in order to advance, compete and differentiate themselves successfully in their marketplace".* Next to the purpose of innovations for market positioning, innovation can differ in its forms. This form can range from radical or disruptive innovations to even incremental or evolutionary ones. Radical innovations often influence technologies, competition and markets, as well as derive from entirely new fields of knowledge incorporating new sources. Incremental innovations, on the contrary, draw on existing knowledge (Appel-Meulenbroek and Danivska 2021). In this sense, innovative projects seek to turn ideas into new products or services that improve systems or develop valuable practices or concepts (Bano et al. 2018). In general, it is assumed that the development and implementation of innovation in project work correlates positively with the economic success of an organization (Gemünden, Lehner, and Kock 2018). Most innovation-based studies investigate quantitatively and draw conclusions about how organizations deal with innovation (Mattes 2010) by focusing on measurement criteria (Tether 2002, Smith 2005), large-scale calculations or data analysis (Blanc and Sierra 1999).

Regarding my research question, a definition is needed that covers innovation in the area of knowledge integration in projects. Nonaka (1994) is one of the first authors that highlighted innovation in a knowledge-based nature way and who argued that the creation of knowledge through explicit and tacit knowledge fosters the approach to innovation in terms of an ongoing learning process. In a similar way, Herkema (2003) considers innovation as *"a knowledge* *process aimed at creating new knowledge and geared towards the development of commercial and viable solutions"*. Tell (2011) identified some approaches of qualitative studies that address the relation between knowledge integration and innovation development. Here, innovation is seen as the result of knowledge integration (Kodama 2009). For example, one stream of research assumes that knowledge integration influences product performance (Iansiti 1995; Marsh and Stock 2006; Takeishi 2002). This positive effect can be seen, for example, in patent citations (Dibiaggio and Maryam 2009; Singh 2008) or by encouraging the emergence of certain products (Brusoni and Cassi 2009; Schmickl and Kieser 2008). Other researchers argue that knowledge integration has a positive effect on the dynamic capabilities of companies (D'Adderio 2001; Söderlund and Tell 2009; Verona and Ravasi 2003), which increase innovation and competitive performance of organizations (Tsekouras 2006).

Innovation is strongly anchored in an *interactive knowledge process*. However, this interaction for innovation development is often seen as challenging. Mattes (2010), for example, assumes that there are organizational challenges in implementing innovations and suggests that these difficulties can be partially solved with the help of projects serving as instruments for good temporary solutions. Likewise, Lundvall (2005) highlights innovation as an *"interactive process"* between actors that occurs at any time. Complementing this, Subramanian, Lim and Soh (2016) anticipate that informal teams facilitate innovation development by sharing knowledge more easily through spontaneous conversations and fewer conflicts of interest. In addition, Schmickl and Kieser (2008) emphasize the connection between innovation within projects and knowledge integration between different experts, when discussing the project-specific mechanism *"modularization"*, *"prototyping"* and *"transactive memory"*. These mechanisms intend to reduce the necessity for knowledge integration between project partners in product innovation (Schmickl and Kieser 2008).

Another attempt at enhancing insight into innovation development within knowledge integration is the *expertise* of project partners. Tiwana and McLean (2005) affirm a positive correlation between knowledge integration and team creativity found in relation to the individual expertise present in a team. Similarly, Amabile (1997) sees expert knowledge as an important factor for innovations. Expertise is, in this context, an essential component of creativity, which encompasses intellectual as well as procedural and technological knowledge. This various type of expertise, which is not always available in one's own organization, must be recombined for innovation (Amabile 1998). Thus, organizations are demanded to look for new ideas and knowledge beyond organizational borders (Amabile et al. 1996; Enberg 2007).

With regard to experts, who may represent a kind of functional knowledge in projects, *heterogeneity* is also recognized as an important source for innovation development within knowledge integration (Fagerberg, Fosaas, and Sapprasert 2012). Nelson and Winter (1982), for example, developed the concept of theoretical innovation, which is attributed to heterogeneous actors. They characterize innovative organizations as having different perception of the world, various routines and other strategic options, compared to the actions of less innovative companies. In their research, they found out that heterogeneous capabilities shape the organizational world differently and create a series of path-dependent results that are important for innovation development (Fagerberg, Mowery, and Nightingale 2012). Heterogeneity is, thus, an important factor for addressing innovation (Crescenzi and Gagliardi 2018). In reverse, innovation development is often limited between organizations from the same knowledge field or industry, when there is restricted proof of diversity between them (Patel and Pavitt 1997). Of particular importance is innovation as an interactive knowledge process between different actors, which leads to the assumption that knowledge integration shows a process character. The next chapter provides an overview on the process perspective of knowledge integration, which is useful in order to better understand and argue the process character.

2.3.3. A process perspective in knowledge integration

Central to this thesis is a process perspective on knowledge integration, especially for answering the second sub-question. Hence, this chapter provides an account of the perspectives on knowledge integration as a process. To begin with, Okhuysen and Eisenhardt (2002) clearly distinguish between knowledge integration and its process. While the process focuses on the activities of the group, which consists of the individual sharing and combining of knowledge to generate new knowledge, knowledge integration per se is the result of this process in terms of shared and combined knowledge (Okhuysen and Eisenhardt 2002, p. 371). In a similar vein, Weick and Roberts (1993) argue that, with regard to the social system, knowledge integration is a collective action consisting of well linked individual knowledge bases as well as individual actors who need to interact with each other or conduct themselves with attentiveness and care. The cooperative aspect is foregrounded here.

In addition to the cooperative aspects emphasized above, Tiwana (2008) defines knowledge integration as a process. This process is able to generate alliances and partnerships between various organizations with the result of exchanging information as well as knowledge.

Likewise, Huang and Newell (2003) define this collective process and knowledge integration as *"an ongoing collective process of constructing, articulating and redefining shared beliefs through the social interaction of organizational members"*. The authors, therefore, emphasize the dynamics and efficiency of knowledge integration in projects across different functions (Huang and Newell 2003). Accordingly, knowledge interaction is more than just developing new processes, products or organizational practices, but revolves around the social process between organizational actors.

Another perspective of knowledge integration as a process derives from Enberg (2007), who focuses on the specialization of actors and the linking of knowledge complementarities. In this sense, the author defines knowledge integration as "*the processes of goal-oriented interrelating with the purpose of benefiting from knowledge complementarities existing between individuals with differentiated knowledge bases"*(Enberg 2007, p. 10). Like Enberg, Berggren et al. (2011b) also refer to the combination of a specialized knowledge base of actors and define knowledge integration as a goal-directed process, the main objective of which is to achieve substantial outcomes for enhancing the organization's competitiveness. This requires a specialized, complementary knowledge base to create internal knowledge and to absorb external knowledge (Berggren, Bergek, et al. 2011b). Likewise, Berggren et al. (2011a, p. 7) describe that knowledge integration is a goal oriented process *"of collaborative and purposeful combination of complementary knowledge"*. It is evident that the researchers agree that knowledge integration is a process triggered by an organization's ability to generate knowledge integration capabilities. These organizational skills are classified as attributes that make it possible for an organization to accomplish their tasks and fulfil their goals (Berggren, Bergek, et al. 2011b). Although there is a strong consensus that knowledge integration is processual, there is an evident lack or research as to how this process is actually undertaken between organizations.

Chapter 2.3 examined knowledge integration, not only in the context of project work, but also for innovation development and addressed the specific process character. With this in mind, the three approaches to knowledge integration will be discussed that specifically tackle the existing research gaps addressed above.

2.4. Three different approaches to knowledge integration

Knowledge integration is currently acknowledged as one of the key factors for innovative projects and has, therefore, attracted growing attention in the past years (Berggren et al. 2011; Majchrzak, More, and Faraj 2012). The leading researchers in this field are Okhuysen and

Eisenhardt (2002), Enberg (2007), Söderlund (2010), Tell (2011) and Wahlstedt (2014). Most of these authors consider knowledge integration as one of the most important, but at the same time one of the most challenging elements in interorganizational collaboration and in fostering innovation (Johansson et al. 2011). On the one hand, knowledge integration is considered as a highly valuable factor for enhancing efficient and successful organizational management in competitive enterprises (Tell 2011). Knowledge integration should, therefore, not only help to explain differences in the innovation development of organizations, but also enables those organizations to differentiate themselves from their competitors (Carlile and Rebentisch 2003; Hoopes 2001). On the other hand, coordination problems can arise as a result of knowledge contingencies, which potentially lead to conflicts in the working relationships in cooperations (Johansson et al. 2011). The difficulty of knowledge integration lies particularly in the high degree of specialized knowledge that is needed in order to obtain high combination possibilities for creating innovations (Enberg 2007). Although differentiation is a crucial factor for innovation development, it entails also the potential risk of disturbing or inhibiting knowledge integration. This risk spans from the attitude and behavior of individuals acting in an organizational context to their differences in cognitive as well as emotional routines (Lawrence and Lorsch 1967). To conclude the dilemma: while the necessity of knowledge integration in an interorganizational context is almost universally recognized, equally identified is the potential for risk and conflict.

Thus, the literature in this field has outlined three main research approaches that attempt to break down knowledge integration under different focal points. Tell (2011) identifies three distinctions to the knowledge integration approach, which are the *"transferring of knowledge"*, *"the use of similar and related knowledge"* as well as *"the differentiation of specialized, but complementary knowledge"*. This section, hence, aims to understand and unravel the different approaches of knowledge integration, to recognize the difficulty of the concept itself and to finally derive research gaps from the three approaches.

2.4.1. Transferring and sharing of knowledge

The first approach of knowledge integration refers to the *"transferring and sharing of knowledge"*, where the focus is on the acquisition of common knowledge for the operation in an organization (Tell 2011). Grant's idea is taken as a point of reference for the initial objective of the approach, which is based on the creation of a common knowledge base through the sharing and transferring of knowledge (Tell 2011). Grant (1996b, p. 115) argued that *"all* *(organizations) depend upon the existence of common knowledge for their operation"*. There is an agreement amongst researchers that this common knowledge is formed by the individual collection of specialized knowledge. In fact, most of the authors belong to the first approach.

By reviewing the literature, the first approach to knowledge integration reveals a different understanding for the transferring and sharing. While some researchers only refer to knowledge integration in the sense of transferring of knowledge, other authors argue that it is more about the sharing of knowledge and some refer to the combination of sharing and transferring. Similarly, it is not clear in the literature whether "sharing" and "transferring" are used as synonyms or whether they remain as separate phenomena and are deliberately chosen by the different authors. Willem et al. (2008) emphasize the combination of both transferring and sharing, arguing that *"knowledge integration includes the sharing and transferring (of) knowledge, but also the collective application of knowledge in cooperative activities"*. The authors, therefore, refer to the sharing and transferring of knowledge in the same vein. Likewise, Yang's definition of knowledge integration is associated with *"creating, transferring, sharing and maintaining (of) information and knowledge"* (Yang 2005). In contrast, authors like Brown and Duguid (1998) highlight only the sharing of knowledge in the process of knowledge integration and assume that *"knowledge is continuously embedded in practice and thus circulates easily, members of a community implicitly share a sense of what practice is and what the standards for judgment are, and this supports the spread of knowledge. Without this sharing, the community disintegrates"* (Brown and Duguid 1998, p. 100-101). Definitions with a focus on transferring, such as those by Mitchell (2006, p. 923), distinguish between internal and external knowledge transfer and highlight the importance of two elements, namely *"access to external knowledge represents an external-to-internal transfer of knowledge, while internal knowledge integration captures an internal-to-internal transfer of knowledge"*. Another contribution within this line of research stems from Subramanian (2006, p. 542), who emphasizes the effectiveness of knowledge integration, arguing that it *"requires that multisource knowledge not only gets transferred but also applied into design features and, ultimately, embodied into products"*. In this regard, the practice of knowledge integration is seen as a collective interaction for achieving a similar knowledge base (Lindkvist 2005). A distinction between the sharing and transferring of knowledge was made by Postrel (2002), who assumes that "knowledge transfer" is an unilateral information flow from a sender to a receiver. In contrast, "knowledge sharing" is the *improvement* of a trans-specialist comprehension of overlapping knowledge fields. Consequently, the approach of knowledge integration suggests the development of a certain basis of shared knowledge between the various experts. Together, the transferring as well as sharing of knowledge are a powerful force for effective integration of knowledge (Tell 2011), both of which have great innovation potential (Brown and Duguid 1991).

Huang and Newell (2003) elaborate further on the alignment of actors' knowledge bases through transferring and sharing, emphasizing the need for *shared beliefs* in the process of knowledge integration. The transferring and sharing of knowledge assumes an equality between actors to generate a common knowledge base. This sameness serves as a structural prerequisite for the emergence of any exchange of specialized knowledge in the integration process (Tell 2011). Newell and Huang (2003) emphasize the importance of shared beliefs and consider knowledge integration as an *"ongoing collective process of constructing articulating and redefining shared beliefs through the social interaction of organizational members"*. In a different paper, Newell et al. (2004) also argue that *"the integration of knowledge depends on joint knowledge integration"*. The studies in the research line particularly address the need for joint knowledge building through the transferring and sharing of knowledge between different experts with the purpose of developing common ground (Bechky 2003). This should avoid misunderstandings that could arise due to different specifications, various interests, norms, procedures, work routines and standards of the actors. Thus, achieving a common ground of understanding each other should improve knowledge integration between heterogeneous actors (Bechky 2003). This first approach to knowledge integration not only adopts a practice-based perspective, but also relies on the development of common knowledge and shared believes.

According to the explanations, a modest sharing and transferring can take place, since the approach is based on the *difficulties of knowledge integration* (Wahlstedt 2014). The challenge of transferring and sharing knowledge derives, in particular, from individual actors having different knowledge backgrounds, educational levels or experiences within a specific field (Wahlstedt 2014). Dougherty (1992) describes this phenomena as "thought worlds", in which actors from different organizational functions exist. These thought worlds strongly affect the behavior of the various actors in ways that can both facilitate and inhibit the cooperation required for knowledge integration. Thus, they have different labor standards, routines, various persuasions and preferences, which could lead to disputes and conflicts between actors (Dougherty 1992). Even when these actors know about their differences and try to overcome them, they are often unable to prevent misunderstandings and problems (Wahlstedt 2014). False assumptions of shared understanding between collaborative partners can lead to misunderstandings even when attempts have been made to overcome the differing thought worlds each party may bring to a project (Wahlstedt 2014).

From this perspective, Scarborough et al. (2004) argues that the transfer of knowledge within knowledge integration generally *serves to solve problems* in knowledge integration. Authors, such as Marsh and Stock (2006, p. 427), refer to the overcoming of knowledge boundaries, suggesting that *"intertemporal integration, or the application of knowledge developed in prior projects contributes to new product development performance, because it enables exploitation of existing knowledge to solve the problems encountered in new product development. When an organization draws on prior knowledge, it reduces the costs of search activities of new product development".* Carlile (2002) offers another attempt to provide insight into the difficulty of knowledge integration, pointing out that knowledge is both a source and a barrier of innovation. Carlile (2004) highlights the "*transferring, translating and transforming*" as processes of knowledge integration, focusing particularly on the differences between actors that can equally lead to knowledge boundaries in the process of knowledge integration (Carlile 2002, 2004). Carlile (2004) expands how the approach of boundary objects serves as a means to develop innovation across knowledge boundaries. Boundary objects reveal how different actors can cooperate despite having different knowledge sources (Star and Griesemer 1989). Likewise, Scarbrough et al. (2004, p. 1582) see the transfer of knowledge as a challenge and argues that *"knowledge integration within a project involves overcoming barriers to the flow and transfer of knowledge arising from pre-existing divisions of practice among team members"*. Hence, the division of practice is a significant contributory factor problematizing knowledge integration.

As indicated above, the communication and coordination of activities in a collaboration can be negatively influenced by differences in culture, values, interests and working patterns of actors (Carlile 2004; Bechky 2003). Different ways of dealing with the difficulties of knowledge integration are described in the approach. For example, knowledge brokers or translators are considered as a way for building this common knowledge (Brown and Duguid 1998). Knowledge translators function as mediators within a collaboration between differing actors and institutional practices by explaining each other's position and perspectives. A translator must be seen as trustworthy by the different parties, have a broad knowledge in the respective fields, and be able to explain the different knowledge and institutional practices in order to negotiate between the actors. However, these translators, such as consultants, are difficult to find, despite their benefit for heterogeneous collaborations (Brown and Duguid 1998). Unlike translators, who usually are external, knowledge brokers often come from inside the organization and join several groups or communities together. Since knowledge brokers are weak ties that are not assigned to a specific group, they are able to improve the knowledge flow in strongly entrenched narrow groups (Granovetter 1973, Brown and Duguid 1998). Thus, they do not mediate in a specific group, but loosen up the group for other new perspectives.

To sum up, the first approach focuses on the difficulty of knowledge integration, which is why only a modest transferring and sharing can take place. However, there are also critical voices to the first approach, claiming that knowledge sharing or transferring is not sufficient to integrate knowledge (Okhuysen and Eisenhardt 2002). These critics refer to the fact that individuals that have a common knowledge base cannot share or transfer this knowledge, because they already have very similar knowledge integrated. The integration would, therefore, become irrelevant (Tell 2011) and innovation capabilities would decrease.

2.4.2. Use of similar and related knowledge

As stated in the introduction, the size and variety of scientific and technical organizations within the energy system are rapidly increasing, crossing geographical and organizational boundaries. This process of growth within the energy markets leads to new specialized networks, roles and functions and often develop in conjunction with the manufacturing of complex products. . This development is also reflected in the energy system, where very specialized knowledge exists, which is reflected in different roles and functions of the partners in order to create a new innovative socio-technical system. In most cases, the specialization can be attributed to the different functions in a system.

The second approach alludes to this specialization of actor and assumes that knowledge integration is based on "*the use of similar or rather related knowledge"* (Tell 2011). Although this second approach is arguable underutilized as a model of explanation, it nevertheless shows an interesting perspective, as specialization and expertise is ascribed an increasingly significant role in controlling and developing complex systems (Newton, Fiore, and Song 2019). In this manner, the second stream of knowledge integration highlights the importance of specialization to knowledge integration and suggests that individuals, whose knowledge is highly specialized, integrate new knowledge more easily (Tell 2011). This means that specialists are more likely to synthesize knowledge in the area of their existing specialization and deepen this specialization than individuals who are broadly positioned and search in the breadth of different knowledge areas (Tell 2011). Specialization in a particular knowledge field is therefore associated with a certain depth of knowledge (Tan 2020). Accordingly, the adherents of this approach assume that specialists integrate knowledge in their own "small world" (Kodama 2009; Stuart and Podolny 1996), in other words a community of a particular research field. In general, this perspective argues that specialists increase the potential for well-managed knowledge integration, leading to co-specialization and better economies of scale and thus improved research outcomes (Becker and Murphy 1992; Chandler Jr. 1990; Teece 1982). Arguably, therefore, the value of specialized knowledge and the skills to integrate it are crucial for the competitiveness of organizations and optimize the outputs of knowledge integration (Huang and Newell 2003; Kogut and Zander 1992). In general, specialization is not only triggered by training, experience or cumulative efforts in a particular field, but also by networks, associations and informal groups which overcome the barriers of geographical location and temporal sequencing (Tell et al. 2017a). Moreover, the capacity of specialized knowledge can be defined by the two essential mechanism "direction" and "organizational routines" (Grant 1996b), which implies that all actors with specialized knowledge do not have to master all issues in the knowledge transfer (Huang and Newell 2003). While direction facilitates a codification of tacit knowledge into unambiguous rules (De Meyer 1998), organizational routines decreases the necessity of explicit knowledge communication (Huang and Newell 2003).

However, this approach has been criticized from a wide variety of viewpoints and, therefore, tends to be less accepted. One of the main *criticisms* concerns the fact that the approach does not really explain the process of knowledge integration, but infers processes from measured results. This led to the challenge in finding conceptual definitions that are consistent with the empirical concept of knowledge integration (Tell 2011). Although specialization seems to have an impact on knowledge integration, it remains open how exactly the process occurs. Another potential problem with specialization is that it could become costly if its role within knowledge integration is not well-managed, for example, an absence of shared knowledge produces missing understanding between individuals or groups (Carlile 2002; Grant 1996b; Postrel 2002). This means that it could result high costs within working environments when incomplete information, challenges in cross-border communication as well as a lack of common knowledge and understanding among each other (Carlile 2002; Grant 1996b; Postrel 2002). Under such circumstances, an appropriate way to integrate knowledge beyond functional heterogeneous specialists is needed (Tell 2017). Equally, specialization can risk inefficient knowledge integration - while specialized actors are often able to dive deeper into a discipline, interconnectivity and linkages to other discipline can also be lost.

Authors of this approach also argue that specialized knowledge integration could be understood and measured by examining the relationships of actors according to their integrated fields of knowledge. The relatedness of the knowledge bases of a group of specialists can be used as an indicator to determine the extent of knowledge integration (Nesta and Saviotti 2006). However, this relational argument is often criticized because the process of generating relatedness between knowledge domains is easy to identify in the breadth of knowledge (Tell 2011), but it is more difficult to examine with regard to the integration of depth of knowledge. The depth can thus only be detected within the specialization (Tell 2011). As a result, the more integrated a knowledge base is, the more specialized it becomes. Hence, the critique relates to the merging of specialization and integration (Tell 2011). Finally, existing literature assumes that cooperating partners are not able to fully integrate each other's knowledge, because of the scale. A complete integration of specialized knowledge would require the transfer of tacit knowledge, which is sticked to the person. In order to integrate specialized knowledge, a knowledge base would therefore have to be created beforehand (Curren 2007). Concluding, specialization comes with some costs. Due to limited time and personal costs, most researchers recommended considering, which specialized knowledge should actually integrated (Dilger 2012).

Although specialized knowledge is necessary to solve complex tasks, it can also lead to challenges in the cooperation between organizations. The acquisition of a specialization requires time (Dilger 2012), since the knowledge is often built up from a deep familiarization with the material and the accompanying experiences. This could lead to the risk that opportunity costs will rise during a collaboration because it is time and personnel intensive (Dilger 2012). As a result, specialists may be trapped in a particular community and therefore have little insight into other disciplines. Some authors therefore suggest the joint learning of the other specializations as a way to handle the differing perspectives that specialized knowledge in collaborations brings. While the second approach hardly looks at the relationship between specialists, the third approach casts a new perspective on the combination of specialized knowledge, which is discussed below.

2.4.3. The combination of specialized, differentiated but complementary knowledge

Today's projects increasingly consist of cross-functional teams of contemporary organizations, which have not only different organizational functions, but also have different goals and require varying knowledge and skills to address them (Dussart, van Oortmerssen, and Albronda 2021; Stipp, Pimenta, and Jugend 2017). This emerging type of cooperation does not necessarily require organizational restructure and is nevertheless very useful in their dealing with challenging organizational tasks (De Meyer 1998; Turner and Keegan 1999). Although cross-functional projects often play a role when integrating external knowledge, research in this area is rather limited (Huang, Newell, and Pan 2001). This limitation mostly refers to the dynamics of a cross-functional integration of knowledge within a project team and not to the dynamics outside the team boundaries (Huang and Newell 2003). Well-known researchers of this approach are, for example, Grant (1996b), Okhuysen and Eisenhardt (2002), Carlile and Rebentisch (2003), Enberg (2007), Söderlund (2010), Wahlstedt (2014) or (Bredin et al. 2017).

Researchers who primarily consider the cross-cutting functionality of project teams can be allocated to the third approach of knowledge integration, that is the *"combination of specialized, differentiated, but complementary knowledge"* (Tell 2011). This category defines knowledge integration as a process or rather an activity that aims to combine different specialized knowledge and, thus, distinguishing knowledge integration from *"knowledge sharing or transferring"* and the *"use of similar and related knowledge"* (Tell 2011). The third approach of knowledge integration highlights the economic use of specialized knowledge and refers to the distinctiveness of projects outputs as a valuable source (Huang and Newell 2003, p.168). In particular, the third approach refers to the need of different specialization of knowledge that should be combined in the process of integrating knowledge (Tell 2011). Regarding these particularities, knowledge integration is *"a process of collaborative and purposeful combination of complementary knowledge, underpinned by specific and focused personal, team, and organizational capabilities, a process that usually involves significant elements of knew knowledge generation"* (Berggren, Bergek, et al. 2011a). Of particular importance here are the individual specialized competencies as one of the most important elements in knowledge integration. However, these competencies and specialized bodies of knowledge do not stand alone, but are linked by agile methods and feedback loops aimed at achieving interdisciplinarity in the project (Bredin et al. 2017). Likewise, Tell (2017a) regards specialization as one of the key mechanisms for the growth of knowledge and is therefore indispensable for the establishment of new knowledge fields. Expert communities are particularly important to build and coordinate such specialized knowledge (Tell et al. 2017a).

This approach to knowledge integration is based on the combination of variously distributed bodies of knowledge, which work in such a way, that access to, and the use of, the individual's specific knowledge for a joint effort is made feasible (Dougherty 1992; Okhuysen and Eisenhardt 2002). Thus, the emphasis often lies on the existing *knowledge complementarities*, which are to be integrated (Enberg 2007; Lin and Chen 2006). Although some activities like sharing knowledge can be part of this approach, they are subordinated to an emphasis upon the distinctiveness of an individual's innovation and an organization's specialized knowledge (Bhandar et al. 2007; Tiwana 2007).

Second to complementary knowledge is an emphasis upon another component, namely *commonalities of knowledge* (Wahlstedt 2014). Authors in this research stream assume that the different specialists need to have something core or fundamental in common, since completely different knowledge bases or paradigms cannot be integrated. This can be described as an additivity between the different kinds of knowledge (Grant 1996c, p.111). Nevertheless, up and beyond these paradigmatic assumptions, a mechanism to integrate specialized knowledge needs to be found, which is considered as rather challenging (Wahlstedt 2014). A certain proportion of the same knowledge and a general absorptive capacity are required, upon which especially new knowledge can be added. These mechanisms facilitate the minimal effort needed for mutual learning between specialized partners, a process that assists with the integration of knowledge (Grant 1996c, p.114).

Knowledge integration in this context contains two main components, namely: 1) the *specialization* that is necessary for gaining economic scope and 2) the *linking mechanism* to streamline and organize the specialized workforce (Lawrence and Lorsch 1967). Against this background, organizations need to combine at least two knowledge bases for reaching their goals (Johansson et al. 2011). Different methods have been established in order to combine the knowledge base between one and another company without hitting boundaries. These include cross-functional teams, knowledge brokers or the documentation of knowledge (Schmickl and Kieser 2008). Successful knowledge integration in innovative projects requires the expertise of individuals, but this process must be managed in order to ensure that no new unsolvable difficulties arise for teammates (Enberg 2007). One of the main tasks of knowledge integration is to *discover, communicate and transfer relevant knowledge* between the collaborating partners (Carlile and Rebentisch 2003; Okhuysen and Eisenhardt 2002). According to Carlile and Rebentisch, knowledge integration is not only the development of new, appropriate knowledge combination from various sources, but also the modification of existing knowledge for the establishment of new solutions across different knowledge fields (Carlile and Rebentisch 2003). To conclude, the various efforts to grasp knowledge integration demonstrate that it is a multilevel process influenced by complexity and uncertainty.

Overall, the approach is highly recognized, because of *two benefits*. Firstly, knowledge integration and its mechanisms are able to minimize the costs of collaborative work (Tell 2011). Secondly, the approach considers the recombination of knowledge is a crucial prerequisite for developing innovation. Thus, the third approach concerns the generation of new knowledge through the complementarity of knowledge specializations (Katila and Ahuja 2002; Rosenkopf and Almeida 2003). Dwelling on the aspect of knowledge combination, complementary and interdisciplinary knowledge are essential prerequisites needed for innovation development (Berggren, Bergek, et al. 2011a). For example, the development of new technologies needs the integration of different kind of technological knowledge, such as component, manufacturing or application knowledge. However, the integration of knowledge describes not only the process of merging different bases of knowledge, but also the creation of new knowledge that is required for a successful integration (Berggren, Bergek, et al. 2011a).

Building on the description of the three different approaches, the next chapter explores where research gaps exist and contrasts the three approaches based on the key aspects that emerged from the baseline review.

2.5. Research gaps in the knowledge integration approaches

As indicated in the introduction, much of the existing literature elaborates on how to develop the technical part of the Smart Grid, but the social collaboration between the heterogeneous actors in Smart Grid projects is almost completely omitted (Paustian et al. 2022). The study of knowledge integration in Smart Grid projects is particularly relevant, as Smart Grid projects represent a new form of collaboration that involves complex networks of collaborative relations that are embedded within complex, heterogeneous technically demanding knowledge-based tasks of Smart Grid projects. Much less is known about the patterns, mechanisms or techniques undertaken by the actors to integrate knowledge successfully in innovate collaborations. It is thus not known: *How and to what extent Smart Grid actors have to integrate distributed and specialized knowledge in innovative Smart Grid projects*. Due to the specific characteristics of Smart Grid projects, it is neither possible to clearly assign Smart Grid projects to one of the definitions of knowledge integration, nor is it apparent whether only one definition of knowledge integration is suitable to understand the complex process of knowledge integration and for describing the new knowledge constellations in the Smart Grid. This indicates that there has been little empirical application of any of conceptualizations of knowledge integration to date, nor there has been any empirical investigation to knowledge integration in Smart Grid projects. In addition to the lack of application of knowledge integration in Smart Grid projects, the concepts itself is not yet mature (Rakevičius and Auzias 2016). Rakevičius and Auzias, for example, argue that knowledge integration is a relatively new concept in the sociological debate of knowledge-based collaboration. The three main approaches of knowledge integration, namely the 1) *sharing and transferring of knowledge;* 2) *the use of similar and related knowledge*; 3) *the combination of specialized but complementary knowledge* (Tell 2011) remain vague and show little practical research in the field because they have not be refined by the rigors of empirical investigation.

Before addressing the precise research gaps in the theoretical approaches to knowledge integration, it is critical to investigate knowledge integration in an *interorganizational context.* Even though studies exist that are based on a project-related level (Bredin et al. 2017; Enberg 2007), most of these studies rely on the individual level (e.g. Bredin and Söderlund 2011; Zika-Viktorsson and Ritzén 2005), the group or the organizational level of integrating knowledge (Castellucci and Carnabuci 2017; Kodama 2009). While studies at the individual level concentrate on competencies and skills that actors need for integrating knowledge (Bredin et al. 2017), studies at the organizational level focus mainly on influencing factors and outcomes of organizational performance (Tell 2011). Hence, knowledge integration has mostly been studied in terms of efficiency, effectiveness or innovative outcomes of organizations, while the remaining aspects are still unclear because of little empirical investigation (Wahlstedt 2014). New forms of organization (Bredin et al. 2017), such as clusters, joint ventures, innovation networks, multinational cooperation etc., have not been included thus far in the knowledge integration debate. This dissertation focuses precisely on this omission, namely, the interorganizational level of knowledge integration that takes place between heterogeneous Smart Grid actors, cooperating, somehow, in a distributed and international arena. Similarly, the existing literature is not only based on classical project work, but also on a traditional notion of knowledge. New project influences, especially through increasing ICT and highly specialized and distributed networks of knowledge, as well as the change of interorganizational structural mergers, is hardly considered in existing knowledge integration research. This dissertation seeks to address this empirically, bringing to the field a greater understanding of practices of knowledge integration undertaken within a globalized interorganizational Smart Grid project.

In the elaboration of the three approaches, different emphases of the characteristics of knowledge integration have emerged. These different foci of knowledge integration are compared in order to identify research gaps by showing which aspects are included in the approaches and which are omitted. Overall, the dimensions of the characteristics of knowledge integration that were shown to be significant are the role of heterogeneity (in terms of specialization), the development of knowledge boundaries, the underlying process of knowledge integration as well as its outcome. These different dimensions are used to determine which approaches incorporate which aspects of knowledge integration and where gaps exist in existing research.

First, knowledge integration is characterized by *heterogeneity*, which is often described in terms of the knowledge specialization of the actors. The first approach to knowledge integration highlights different specializations of actors, but such a high degrees of specializations among actors can also act as a barrier to knowledge integration, as there may be a lack of comprehensive understanding among them. This can lead to misunderstanding and poor cross-fertilization of ideas that must first be overcome. In the first approach, heterogeneity is the origin why knowledge can only be transferred and shared, and therefore requires a basic sameness of knowledge to enable knowledge integration in the first place. For example, Tell (2011) states that *"... some basic sameness is a structural condition for the occurrence of any sharing and subsequent integration of specialized knowledge"*, but at the same time *"...two individuals having exact the same knowledge cannot share or transfer such knowledge"* (Tell 2011). Hence, a certain extent of commonality is needed to promote understanding, but too much risks knowledge uniformity and the loss of innovation potential, as few new knowledge paradigms are merged and synthesized.

The second approach to knowledge integration excludes the potential heterogeneity can bring by emphasizing the integration of knowledge from the same specialization, thereby promoting further depth of specialization. Hence, the integration between actors with different specializations is not even addressed here. The first and second approach, therefore, are based on a certain equality of actors for knowledge to be integrated (Tell 2011). In the third approach, heterogeneity plays a crucial role, as the approach stresses the integral value of the different specializations of the actors for knowledge integration. Here, the focus is particularly on the diversity of the knowledge from heterogeneous actors, which forms the basis of innovative knowledge combination. However, the integration of specialized knowledge requires strenuous exertion of all actors and is often accompanied by difficulties. The difficulty of heterogeneous actors is considered in the third approach, but is not a hindrance per se for performing knowledge integration. This therefore begs the question: what role heterogeneity plays for knowledge integration and how it can be addressed in collaborations. It is therefore unclear to what extent actors have to be equal or whether a distinction between them is needed for knowledge integration. None of this has been sufficiently researched, empirically or theoretically.

The influence of *knowledge boundaries* on the knowledge integration also remains under researched. Indeed, the first approach highlights the occurrence of difficulties in knowledge integration and assumes that boundaries develop in knowledge integration. The approach emphasizes throughout that the purpose of knowledge integration is the overcoming of these boundaries and shows different strategies to deal with them: *"... it [knowledge integration] enables exploitation of existing knowledge to solve the problems encountered in the new product development."* (Marsh and Stock 2006). Only the solving of these difficulties allows the transfer of knowledge. Accordingly, *"knowledge integration within a project involves overcoming barriers to the flow and transfer of knowledge"* (Scarbrough et al. 2004). Likewise, Carlile (2002) argues that knowledge boundaries created by the division of practice, which are thought to render heterogeneity in projects highly problematic, need to be overcome in order to facilitate the transfer of knowledge between the members of a project. As with heterogeneity, knowledge boundaries do not exist in this second approach since knowledge is integrated within the same specialization, promoting a strong common ground for problem solving and viewing knowledge integration as a largely incremental development. In the third approach, knowledge boundaries again play an important role, since cross-functionality can lead to high costs but equally high rewards, particularly when radical innovation of synthesizing specialized knowledge is successful. According to Tell (2011), knowledge boundaries *"calling for knowledge integration mechanism to minimize costs of cross-learning inefficiency"*. The approach therefore emphasizes the emergence of knowledge boundaries, but does not elaborate on how to deal with them. How knowledge is integrated despite the boundaries remains rather open for further analysis. The identification of knowledge boundaries is particularly important, as the integration of knowledge, especially in interorganizational collaboration, represents a new challenge in Smart Grid projects and should therefore not be neglected.

The *underlying processes* that are necessary for integrating different experts' knowledge have not been yet fully investigated and is therefore little understood by existing approaches (Tell 2011). The exact process of knowledge integration and how it occurs in very heterogeneous and specialized projects such as innovative Smart Grid projects therefore remains unclear. Although there are different arguments for the three main approaches to knowledge integration exist, none of them clarifies the exact processes behind them. A research gap in the definition and the processes of knowledge integration can therefore be identified.

One of the strands for describing the underlying process of knowledge integration has been preliminary identified as *learning*, which is partially mentioned. Here, however, a distinction must be made between the individual, organizational and interorganizational levels of learning. The first approach mainly considers the transferring and sharing between a sender and a receiver on an individual level or within a community of actors. A simple integration of knowledge through sharing and transferring is assumed as boundaries develop in the process. Nevertheless, efforts are made to transfer knowledge, despite these boundaries, which could indicate learning between them. However, these assumptions leave unexplained if and how deep learning actually occurs between interorganizational actors. In the second approach, knowledge is only integrated in a particular community of the same knowledge field. Learning can consequently only take place on individual or organizational level within the specific community. The only approach that considers an interorganizational level of learning is the third approach, which assumes that a *"cross-learning"* between organizational members is necessary in order to integrate knowledge at an interorganizational level (Grant 1996b; Tell 2011). Nevertheless, it remains open how exactly collaboration and knowledge integration takes place under these new conditions. However, the third approach could serve here as a starting point for investigating interorganizational learning empirically as an important new way of integrating knowledge in collaborations.

Since learning is not always explicitly mentioned in the three existing approaches, it remains open whether knowledge integration can also take place through *another new underlying process*. New processes for the knowledge integration could be considered necessary, which takes into account new forms of collaboration, but which have not yet been further explored in the debate. Contrary to learning, some approaches mention boundary-bridging mechanisms as a process of knowledge integration. In particular, since high efforts are required to overcome knowledge boundaries, learning processes involve high efforts that cannot always be mustered under the new conditions of collaboration. In existing literature, only the third approach assumes that new mechanism need to be found for integrating different specialized knowledge. In particular, the various specialized bodies of knowledge. Hence, new linking mechanisms are required for combining different specialized bodies of knowledge. The most important question in the underlying process of knowledge integration remains to what extent the knowledge of other actors is integrated at all in collaborative projects.

Similarly, it remains unclear within existing approaches what exactly the outcome of knowledge integration is. In this sense, the first approach assumes that *"Knowledge integration focuses on the sharing and transferring of knowledge in order to draw upon, obtain, or sustain such common knowledge"* (Grant 1996b). In this sense, the development of a common knowledge base is needed for their operation (Grant 1996b). Similarly, the second approach seeks a common knowledge as an indicator for knowledge integration: *"The coherence of a group or firms knowledge base is a proxy for the degree of knowledge integration achieved"* (Nesta and Saviotti 2006). The third approach, however, assumes that completely different bodies of knowledge bases cannot be integrated, which is why the development of a common knowledge base is viewed rather critically.

New forms of the outcome of knowledge integration can be seen, for example, in the first approach, insofar as the development of boundary objects is a means of overcoming knowledge boundaries. For example, Patnayakuni et al. (Patnayakuni, Rai, and Tiwana 2007) assume that "*specialized organizational knowledge is integrated in the information system development process through the development and use of boundary objects"*. However, the second or third approach does not explicitly mention the exact outcome of the knowledge integration process and tend to remain less explicit about innovation realm. It is therefore essential to discover how knowledge integration is synthesized mainly for the development of innovation. While the first two approaches tend to leave this link to innovation development more open. The third approach highlights: *"...knowledge combination as an important determinant of innovations"* (Tell 2011). Therefore, it is precisely the combination of different knowledge that the third approach sees as a source for innovation development.

To sum up, existing theoretical approaches to knowledge integration show serious shortcomings, e.g. in theorizing the emergence of heterogeneity and boundaries, and in the underlying processes and outcomes of knowledge integration. The ambition of this thesis is to provide insights for future development of the critical field of knowledge integration in Smart Grid projects. The aim of this study is to explore how the underlying processes that produce the boundaries that emerge from heterogeneity are negotiated at the interorganizational level. Hence, this research will not be limited to the integration of knowledge to the operation within firms (Grant 1996a), to its relation to product development (Bredin et al. 2017), to the formal interventions of knowledge integration (Okhuysen and Eisenhardt 2002) or only to the knowledge integration challenges (Tell et al. 2017a). Table 1 below is a comparative summary of different emphases of knowledge integration in the three approaches.

Table 1 Research gaps in the knowledge integration debate

		Approaches to knowledge integration		
Research gaps in knowledge integration	**Emphases from the three approaches to knowledge integration**	**Transferring and sharing of knowledge**	**Use of similar and related knowledge**	**Combination of specialized, differentiated and complementary knowledge**
	Heterogeneity	Heterogeneity is the origin why knowledge can only be transferred and shared easily.	Heterogeneity is not considered because knowledge is integrated only in own specialization.	Heterogeneity and different specializations are necessary to integrate complementary knowledge.
	Knowledge boundaries	Knowledge boundaries arise in knowledge integration. Only when these knowledge boundaries dissolve, knowledge can be transferred.	Knowledge boundaries do not arise, as the use of similar and related knowledge does not lead to knowledge boundaries.	Knowledge boundaries develop due to cross-functionality of actors in knowledge integration.
	Interorgani-zational learning	Learning on a deeper level is questionable due to knowledge boundaries and the evasion to transferring and sharing.	Learning is not clearly brought forth, but it is assumed to take place in the community of specialization.	Cross learning is needed for knowledge integration.
	New processes of knowledge integration	Methods of bridging are highlighted as new processes.	No new processes are needed for knowledge integration.	New linking mechanism for integrating specialized but complementary knowledge is required.
	Common knowledge base	The aim of transferring and sharing is the development of a common knowledge base.	The coherence of a group knowledge base is set as an indicator of knowledge integration.	Completely different knowledge bases cannot be integrated between actors.
	Outcomes from knowledge integration	Boundary objects can be used overcoming boundaries in knowledge integration.	New outcomes from knowledge integration are not explicitly mentioned.	New outcomes from knowledge integration are not explicitly mentioned.
	Innovation development	The significance and the connection between knowledge integration and innovation development remain rather unexplained.	The connection between knowledge integration and innovation development remain rather unexplained.	The purpose of knowledge integration is innovation development in cross-functional teams.

3. Conception of knowledge integration in Smart Grid projects

The purpose of this study is to disentangle knowledge integration in Smart Grid projects. Knowledge integration is highly interwoven and complex, influenced by various heterogeneous yet interdependent actors. The emergence of more complex relationship constructs in the Smart Grid brings not only new knowledge constellations, but also heterogeneous dependencies leading to new challenges in the knowledge integration. Although various approaches exist in the literature to describe knowledge integration (Tell 2011), there are still many gaps and uncertainties for the conception. The mission of this study is to shed light on how knowledge integration actually occurs in Smart Grid projects. To that effect, a new empirically grounded conceptual model is offered, one that is based on the different unknown aspects of the theory identified in chapter 2.6. This concept provides a new perspective to decipher knowledge integration in specific Smart Grid projects, and draw inferences to reinforce the theoretical basis. My own concept consists of the novel combination of different theories, which have not been merged in this holism before. In this sense, the five core theories, namely proximities (Boschma 2005), knowledge boundaries (Carlile 2002), interorganizational learning (e.g. Larsson et al. 1998; Lundvall and Johnson 1994), knowledge bridging (e.g. Grunwald and Kieser 2007; Mattes 2010) and boundary objects (Star and Griesemer 1989) are reformulated to elucidate the conditions and characteristics of Smart Grid projects and to clarify the research gaps in the knowledge integration debate.

To start with, the aspect of heterogeneity, especially in terms of specialization, has repeatedly resurfaced in the first and third approach to knowledge integration, but has never been concretely defined in the debate. Although an increasing influence of heterogeneous actors is assumed to affect collaborations, it remains poorly researched. For this research, the *concept of proximity* is adopted because it examines how close organizations are in collaborations based on different dimensions, namely organizational, institutional, social, cognitive and geographical proximity, all of which underpin the social interaction as well as the underlying dynamics between the organizations in collaborations (Paustian et al. 2022).

Another aspect that has played a major role in the first approach of knowledge integration is the role of knowledge boundaries. Although innovations often take place at the boundaries of specializations or disciplines, the joint work at these boundaries sets difficult challenges for the project partners to gain a profitable advantage (Carlile 2004). The first approach assumes that knowledge boundaries have to be overcome before knowledge integration can take place.

However, it has not made clear in the existing approaches how knowledge boundaries arise or if they assume a general form, and what impact these may have on the knowledge integration process. To shed more light on this, the concept of proximity provides insights into the emergence of syntactic, semantic and pragmatic knowledge boundaries (Carlile 2002). This conceptualization is potentially very valuable because it not only considers basic communication, but also addresses the interpretation of information and the use of knowledge to achieve a certain effect. By connecting the two theories of proximities and knowledge boundaries empirically, the different dimensions of proximity are not only able to depict the heterogeneous relationships of Smart Grid actors but can also identify how heterogeneity affects knowledge boundaries. The combination of both concepts forms the basis for answering the first sub-question: *Which boundaries of knowledge integration develop in Smart Grid projects due to heterogeneity?*

The second focus is on how and to what extent actors have to integrate knowledge from other project partners. The change in new organizational forms suggests that learning becomes more complex between different organizations. The specific expertise of the actors need is reflected in the prerequisite required for a deep (technical) understanding for the development of the Smart Grid. Smart Grid projects are temporary and are under pressure to achieve results. My own concept aims to investigate the underlying process in terms of the two possibilities: interorganizational learning and knowledge bridging. While the first and second approach mainly refers to learning as the underlying process, the third approach highlights the need for a new linking mechanism in knowledge integration. Knowledge bridging is considered here as an alternative approach to interorganizational learning, although both entail plausible rationales for the underlying process of knowledge integration. While knowledge bridging relates to the bridging of only relevant knowledge in order to fill a specific knowledge gap in the project (e.g. Grunwald and Kieser 2007; Mattes 2010), interorganizational learning assumes a deeper integration of a project partner's expertise in order to build a common knowledge base (e.g. Lubatkin, Florin, and Lane 2001). Interorganizational learning is a recent approach that is particularly useful in this context because it deals with the learning undertaken between different organizations and therefore goes beyond the individual and organizational level. It is worth noting that the same can be assumed for knowledge bridging, as it could be suitable for the process of knowledge integration, by highlighting the difficulties of learning expertise between organizations and therefore represents a non-learning alternative. However, it is not certain whether and how both theories elucidate the process of knowledge integration, because it is not yet empirically clear whether the project partners actually learn from each other or merely bridge the knowledge between the heterogeneous partners. For the purpose of answering the second sub-question "*To what extent do actors have to integrate expert knowledge from other actors in order to develop Smart Grid innovations?*", my own conception to knowledge integration aims at elaborating both approaches and empirically investigating their use and interrelation in Smart Grid projects.

While the interorganizational learning theory assumes the emergence of a common knowledge base as the outcome, in contrast, my concept of knowledge integration in Smart Grid projects proposes the development of boundary objects as the result of knowledge bridging. The concept of boundary objects, like knowledge bridging, assumes that only relevant expert knowledge needs to be bridged. The theory of boundary objects highlights the problem of translating different perspectives from diverse social worlds in innovation cooperation by demonstrating the relevance of shared insights in different fields. Objects are located at the boundaries of different disciplines, and this could be arguably why no intensive learning is needed for innovation development (Star and Griesemer 1989). Thus, boundary objects deal with the question of how coherence can be established, especially if the social worlds of the actors strongly vary (Hörster, Köngeter, and Müller 2013). The second sub-question concerning the extent of knowledge integration also intends to determine whether joint learning creates a common knowledge base or whether the project partners remain experts in their fields, bridge their knowledge and establishing boundary objects.

In summary, the amalgamation of the five theories should provide answers to the questions of my dissertation. The proprietary concept is coherent to not only to fill the gaps in the current debate, but also offer implications for future Smart Grid projects. The concept is therefore based on the assumption that collaboration will become increasingly complex and face new challenges in the future, meaning that it should not be taken for granted. In this sense, my concept aims to create a stronger understanding - of not only the influences and difficulties of knowledge sharing, but also of the process of integration itself and its outcomes.

The different parts of my concept are represented in the following figure 2. The lower part of the figure 2 shows the heterogeneity in the knowledge integration process, which can be determined on the basis of various dimensions. The concept is exemplified in the following model via the three major player's distribution system operator (DSO), transmission system operator (TSO) and research and development (R&D) institutes, who have a specific knowledge of the energy industry. The bottom arrow is based on the first sub-research question, which is related to the impact of heterogeneity on the knowledge boundaries represented in the triangle. The second sub-research question refers to the upper part of the model and clarifies to what extent expert knowledge needs to be integrated by examining the two different processes of knowledge bridging and interorganizational learning that lead to either the boundary object or the shared knowledge base.

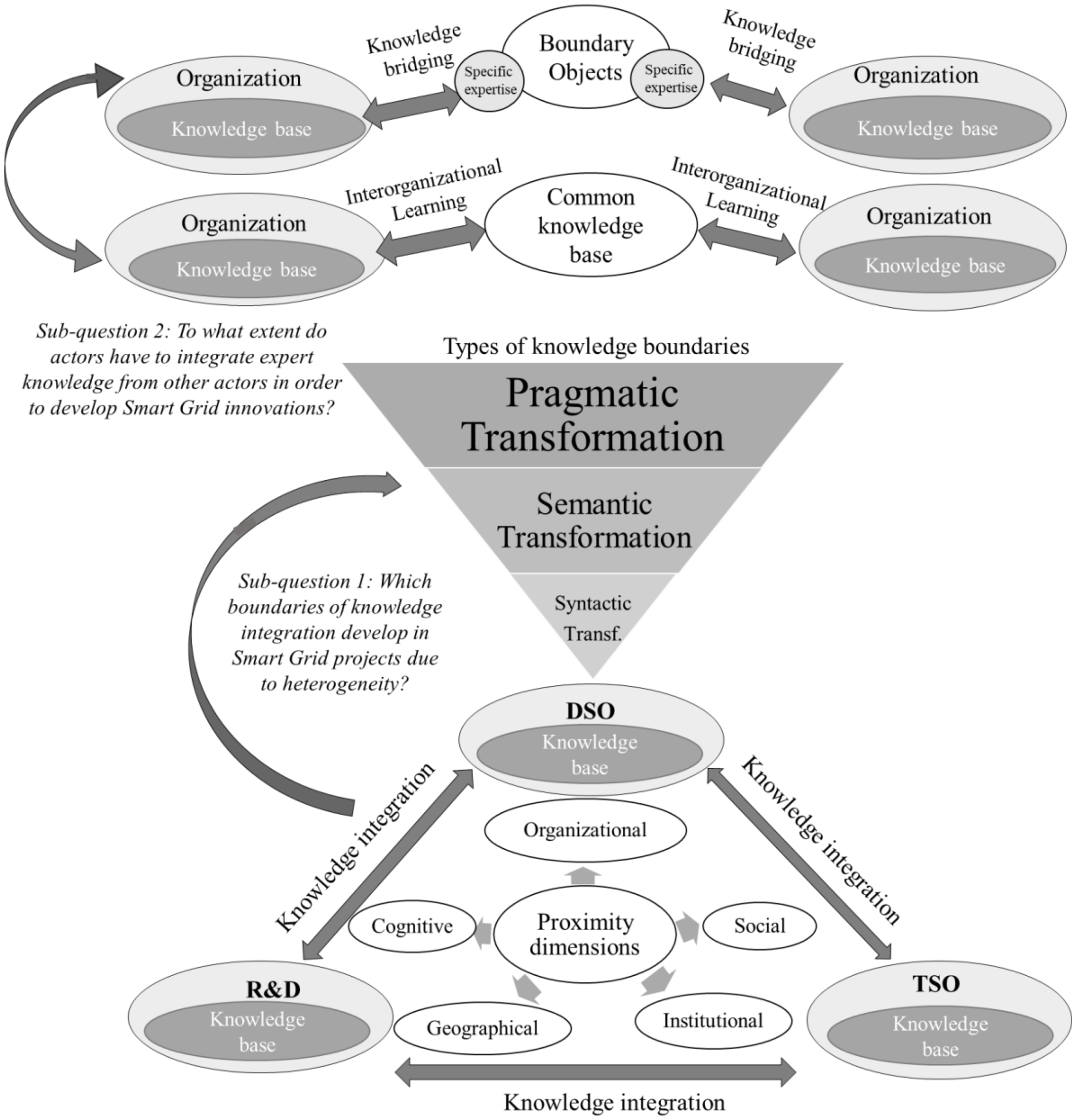

Figure 2 Conceptual design of knowledge integration in Smart Grid projects

3.1. Managing knowledge integration beyond boundaries in projects

As today's workforce becomes increasingly specialized, organizations are looking for ways to connect and mobilize social and work practices in order to prevent fragmentation (Hermans 2010). In Smart Grid projects, the main challenge to overcome technical and social differences is the integration of specialized and distributed knowledge between heterogeneous actors. Researchers have attempted, with varying degrees of success and rigor, to address collaborative challenges by exploring and defining the concept of *knowledge boundaries* and possible measures to overcome them (Bernstein 1971; Carlile 2004; Engeström, Engeström, and Kärkkäinen 1995; Suchman 1994). In general, most of these researchers perceive boundaries as a socio-cultural difference that leads to a discontinuity in common operation or interaction (Akkerman and Bakker 2011). Studies from different countries have addressed the managing of these boundaries within collaboration and developed approaches on how different expert groups design mechanisms, processes or methods for developing new knowledge in different social and organizational contexts (Tell et al. 2017b). Hence, several approaches exist on how to deal with knowledge boundaries, but there is only little literature dealing with the natural origins of knowledge boundaries. However, one thing can be observed in all studies: they proof that various types of boundaries lead to limitations in the development of innovation in organizations (Grant 2017).

A significant reason for knowledge boundaries could be caused by the heterogeneity of individuals and organizations (Enberg 2007). For example, von Meier (1999) emphasizes that knowledge boundaries develop in the course of various professional cultures that exploit diverse mental models and cognitive representations of technologies. These are adapted to their specific work contexts (Von Meier 1999), leading to potential conflicts in the knowledge integration process, and in the worst case, a complete stagnation of communication (Grandori 2001). Likewise, the ability of common understanding, the decoding of messages and the utilization of knowledge from others can diminish with growing heterogeneity of knowledge (Grandori 2001). During this process, boundaries can develop as a result of heterogeneous knowledge sources, which project members then have to overcome (Scarbrough et al. 2004). Summing up, the energy system is becoming increasingly heterogeneous, which poses new challenges for knowledge integration. The following chapter will therefore examine the origins and characteristics of heterogeneity and will then break down the individual dimensions in more detail by using the proximity approach by Boschma (2005).

3.1.1. The dilemma of heterogeneity in knowledge integration

As stated, a high degree of specialization among project partners plays an increasingly important role in collaboration, owing in particular to the new actor constellation and the shifting of spheres of influence and roles in the Smart Grid. Heterogeneity introduces a completely new dimension to cooperation within the energy system. However, while specialization mostly focuses on cognitive expertise, this is considered as overly restricted given the increasing heterogeneous complexity of Smart Grid projects. With this in mind, the understanding of heterogeneity in Smart Grid projects shall be improved by highlighting the dilemma and its role for innovative project work.

Colloquially, heterogeneity is often used synonymously with the terms diversity or variety and must therefore be differentiated from them. Blau (1977, p. 255) defines heterogeneity as *"the probability that two randomly chosen persons do not belong to the same group"*. In this sense, he assumes an inequality concerning the distribution of individuals within an organization in the form of a status continuum described by graduated parameters (Blau 1977b). In another work, Blau and Schwartz (1984) define heterogeneity as *"the number of social positions in each dimension of social life"*. Similar social positions have, therefore, a higher probability of social interaction (Centola 2015). Gläser et al. (2004) define heterogeneous groups as *"a joint venture of different sources in the dimensions of knowledge, language and interests"*. In contrast to this, homogeneous groups are characterized by an *"interpersonal similarity along one, or several, dimensions"* (Murray 1989). The age, ethic, mentality, gender, background or tenure of the individuals in the group express a common dimension of social life (Earley 2013; Murray 1989). A group can, therefore, be homogeneous in relation to a particular criterion and at the same time heterogeneous in relation to another aspect (Earley 2013). In this vein, many researchers state that all dimensions of difference between individuals influence groups in a certain way (Stahl et al. 2009). However, the relation between heterogeneity and project work is controversial discussed in literature, posing the question whether the influence is beneficial or adverse for project work.

The need of heterogeneity for innovation activity was already described by Schumpeter almost 100 years ago (Fagerberg, Mowery, et al. 2012). He envisioned heterogeneity as the key to transforming new ideas into innovation and proposed that an entrepreneur should take risks, access new resources, as well as combine different knowledge (Malerba and McKelvey 2018). The combination of a variety of knowledge was seen as an important component for innovation activity. Even today, many other authors focus on heterogeneity as an organizational resource for innovation. For example, Laursen (2012) highlights the importance of a actor's in her research and describes innovation as *"a result of the novel integration of previously separate bodies of knowledge that has a commercial application"*. Innovation work in this context is, therefore, based on knowledge-intensive entrepreneurship between a variety of organizations with different institutional settings, rather than operating as single individual actors (Malerba and McKelvey 2018). Heterogeneous knowledge is also expected to promote creativity as well as the ability to integrate new ideas due to more knowledge combination possibilities (Zhang and Sternberg 2011). Similarly, a positive impact of heterogeneity on individual and organizational learning can be observed. Authors of this research stream suggest that learning in organizations is greater when the experiences and knowledge of heterogeneous actors is more distant and, thus, the gap between differing bodies of knowledge is more extensive (Wang and Chugh 2014). Taylor and Greve (2006) argue that heterogeneous knowledge and experiences foster a vigorous learning environment, allowing new combinations of knowledge as well as a greater number of innovative outcomes.

Despite this attention to the positive effects of heterogeneity on innovation development, it can also be accompanied by difficulties in collaboration. Although heterogeneous partners are indeed more innovative as a result of their different ways of combining knowledge (Gläser et al. 2004), trust as well as solidarity is often less present than in homogeneous groups (Powell 1990). Especially in uncertain environments characterized by rapid change, trust becomes critically important in integrating ideas deemed worthy of protection. Likewise, trust must underpin innovation and implementation. Heterogeneous groups are often attributed as the cause of conflicts that can destabilize the group, intensify rivalry and worsen communication between them (Deborah Gladstein Ancona and Caldwell 1992). In contrast, homogeneous groups are characterized by a similar or common knowledge background, which can enhances the understanding of each other. This common knowledge background is often missing in heterogeneous groups, leading to more vulnerability that could destabilize the group, intensify rivalry and worsen the communication between them (Deborah Gladstein Ancona and Caldwell 1992). In the same way, Blau (1977a, p. 44) assumes poorer social communication in cross-group relationships as compared to intra-group relationships. With regard to the learning environment, not only positive effects are discussed, but the attachment of individuals to different roles and functions can cause tensions within a group and, thus, negatively influence learning and the willingness to share and collaborate (Edmondson and Harvey 2017).

To summarize, the existing literature indicates that the relationship between heterogeneity and learning is neither only positive nor negative, but may be distorted by other mechanism or conditions (El-Awad 2018). Having described the dilemma of heterogeneity, it appears that heterogeneity can be analyzed in terms of different aspects. To investigate heterogeneity more specifically for actors in innovative Smart Grid project, the concept of proximity by Boschma

(2005) was chosen as it systematically addresses five different dimensions of heterogeneity. These five dimensions are ideally suited to create a comprehensive picture of the relations and characteristics of organizational actors involved in the Smart Grid project.

3.1.2. Proximity dimensions in innovation projects

Dwelling on the first sub-question of the thesis, the influence of heterogeneity on knowledge boundaries will be investigated as a first step to unravel the process of knowledge integration. Since heterogeneity can be measured by an infinite number of criteria, the dissertation focuses on the five proximity criteria developed by Boschma (2005). He particularly stresses the importance of the co-development of new (technical) solutions to innovation and incorporates different aspects of learning within organizational relations. Boschma (2005) sees as the core of his research the problem of coordination resulting from a combination of different types of proximity between collaborating actors.

In essence, all proximity dimensions can be applied to Smart Grid projects, which Boschma claims as relevant to innovation projects (Paustian et al. 2022). Hence, partners in Smart Grid projects are generally not only influenced by interpersonal relations, for example, by existing social constellations, but also by different cognitive knowledge backgrounds, as evidenced through diverse functions and roles in the energy system (Paustian et al. 2022). Likewise, external impacts, such as different organizational structures are available, forming a diverse landscape ranging from corporate structures to start-ups. Likewise, institutionally different political frameworks and regulations are to be assumed, as they stem from different geographical locations of the Smart Grid actors (Paustian et al. 2022).

Organizational proximity

When differentiating between the actors in the Smart Grid, diverse organizational units with different organizational structures must be taken into account. Organizational structures become especially relevant for innovation development, since cooperating partners need the organizational ability to coordinate the exchange and integration of complementary knowledge. This capacity requires organizational arrangements between different organizational entities (Boschma 2005). Organizational networks are, therefore, seen as mechanism for coordinating transactions that enable the transfer of knowledge and information (Cooke and Morgan 1998). Of particular importance is the consideration of transaction costs in economic processes, which puts different forms of governance in the spotlight. These relate, among other things, to the autonomy of organizational partners and the control exercised over knowledge flows (Boschma and Frenken 2010). These two aspects are also included in Boschma's definition, which suggests that organizational proximity can be defined as *"the extent to which relations are shared in an organizational arrangement, either within or between organizations"* (Boschma 2005). Other authors, such as Gilly and Torre (2000), assume that organizational proximity is characterized by *"the same space of relations"*, which is based on constructive variable types of interactions as well as similarity between the actors. These, in turn, are based on the exchange of the same knowledge and a common space of reference (Gilly and Torre 2000). Complementary to these aspects, market conditions as well as related competition between the organizations can be considered to describe organizational proximity, which depend on the organizational logics (Paustian et al. 2022). Particular attention is paid to emerging start-ups and established organizations that are reshaping the market as incumbents and challengers (Paustian et al. 2022).

Boschma (2005) distinguishes between informal as well as opposing formal relationships, characterized by the different degrees of autonomy and control in the organizational relationship. These different forms of relationships range from very strong ties to loosely coupled organizational ties, up to very weak coupled organizational ties. For example, actors in an "on the spot market" have extremely weak ties, whereas informal relations are evident in the occurrence of interlocking, and formal relationships can be identified in franchises or joint ventures. A more extreme organizational structure is reflected in the group structures (Boschma and Frenken 2010; Williamson 1985). Organizational relations with weak ties are characterized by simple and flexible connections that have a low degree of organizational proximity, while highly hierarchical organizations or networks tend to represent a high degree of organizational proximity (Boschma 2005).

The literature also points to a link between organizational proximity and interorganizational learning, which is seen both facilitating and hindering for innovation development (Boschma 2005). On the one hand, knowledge creation requires strong control mechanisms, not only for securing intellectual knowledge but also for using it effectively in the organization. In a common sense, *strong organizational ties* are necessary for knowledge creation but also to facilitate the exchange of complex knowledge, for developing products and for giving valuable feedback to organizations (Hansen 1999). Strong organizational proximity can also diminish uncertainty and opportunism, and guarantee intellectual and ownership rights (Boschma 2005). On the other hand, *too strong organizational ties* are considered as risky for knowledge exchange and innovation capacity building. The risk arises from strict hierarchical governance structures that severely restrict organizational flexibility required for innovation (Blanc and Sierra 1999). Negative effects on flexibility and innovation can therefore arise between ties of strong hierarchical organizational governances, leading to lock-in effects and less innovative initiatives (Boschma 2005). Highly coupled, but asymmetrical organizational relationships can also be negatively affected by different organizational sizes and different share of power in a network. Asymmetrical relationships, thus, require a high level of communication and understanding. The discovery of new channels is more difficult for asymmetrical relationships, leading to a restricted access to new information (Boschma 2005).

Generally, due to their relatively decentralized controlled units, *loosely coupled organizations* have an easier time integrating new knowledge and incorporating it into their organizational structures (Lawson and Lorenz 1999). Based on their organizational distance, they not only have access to more information, but also show a broader field of learning including more interfaces. However, networks that are *too loosely coupled* can also generate difficulties of control, resulting in knowledge leakages and the risk of adopting opportunistic behavior (Boschma 2005). In other words, while too much organizational proximity leads to a deficiency in flexibility, resulting in less innovation and learning capacity, too little organizational proximity is associated with a lack of control that could increase opportunism. However, it is argued that loosely organizational relationships can meet both requirements (Boschma 2005): they can guarantee organizational autonomy and flexibility, and conversely, are able to build network connections for access complementary knowledge. Since loose organizational ties require a significant amount of coordination to bring together the different bodies of knowledge, interactive learning is encouraged (Lawson and Lorenz 1999).

Institutional proximity

The creation of new knowledge, such as in Smart Grid projects, is often distributed across different institutions. In this sense, Boschma (2005) assumes that intra- and interorganizational relationships are strongly embedded in institutional settings. In general, institutions can be defined as *"sets of common habits, routines, established practices, rules or laws that regulate the relations and interactions between individuals and groups"* (Edquist and Johnson 1997). In essence, institutions are characterized as adhesives, since they are alleged to reduce uncertainties as well as lower transaction costs (Boschma 2005). North (1990) assumes that institutional proximity is associated with the institutional environment at the macro level, which is based on the same norms and behavioral values in a cooperation. In reverse, they do not refer to the micro level of institutional arrangements, as they do not represent these norms and values in the exchange relationship (North 1990). Boschma distinguishes between formal and informal institutions. While laws and rules are assumed to be formal aspects of institutions, cultural norms and habits are indicators of informal institutions, both of which strongly influence the way organizations operate (Boschma 2005). Specifically, institutional proximity relates to the fact that actors often embrace the same ethical or religious values and are often culturally close to each other (Boschma 2005).

Different cultures meet in international Smart Grid projects, which introduce another emphasis to the institutional relationships between organizations. Most definitions assume that the cultural differences relate to nations, specifically the sharing of common values (Voich and Stepina 1994). For example, Kroeber and Parson (1958) define national culture as *"transmitted and created content and patterns of values, ideas, and other symbolic-meaningful systems as factors in the shaping of human behaviour and the artifacts produced through behavior"*. The national culture differs from the basis of physical borders of a nation-state (Groeschl and Doherty 2000) and is, therefore, bound by the framework set by its government. Although members of a national society could have a variety of individual cultural identities, most researchers recognize the existence of a cultural identity of a nation that transcends the individual cultural practices of its members (Forgas-Coll et al. 2012). This broader cultural surrounding encompasses formal as well as informal forces that incorporates regulatory, normative and cognitive frameworks that influence the behavior of people and organizations (Meiseberg and Dant 2015, p. 9). Thus, the national-culture of an actors identity is shaped by political directions, labor and financial markets as well as regulations, but also by public policy, standardizations and the educational system of a country (Lundvall 2007; Malerba and McKelvey 2018).

Lundvall (2007) argues that the generation of new knowledge and, thus, the innovativeness of organizations are strongly influenced through the nationality of the actors. On the one hand, some authors, for example, Hong and Page (2004), Niebuhr (2010) or Ozgen et al. (2014), assume that different nationalities are usually seen as a driver for innovation because of their diverse problem-solving abilities. Accordingly, national cultural heterogeneous actors are supposed to be more creative and find better solutions for complex issues in comparison to homogeneous groups (Hong and Page 2004; Niebuhr 2010; Ozgen et al. 2014). A major point is here the cultural distance between the project partners. It can be assumed that the more unusual the composition of different ethics, the more extraordinary the ideas that result from the cooperation (Brixy, Brunow, and D'Ambrosio 2017). Various studies assume that a group containing a number of actors from diverse ethnic backgrounds and cultures can contribute in a positive way not only to innovation (Brunow and Nafts 2013), but also to the productivity in the group resulting from complementary effects of knowledge spillovers (Trax, Brunow, and Suedekum 2012).

On the other hand, different cultures in a cooperation may also have negative effects on innovation development, such as the raising of costs of coordination as well as a lack of communication because of different languages or cultural interests (Jaatinen and Lavikka 2008). For example, Baland and Platteau (1999) highlight the role of cultural inequality in cooperation, which would reduce the capacity of a group to manage resources and recognize ecological matters. Individual interests arising from different cultures may also lead to irreconcilable differences of opinion or can distort the way how collective goals are met. Cultural differences could, therefore, cause conflicting interpretations of general standards, guidelines or governing rules, in particular with regard to rights of use and appropriation of resources (Ballet et al. 2015).

The institutional framework can promote or inhibit to the various processes of learning and knowledge sharing and can, thus, have a significant impact on the development of innovation (Boschma 2005). Organizations that are institutionally close not only often share a similar culture and its habits, but also often operate within common regulatory as well as law systems that protect the organization. This can also lead to greater trust at the social level (Maskell and Malmberg 1999). Attaching greater priority to institutional proximity and interorganizational learning has a positive factor in the cooperation of organizations. Although a stable institutional bond between organizations can lead to an effective learning environment, too *much institutional proximity* can also have negative effects on interorganizational learning and, thus on the ability to innovate. The risk of local inertia could develop as institutions are made up of interdependent parts (Boschma 2005). Any small environmental change can, therefore, lead to instability in a complex network within fixed institutional organizations, as the positions in the networks could be disrupted (Hannan and Freeman 1977). In particular, very close institutional organizations with very powerful actors tend to have an inward looking perspective, leading to conservative reactions to external changes (Grabher 1993). The development of inertia in institutions could ultimately inhibit the capacity for innovation and lead to lock-in as a result of missing new potentials. However, too few institutional ties between organizations can also have a negative impact on collective action due to the lack of formal structures, joint values and overarching social cohesion (Boschma 2005). The right balance between a certain institutional proximity and distance is important to establish institutional stability and maintain an openness for new potential and to maintain flexible relations with new institutions (Boschma 2005).

The institutional dimension is also strongly linked to other proximity dimensions. Gertler (2003) assumes that social and organizational proximity are closely connected to institutional proximity as organizations cannot learn interactively if they do not cooperate within a certain institutional context. Institutional structures, therefore, lead to better organizational arrangements and allow institutions to deal more effectively with various transactions and uncertainties encountered (Knack and Keefer 1997). Likewise, missing institutional structures can be compensated by the use of social proximity. Finally, a relationship between geographical and institutional proximity is hypothesized, suggesting that informal institutional ties occur at the local level, while informal ties, such as through legislation, often exist at national or supranational level (Boschma 2005).

Cognitive proximity

Different technical data and knowledge fields of the various heterogeneous actors has increased the number of stakeholders in the current energy system (Misra and Bera 2018). Because of this proliferation of heterogeneous knowledge sources, key organizational actors use Smart Grid projects as a means to learn different (technical) knowledge from each other. Accordingly, organizations today need to acquire skills to deal with specific technologies in the energy markets. It is widely assumed that organizations that have failed to integrate new data and knowledge fields, and whose knowledge bases are too far apart, will incur high costs to acquire that knowledge, resulting in negative organizational relationships (Perez and Soete 1988). Much of this technological knowledge tends to be tacit in nature (Constant 1983; Laudan 1984), making the articulation of this knowledge a critical component of knowledge sharing among organizations and the training of key actors in the energy industry. Similarly, it is believed that the tacit part of technological knowledge has become increasingly diminished over the past few years (Laudan 1984). This is due to the fact that the number of engineering professions has increased and their training is becoming more formal, while at the same time their technical knowledge is becoming increasingly explicit (Laudan 1984).

Boschma (2005) calls this dimension the “cognitive ability” and describes that a certain cognitive proximity between organizations is necessary for learning technical knowledge from each other and develop innovations. However, he assumes that the cognitive abilities of organizations are not natural, as they are tied to rationality and are always limited in some way by their ability to share expertise. Given this difficulty, organizations usually seek for knowledge in their existing profession that is easy to acquire. However, what an organization gains in terms of the speed of knowledge acquisition, it loses in complexity, limiting the development of innovative new knowledge (Boschma 2005). Based on this assumption, Boschma (2005) argues that innovations usually emerge from localized and cumulative knowledge, which implies a high proportion of tacit knowledge. However, the tacit nature of cognitive differences often persist between organizations (Boschma 2005). Organizations, thus, face the challenge of sharing cognitive knowledge because of inadequate access to it, but also because not all partners are able to absorb it. In this sense, Cohen and Levinthal (1990) assume that a certain absorptive capacity is necessary to utilize, recognize as well as interpret novel knowledge.

A certain cognitive relatedness is perceived as both desirable and indispensable to bridge knowledge. Cognitively close organizations can, therefore, not only communicate more effectively, but also understand and process knowledge even better (Boschma and Lambooy 1999). Nevertheless, a certain distance should be maintained to ensure that organizations also remain open to new areas of knowledge that are often distant to their own knowledge base. However, *too much cognitive proximity* in the relationship between companies can also have a negative effect on learning and innovation, which is why a certain cognitive distance is often advocated. Cognitive distance is justified by disseminative and complementary knowledge, which requires a certain creativity and openness to ideas (Cohendet and Llerena 1997). Similarly, lock-ins resulting from too similar cognitive knowledge can cause organizations to become trapped in their own routines and, thus, be less open to new technologies. As a result, organizations in entrenched structures are unable to explore or utilize new knowledge and innovative practices. Hence, the so-called competence trap describes habitual dependence on old routines and habits, that have become redundant over the years and lead to non-learning (Lambooy and Boschma 2001; Levitt and March 1996). Thus, if innovation is to be sustained in any organization, it must collate and synthesize knowledge from a multiple of sources. Moreover, a *low cognitive proximity* entails the hazard of involuntary knowledge spillovers, since knowledge is not always fully appropriate (Boschma 2005). For example, organizations that work closely together because of their professional proximity could more easily overlook knowledge spillovers (Cantwell and Santangelo 2002). In summary, fruitful cognitive proximity is necessary to learn new technologies from each other, but too much cognitive proximity can also lead to lock-ins and too little cognitive proximity to involuntary knowledge spillovers (Boschma 2005).

Social proximity

Alongside the dimensions of organizational and institutional proximity are the social relationships between organizations in the energy system that are strongly interwoven (Paustian et al. 2022). Social proximity has its origin in the embedding theory (Polanyi 1944). Polanyi (1944) argues that all economic relationships are intertwined with social relations and are necessarily socially embedded to a certain degree (Gemici 2008). Economic principles and relations can, therefore, not be considered in isolation from the social networks. On this basis, Boschma (2005) defines social proximity as the socially embedded relationships among various stakeholders at the micro level that are characterized by trust, experiences, kindness and friendship. Specifically, trust is one of the key factors in facilitating the exchange of tacit knowledge in collaborations, which is difficult to share across different economic markets (Maskell and Malmberg 1999). However, social proximity is not perceived as sharing values in a cultural, ethnic or religious sense, as this takes place at the institutional macro level. Rather, it is based on social interaction, such as loyalty and understanding between individuals (Boschma 2005). However, social proximity presupposes institutional proximity because social proximity is based on a common language and habits that characterize the informal institutional relations and builds on the accompanying formal legal systems (Maskell and Malmberg 1999).

Boschma (2005) argues that a *high social proximity* between the organizations enables open, rationale and social communication, which does not purely focus on calculation of costs and market orientation. In general, he argues that the closer the social bond between organizations, the more rewarding and interactive the learning. This leads to superior innovative and economic performance. This interactive learning, thus, requires enduring and meaningful relationships (Boschma 2005). However, as with the other proximity levels, *too much or too little social proximity* is a weak point for project work because it impairs the potential for innovation. Boschma (2005) argues that *too much social proximity* can limit the ability to learn interactively and, thus, innovate. Increasing loyalty in relationships based on high emotional attachment is supposed to lead to opportunistic behavior as trust in particular can be exploited to extract greater gains from the project outputs. Likewise, socially narrow and closed networks hardly allow for innovative influences from the outside. This can prevent actors from doing things differently, causing lock-in effects. However, *too little social proximity* can also signify that trust cannot be built because less commitment reduces the propensity to share (Boschma 2005).

In the literature, the influence of social relations in terms of the degree of embeddedness and innovation performance is discussed. First, the neoclassical model assumes that the less socially embedded organizations are, the higher their innovation performances. By contrast, Boschma (2005) uses the embeddedness model to argue that the more embedded the relationships of organizations, the more effectively they can learn from each other and develop innovations. However, this is only possible up to a certain threshold of embeddedness, since too much social embeddedness could also have a negative effects on learning and may thus weaken innovation capabilities (Boschma 2005). The so-called U relationship, therefore, indicates that economic performance increases up to a certain point and then decreases again (Boschma, Lambooy, and Schutjens 2002). The third model is the Uzzi model, which proposes that a combination of embedded and market relations at the network level is needed for establishing a certain social proximity, but one that equally maintains a certain distance between the organizations (Uzzi 1997). Therefore, the relationships in his model consist of a mixture of open-minded relationships that equally maintain a critical distance. These maximize interorganizational learning and reduce the transaction costs at the same time (Uzzi 1997).

In summary, social proximity between organizations can promote interorganizational learning through trust and consensus, but too much social proximity can also lead to lock-ins, over-trust or the risk of opportunism, which could decrease interorganizational learning as well as innovation (Boschma 2005). To avoid social ties that are too close, agglomerations are seen here as opening strategies for new potential partners (Gordon and McCann 2000). Social proximity is also not irrelevant for other dimensions (Boschma 2005). For example, social proximity is thought to cause cognitive abilities to decline over a longer period. Similarly, organizational proximity can be associated with a lack of social proximity, since hierarchical forms often show a lack of trust. Finally, a positive correlation between geographical and social proximity is presumed, since the physical closeness promotes social interaction and trust (Boschma 2005).

Geographical proximity

Smart Grid projects are often carried out by international actors from various geographical locations. Through these increasingly globalized project structures, knowledge is spatially dispersed among partners, but at the same time each partner is embedded within their regional context (Mattes 2012). Knowledge is, therefore, developed under local conditions and reinforced by idiosyncratic linguistic terms as well as collective norms. Likewise, the formulation of problems as well as potential solutions in projects varies from place to place

(Tell 2017). In order to analyze the influence of geographical proximity between Smart Grid project partners, it is necessary to take a closer look at the geographical dimension (Boschma 2005).

Boschma and Frenken (2010) assume that geographical proximity is *"the physical distance between actors in absolute or relative terms"*. The authors contend that organizations that are geographically close to each other can develop innovation with greater ease and have more effective ways of learning (Boschma and Frenken 2010). Boschma (2005) suggests that organizations that are geographically close also benefit from knowledge externalities because maintaining personal contacts allows information to be better maintained and knowledge to be shared (Boschma 2005). A necessary condition for face-to-face contacts is the geographical proximity, which is intended to contribute to building trust and anchoring stronger social relationships. Accordingly, tacit knowledge can be more easily transferred between geographically close organizations. On the contrary, a large spatial distance between cooperating organizations leads to a less intensive exchange of tacit knowledge, but also of codified knowledge, since the latter requires interpretations and assimilations of tacit knowledge (Howells 2002).

Drawing on the influence of geographical proximity on interorganizational learning and innovation capacity, dependencies on the scale of geographical proximity can be identified. Close geographical distances are more likely to bring partners together, which encourages communication and sharing experiences. Although a high number of knowledge sources in a given area increases the potential for innovation and interorganizational learning between local actors, geographical openness is still essential to avoid regional lock-ins (Boschma 2005). A mix of local buzz and extra-local linkages offers possible solutions to maintain some openness in otherwise geographically tight networks. This also demands local organizations to offer open memberships in order to benefit from knowledge externalities. Hence, geographical proximity only becomes significant for networks if, for example, geographical proximity is a prerequisite to the network membership (Boschma 2005). This tends to form stable relationships between geographical close organizations, which is known as pure agglomeration (Gordon and McCann 2000).

The ability of geographical proximity to foster interorganizational learning is related, above all, to the fact that it fosters the development of other dimensions of proximity (Hausmann 1996). Geographical proximity, therefore, plays a particular role in strengthening and complementing the other dimensions of proximity, as it has an indirect impact on the promotion of informal relationships (Audretsch and Stephan 1996). Interorganizational learning is, for example, dependent upon geographical and cognitive proximity, both of which are prerequisites for absorbing and processing external knowledge (Antonelli 2000). Moreover, networks in which interorganizational learning takes place also hinge on organizational proximity for ensuring the coordination of tasks through a central authority. Accordingly, geographical proximity plays a subordinate role in networks that have a strong cognitive and organizational proximity (Boschma 2005). Finally, institutional proximity, which is required for the sharing of the same values and expectations between local and non-local actors, is also encouraged through geographical proximity (Gertler 1997).

However, Boschma (2005) argues that *too much geographical proximity* can also hamper interorganizational learning and ultimately innovation. This is the case when, first, only knowledge available in the network is used and, second, this network is tightly meshed and hardly allows any leeway or openness for external knowledge. In many cases, this has the effect of limiting innovation and, ultimately, preventing actors from discovering new technologies or ideas. For example, too much geographical proximity between organizations can lead to lock-ins, in which actors shut themselves off from the outside world and only look inward (Grabher 1993). The argument that geographically close actors are more capable of exchanging tacit knowledge is premised upon the assumption that occasional trips are sufficient to share tacit knowledge. Therefore, it is argued that no permanent geographical proximity is necessary for joint cooperation across national borders (Boschma 2005). A balance between local and non-local relationships generate qualitative superior knowledge by bringing new impulses and ideas into the geographical network (Jaffe, Trajtenberg, and Henderson 1993). However, Breschi and Lissoni (2002) argue that geographical proximity is less crucial for knowledge spillovers in a network than social ties between them. Networks can, therefore, exist between spatially close actors, but they do not have to.

To conclude, the concept of proximity provides a generally interesting approach to analyzing the characteristics of the actors and their relationship to each other in innovation projects. Since the relationship of Smart Grid project partners does not remain only at the technical, knowledge-based level, this approach addresses other aspects of the heterogeneous influences in cooperative organizational relations, thereby making the feature of heterogeneity more concrete. The dimensions of organizational, institutional, cognitive, social and geographical proximity are essential to the empirical analysis of heterogeneity, their relationship to each other and its influence on knowledge boundaries. The theoretical fundamentals of knowledge boundaries will be examined in more detail in the following chapter.

3.1.3. Three types of boundaries in the process of knowledge integration

Since project work in the Smart Grid is seen as fundamentally challenging, this chapter takes a closer look at the difficulties of cooperation between heterogeneous organizational actors. Different theories exist regarding the problem of knowledge integration, such as the difficulty of knowledge transfer (Szulanski 1996), the tacit character of knowledge (Von Krogh, Ichijo, and Nonaka 2000; Nonaka and Takeuchi 1995; Polanyi 1966) or the stickiness of knowledge (von Hippel and Tyre 1996). However, this thesis focuses in particular on the development of innovation creation in Smart Grid projects and, therefore, requires a more concrete level of analysis to explain the increasing critical character of knowledge integration in heterogeneous projects. One of the most prominent approaches to knowledge boundaries in innovation projects originates from Carlile (2002, 2004). In an ethnographic study, he investigates knowledge boundaries across different function that develop in the process of innovation development; this he calls “knowledge in practice” (Carlile 1997). In his research, he builds on the established syntactic and semantic approach for the analysis of knowledge boundaries and proposes a third pragmatic approach (Carlile 2002). At this new pragmatic level, Carlie (2002) recognizes the consequences that arise from the interdependencies of heterogeneous knowledge integration. His approach to analyzing knowledge boundaries is, therefore, particularly useful for my study, as the merging of complex and distributed knowledge from increasingly heterogeneous actors poses new challenges to collaborative projects today.

Syntactic knowledge boundaries

The first dimension for identifying knowledge boundaries in this work is based at the syntactic level. Syntax is generally described as signs that refer to a particular object and are based on the grammatical-linguistic consideration of sentences in the semiotic sense. Given that, syntax provides a set of rules and structures for creating semantic explanations (Burger, Norrick, and Dobrovolʹskij 2008). Bochenski (2012, p. 82) argues that syntax is determined by rules that allow a sign to be replaced by another. This semiotic level introduces a certain arrangement of interlocking signs through which they are brought into a mutual relationship and information is formed from them. Accordingly, the combination of signs, which are in a concrete relation, forms the core of the syntax. This relationship of signs, characterized by specific rules, is generally seen as highly formal (Morris 1938).

Carlile (2002) addresses the historical development of syntactic knowledge boundaries in the context of new product development. According to Carlile (2002), syntactic knowledge boundaries were initially established by Shannon and Weaver, who developed a mathematical concept for characterizing communication. In their research, Shannon and Weaver (1949) found that a syntax, which is stable beyond a boundary in a communication, focuses primarily on information processing. The authors define the syntax as a precise exchanging of information between a sender and receiver that crosses a specific boundary. In this sense, the communication between both parties is intended to address many contradictory information processing problems (Shannon and Weaver 1949).

Systems theory assumes that the meeting of the boundaries of an organization with its environment is the main problem of information processing, which must be generally solved (Ashby 1956; Bertalanffy 1956; Buckley 1968). In order to do so, Lawrence and Lorsch (1967) developed a model of differentiation and integration, which seeks to address and solve the challenges an organization faces when it effectively manages its environment and its various accompanying uncertainties (Lawrence and Lorsch 1967). This model aims to measure the difficulties of knowledge integration between different subunits of an organizations, which is influenced by corresponding disparities or levels of uncertainties (Lawrence and Lorsch 1967). The result of this was that a shared and stable syntax is necessary to compensate differences and guarantee the quality of information exchange (Lawrence and Lorsch 1967). In the 1970s, Galbraith (1973) provided a predominant boundary-spanning approach as a syntactical prerequisites for the ability to process information appropriately. Allen (1984) uses the concept of Lawrence and Lorsch to obtain more accurate results in terms of distances and success between individuals involved in innovation development. In the 1980s and 1990s, the concept of information processing and spanning of boundaries was generally used a basis for research in the field of effective product development (Deborah Gladstein Ancona and Caldwell 1992; Carlile 2002; Joyce 1986; Keller 1986). External communication was also examined, based on the assumption that the more communication that takes place, the greater the success of innovation development (Deborah G. Ancona and Caldwell 1992; von Hippel 1988). In the 21st century, however, it became apparent that the organization's environment was in a state of accelerating change. This speeding up of change and innovation led Carlile to question whether the syntax for the processing of information would remain sufficiently robust in the face of new organizational demands (Carlile 2002). He describes this as shifting the difficulties to grasping *new conditions* for information processing and knowledge. Carlile (2002) identifies emerging requirements outside the syntax and states that new and different syntax is required for an effective communication.

Actors in Smart Grid projects are also influenced by the shifting patterns of syntax embedded in the forms of technical discourse (Liu and Li 2018). As the environment of Smart Grid projects is driven by big data, data is taking on a new significance in project work in order to achieve technical interoperability between the systems of organizational actors. ICT tools are not only used to handle and manage new data, but also to enable new business processes and innovative digital systems (Clabby 2003). As the exchange of data between all relevant market participants becomes increasingly important, a common vernacular of technical terminology can contribute to reaching interoperability and allowing the technical connection of different systems through ICT and their respective standards (Liu et al. 2013). To achieve this syntactic interoperability, data formats, communication protocols or data serialization are required (Uslar et al. 2012). Therefore, it is necessary that the data, the respective programming language and the formulas within the different information systems can be understood and identified (Liu and Li 2018). Organizational actors are, thus, encouraged to utilize the same format and structure of data or information to facilitate technical communication and enable other actors to read it on a syntactic level (Liu and Li 2018). Consequently, syntactic interoperability is the basis for creating reference architectures of novel systems that represent all functionalities, which can be realized by a system (Ian Sommerville 2010). Interoperability can, thus, be defined as the capacity of organizations to collaborate on common technical or specific organizational issues by connecting heterogeneous data and information (Liu et al. 2013).

This image underlines that syntactic knowledge boundaries are, on the one hand, a matter of social communication from a linguistic point of view and, on the other hand, a concern of technical communication linking different data, components and technical systems of the respective actor. Both forms of syntax can play an important role for Smart Grid projects. In order to use the syntax, it must be embedded in the proper semantic context, which will be discussed below.

Semantic knowledge boundaries

While the relationship of signs plays a role for building a common syntax, the semantic level attends to the development of a common understanding of the transmitted information between different knowledge practice (Marheineke 2016). In this vein, the semantic level highlights the meaning of the transported information in a sense-making way (Kotlarsky, van den Hooff, and Houtman 2015). The rise of new conditions for information processing led Carlile (2002) look at knowledge boundaries from a semantic point of view. He notes that even when a common syntax exists in collaborations, different interpretations arise that lead to communication problems between the partners (Carlile 2002). While interpretative differences due to cultural disparities in communication have been studied for many years (Redding 1972; Reddy 1979), the problem shift already addressed in the syntactic approach can also be seen in interpreting and learning from different sources where the information originates from. This causes semantic differences between organizations in collaborations (Carlile 2002). Looking at the origins, Fleck (1979) adds that communication problems arise because individuals have differing meanings and interpretations depending on their functional environment. Accordingly, interpretations made by the partners are mainly derived from their situated as well as experiential knowledge (Kotlarsky et al. 2015). In this sense, interpretations are often made unconsciously, as they are based on the core values and beliefs of their "thought world" (Carlile 2002; Dougherty 1992). While these assumptions are self-evident to them, that is tacit and ready to hand, these backgrounds may remain obscure or strange to non-members. The insertion of information into different contexts could lead not only to different forms of communication in individual thought worlds, but also to a lack of shared mental models amongst participants. This could lead to serious misunderstandings, as information cannot be explained as it ought to be and actors are unable to embed it in their environment (Canon-Bowers, Salas, and Converse 1993).

Nonaka and Takeuchi (1995, p.58) distinguish between syntactic and semantic boundaries by highlighting the problem of “conveyed meaning” and potential different interpretations by individuals. Thus, analysis of semantic boundaries in the process of knowledge integration needs to take account of contextual factors as well as tacit aspects of knowledge. In particular, tacit knowledge is considered more difficult to interpret and put into the right context. To eliminate semantic confusions, Nonaka and Takeuchi (1995, p.72). suggest that a common understanding must be developed and integrated through increasing communities of interaction. However, this approach does not consider the consequences and effects that result from these dependencies (Carlile 2002).

In addition to the interpretation of information, the technical data between computational systems of the actors must also be interpreted within its specific context. From a technical point of view, data must be placed in an appropriate context in order to give it a certain meaning (Liu and Li 2018). This context is predefined with the help of rules that are defined by the organization and executed by the technical computer system. Such a computational system verifies whether the data falls under the predefined rules or not. In this sense, the computer does not interpret the data, but put it in a specific scheme. Only rarely do computers misinterpret data, as misinterpretations are usually based on human errors in developing the programs. If the system has been built correctly and no human errors have occurred, the data can be interpreted according to a given scheme (Liu and Li 2018). Nevertheless, organizational stakeholders also need to interpret new data to ultimately use it for new applications within and outside their organizations (Köhlke 2019a).

Communication can, therefore, also take place at the semantic level between systems, which require a high level of interoperability for data exchange. To achieve this, human actors need to reach an agreement about the content-specific reference model for transferring information. The data and information to be transmitted should be semantically identical, e.g. the information should be interpreted in the same way by the receiver and the sender (Uslar 2010). In summary, semantic interoperability is required for data exchange between two organizations in order to allow the transfer of data and information between their systems (Liu and Li 2018).

Pragmatic knowledge boundaries

Since information in Smart Grid projects should also become knowledge to be applied in collaborative projects and thereby serve a higher purpose, pragmatic knowledge boundaries are addressed according to the approach of Carlile (2002). The origin of the pragmatic approach can be traced back to the end of the 19th century, when the philosophers Peirce (1898) and James (1907) define pragmatic boundaries as the comprehension of consequences, which arise between divergent and interdependent subjects. Later research in this field, such as Bourdieu's "Within-Practice" was devoted to the question of how knowledge is directed towards achieving a specific effect. The research showed that individuals were more inclined to devote themselves to their specific knowledge, which they viewed as a hard-earned accomplishment (Bourdieu 1977). In the later research of relational structuralism, Bourdieu (1977) argues that interactions between practices should not be neglected, as knowledge gathered and used by individuals, can be compromised. The pragmatic approach generally assumes that individuals are more reluctant to change their knowledge and skills because it is costly and requires effort. Bourdieu (1977) sees the problem not only in communication itself, but also in the averting of negative effects by individuals from any function. As a consequence, individuals should be willing to modify their knowledge and be able to influence and change the knowledge applied by different functions (Bourdieu and Wacquant 1992). The pragmatic approach, therefore, includes all distinctions, dependencies and novelties and their consequences, negative or positive, in the process of transforming knowledge (Carlile 2002). The following figure 3 shows the transforming of knowledge in terms of innovative product development, which increases from the syntactic, to the semantic and, lastly, to the pragmatic level. Transformation in this sense is, thus, referred to the process of changing current knowledge, developing new knowledge and validating it within and across functions (Carlile 2002).

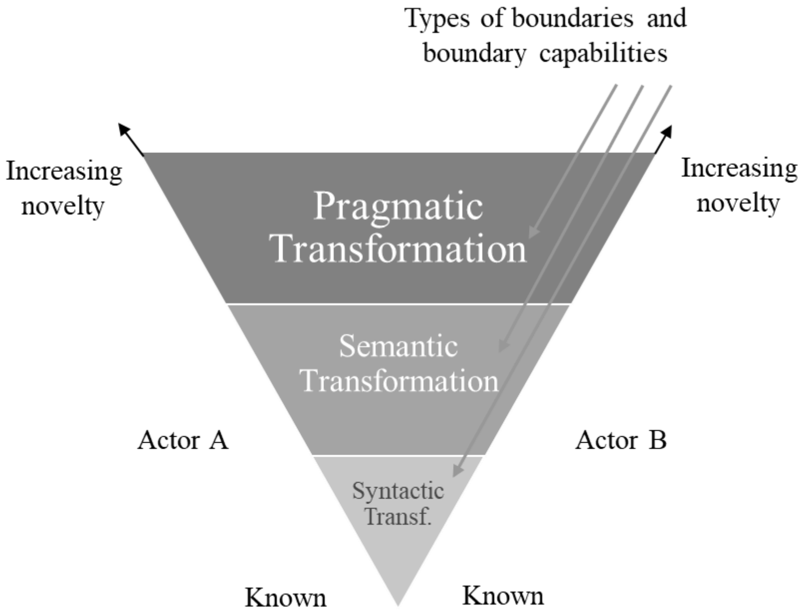

Figure 3 Transforming knowledge across boundaries (Carlile 2004)

Certain novel situations, such as new environmental conditions of companies, force organizations to create new innovative knowledge (Carlile 2002). Carlile (2002) points out, however, that instead of exploring innovative knowledge, partners in collaboration often create innovations that are close to their old, pre-existing knowledge base, which puts them at risk of falling into the "competence trap" (Barnett and Hansen 1996). Accordingly, such partners tend to use the knowledge that already corresponds to their competencies. Based on these considerations, Carlile (2002) states that in a group, individuals have an existing body of knowledge, which can bring different expectations and ideas of goals and purposes to the projects. In doing so, individuals prefer varying interpretations that match prior knowledge, leading to the exclusion of other group members. Along these lines, Carlile (2002) argues that project partners may be unable to learn from each other because their assumptions are deeply rooted in their past experiences.

While Carlile considers the development of pragmatic knowledge boundaries through the application of knowledge for a specific purpose, the Grid Wise Architecture Council (GWAC) developed a pragmatic level for technical and informational interfaces (Gottschalk et al. 2017).

From a technical perspective, this pragmatic level depends on a seamless connection of the systems and further includes business procedures, business objectives and, lastly, economic and regulatory policies (Gottschalk et al. 2017). The creation of and adherence to standards for syntactic data and information transfer and interpretation is ultimately the basis for pragmatic interoperability in systems. Systems, therefore, use data and information for specific purposes and applications set by their organization.

3.1.4. Existing approaches for overcoming knowledge boundaries

Carlile's approach demonstrates how different knowledge boundaries can affect coordination and cooperation during innovative product development at an interorganizational level (Carlile 2002). In order to limit negative influences of knowledge boundaries, different tactics have emerged, which often stem from coordination strategies between partnering firms and research and development (R&D) collaboration (Johansson et al. 2011). These most prominent attempts range from *cross-functional teams* (Argyris and Schön 1978; Nonaka and Takeuchi 1995), to *knowledge brokers*, *liaison engineers* and *boundary spanners* (Brown and Duguid 1998; Tell 2017), to *boundary-bridging mechanism* (Tell 2017).

The *cross-learning approach* is based on the assumption that specialists from different knowledge fields need to learn intensively from each other (Schmickl and Kieser 2008). Cross-learning is often equated with the interorganizational learning approach and assumes that groups of experts transfer their specialized knowledge for developing shared "organizational maps" (Argyris and Schön 1978). These maps are the basis for an effective recombination of knowledge and, further for innovation development (Argyris and Schön 1978). An intensive cross-learning knowledge exchange is, therefore, needed to create an overall understanding, overcome knowledge boundaries and develop joint innovations (Schmickl and Kieser 2008). Nonaka and Takeuchi (1995, p. 24) presume that a time-consuming dialogue between cross-functional project members is needed to develop new organizational knowledge that is used for generating new concepts or products. However, cross-functional teams require a lot of time for joint learning and therefore place high demands on overcoming knowledge boundaries.

Other authors advocate using outside help in the form of *knowledge brokers, liaison engineers or boundary spanner* to overcome knowledge boundaries (Johansson et al. 2011; Schmickl and Kieser 2008). Liaison engineers aim to connect related specialized departments mostly within the coordination platform of formal meetings (Clark and Fujimoto 1991). Here, small groups or multifunctional task forces are formed to work on specialized components (Clark and

Fujimoto 1991, p. 103). Brown and Duguid (1998) have developed an architecture to overcome knowledge boundaries based on the three mechanisms of organizational translators, knowledge brokers as well as boundary objects. While organizational translators facilitate the activities that are going on between two or more group participants and are, thus, able to translate between them, knowledge brokers go a step further and not only translate the knowledge of both specialized groups, but take part in both worlds of knowledge fields (Brown and Duguid 1998). Boundary objects, as they are understood, consist of contracts, objects or other concepts, which demand a common interpretation between specialized groups (Brown and Duguid 1998). In the same strand, boundary spanning is often seen as a way to bond organizations across knowledge boundaries. In this vein, boundary spanning consists of collating information and using tacit knowledge to identify, sense, learn and translate the specialist bodies to knowledge between participants in order to fuse the existing knowledge boundaries together. In essence, the boundary spanner, who also appear in the literature under the terms "liaisons", "brokers" or "gatekeepers", bridge and translate various specialized bodies of knowledge and their accompanying vernacular to all project participant, even across geographical borders (Tell 2017). Subramanian et al. (2013) suggest that bridging scientists can also act as substitutes for academic R&D partners, which have a positive influence on the cooperation between industry organizations and universities (Subramanian et al. 2013). The bridging scientists consequently promote the spanning of organizational and knowledge boundaries (Subramanian et al. 2016).

The third approach for overcoming knowledge boundaries relates to boundary bridging mechanism. Tell (2017) identifies five different *boundary-bridging mechanisms* in order to overcome knowledge boundaries. These five mechanisms are knowledge search, knowledge acquisition, knowledge assimilation, knowledge accumulation and knowledge transformation (Tell 2017). The *knowledge search* derives from the Carnegie School as one of the core factors in behavioral theories (March and Simon 1958) and is based on the assumption that organizations are always looking for solutions to solve short-term or long-term problems. March (1991) argues that knowledge search can be distinguished in local as well as distant search of organizations. While the local search deals with the exploitation of already existent knowledge; distant knowledge search aims at the exploration of new research (March 1991). During the search of knowledge *analogies* have also emerged as a method for bridging boundaries that can be used for analogical reasoning (Gentner 2002) and for comparing baseline and target knowledge area. Tell (2017) suggests that local search for similar knowledge from a particular domain leads to a better understanding between actors with different knowledge backgrounds. Finally, *hypotheses* are mentioned as mechanisms for boundary bridging as they could provide formal assumptions about relationships between different variables. Formal hypotheses imply the codification of knowledge in e.g. software documents. This decoding enables the understanding and bridging of knowledge from different areas (Tell 2017).

Another boundary-bridging mechanism is the *acquisition of knowledge*. This mechanism implies that appropriate knowledge has to be absorbed and, thus, no complete knowledge transfer has to take place, which is likely to result in inefficiencies (Grant 1996b). The literature of knowledge acquisition proposes that the acquisition of knowledge can facilitate the establishment of what knowledge is actually transferred and how it is represented. This can be most clearly seen with the *enrolment* of new employees to promote the acquisition of expertise in order to build some basic understanding in the organization (Tell 2017). The acquisition of knowledge can be accomplished by the hiring, buying or recruiting of new knowledge from individuals, such as a temporary employment (Borg and Söderlund 2014; Söderlund and Bredin 2011). Besides enrolment, *object*s can also serve as boundary-bridging mechanism as they derive from tacit and codified elements of artifacts (Star and Griesemer 1989). These boundary objects can represent an idea or a prototype, which is weakly-structured in general use, but can be strongly-structured in individual use. Lastly, intellectual property in form of legal documents can be used as boundary-bridging mechanisms (Somaya 2012; Teece 2007). Ownership rights of knowledge can, therefore, be transferred via patents or copyrights and, thus, knowledge boundaries can be bridged (Tell 2017).

Another mechanism for boundary-bridging is *assimilation,* which is often used in R&D collaborations (Nonaka 1991; Nonaka and Takeuchi 1995). By assimilating new knowledge, organizations invest in their R&D capabilities in terms of their absorptive capacity and can thereby achieve learning advantages (Cohen and Levinthal 1990). Cohen and Levinthal (1990) assume that the exploration of a particular type of knowledge through R&D activities is only one element of the development of technological capabilities. Consequently, this would mean that more general knowledge, created through ongoing R&D activities, would ease the uptake of more specialized knowledge (Tell 2017). Within assimilation, three distinctions can be made, namely socialization, concept formalization and exact replication. *Socialization* indicates that knowledge is able to cross boundaries in social interactions through imitating behavior. Therefore, the tacit character can be preserved when applying the knowledge within other contexts. When individuals are assimilated, knowledge can be transferred across personal, domain-specific, geographical and temporal knowledge boundaries (Tell 2017). In contrast, *concept formation* aims at determining the characteristics of a certain phenomenon for overcoming boundaries, while *exact replication* is an identifiable part of template knowledge, which is transmitted through a boundary. Lastly, ensuring the confirmation of the knowledge transfer is presented as a replication of the specific knowledge (Bengtsson and Lindkvist 2013; Winter and Szulanski 2001).

Accumulation is another boundary-bridging mechanism that explores how an important learning activity enables knowledge integration by recombining accumulated knowledge. For this purpose, the accumulated knowledge must be retrievable. Within knowledge accumulation, skills and routines can serve for a seamless coordination between specialized actions (Nelson and Winter 1982). While skills are used to perform specific activities (Polanyi 1966), routines enable coordinated actions across knowledge boundaries (Dionysiou and Tsoukas 2013). *Dialogue* is also used as a method for communicating between practitioners in order to bridge knowledge boundaries in cross-functional product development teams (Nonaka and von Krogh 2009; Tsoukas 2009). Similarly, the compliance with *rules* that arise or are imposed can be used as a boundary-bridging method to coordinate expertise across boundaries. Rules, formalized as standards or guidelines, therefore provide coordination without costly communication and are identified by Grant as the original form of the knowledge integration mechanism (Grant 1996b).

The transformation of specialized knowledge is the final boundary-bridging mechanism but perhaps the most important as here theory seeks to trace the brokerage of technology, that is, the combination and recombination of knowledge as well as the arbitrage of knowledge (Carnabuci and Operti 2013; Gruber, Harhoff, and Hoisl 2012; Hargadon 2002; Teece 2007). Knowledge transformation, echoing Schumpeter (1934), suggests that it is the combination of knowledge rather than the invention of new knowledge that is important for innovations. This innovation is a key factor for organizational strategies (Kogut and Zander 1992). Transformation is equally often carried out with the help of *bricolage*, i.e. improvising the knowledge that has emerged as an important source for recombining and applying new challenges and opportunities (Salunke, Weerawardena, and McColl-Kennedy 2013; Senyard et al. 2014). Furthermore, *bisociation* can be considered as the capability to put an association into different contexts. The approach assumes that two habitually incompatible frameworks for knowledge creation collide. This collision is seen as a creative act through the creation or synthesis of new ideas, (Koestler 1964). Lastly, *combination* is a boundary-bridging mechanism for codified knowledge, which assumes the reorganization of explicit knowledge (Tell 2017).

3.1.5. Identifying processes of knowledge integration in Smart Grid projects

Chapter 3.1 showed that the extent of heterogeneity of actors can be determined by their proximity to each other, which can positively and negatively influence collaboration in terms of learning and innovation development (Boschma 2005). Building on these challenges arising from heterogeneity, the concept of knowledge boundaries was introduced, which occur at the syntactic, semantic and pragmatic levels and can affect the cohesiveness of a project. Arguably, the two concepts of proximity and knowledge boundaries are central to understanding the nature and influences of knowledge integration within Smart Grid projects and to answering the first sub-question.

With both approaches in mind, the following chapters 3.2 and 3.3 focuses on the actual process of knowledge integration. In approaching the second sub-question, *to what extent do actors have to integrate expert knowledge from other actors in order to develop Smart Grid innovations?*, my concept explores the two additional but less researched processes: interorganizational learning and knowledge bridging. While learning focuses on the release of individual knowledge and contextual information in order to make it understandable for other persons and to achieve a deeper understanding between them (Lundvall et al. 2002; Schmickl and Kieser 2008), knowledge bridging concentrates on closing the knowledge gaps between partners without explicitly exchanging all expertise (Mattes 2010). The underlying processes of knowledge integration in Smart Grid projects is complex, why the exact ways that learning and bridging feeds into knowledge integration needs to be explored. Both concepts are reviewed as possible processes in knowledge integration. In describing them, the subsequent chapters 3.2 and 3.3 discuss the origin, the type of knowledge used, the processes themselves, and how they influences knowledge integration.

3.2. Interorganizational learning – as the underlying process of knowledge integration

The research around interorganizational learning is becoming more significant given the increasing importance of interorganizational collaboration and knowledge integration across organizational boundaries. Generally the concept of learning is complex and involves many distinctions in form of levels, processes, and intentions, leading to confusion about what learning really is. Most approaches emphasize that learning occurs at the individual level, the group level or the organizational level and cover a wide range of scholarly contributions (Ellström 2010) that address how organizations expand their knowledge (Lane and Lubatkin

1998). In contrast, interorganizational learning is undertheorized, particularly how it actually takes place (Mariotti 2012). Consequently, there are only few insights into the underlying process and its multilevel nature (Crossan, Maurer, and White 2009). The complex and processual character of interorganizational learning is, therefore, not fully understood (Mariotti 2012). This chapter reviews the current state of research on interorganizational learning that range from the new perspective, the project-based perspective of learning, the characterization of knowledge to be learned, the process, the influences, and finally the common knowledge base.

3.2.1. Interorganizational learning as a new learning perspective

To understand and uncover the underlying process of interorganizational learning, the concept has to be distinguished from other existent levels, reaching from the individual level, the group level to the organizational level of learning (Ellström 2010). Most of the literature assumes that an *individual level* of learning is required for knowledge integration in alliances or networks. These theories focus on the learning of individuals in an intrafirm collaboration (Hamel 1991; Lane and Lubatkin 1998; Larsson et al. 1998). Studies that emphasize the individual level of learning in organizations often defend its focus with the theoretical concepts of absorptive capacity (Cohen and Levinthal 1990) or working memory (Baddeley and Hitch 1974). According to Cohen and Levinthal (1990), the individuals who absorb, integrate, and apply new information for a commercial purpose are the main factors in identifying a firm's capability. In contrast, working memory is concerned with the absorption of information into short-term memory, which are eventually stored in long-term memory (Baddeley and Hitch 1974).

Less well researched is the nature of learning that takes place at a *group level*. What is important here is that knowledge acquisition takes places within groups and is collectively owned by the team from the organization (Ellström 2010). Knight (2002) emphasizes this clearly as: "*learning by the individual organizations in the context of groups or pairs of organizations"*. However, collective learning in the group is not only the sum of all individuals and their knowledge, but it also includes cognition cycles, reflection and feedback as well as actions by the individuals (Edmondson 2002; Ellström 2010). According to Senge (1990), groups or teams are considered highly crucial for learning in organizations because most of the important decisions are made by them. Accordingly, individual learning becomes even more irrelevant, as only learning in teams is able to connect the microcosm of the entire organization (Senge 1990).

In contrast to the cognitive specificities of individual and group learning strategies, organizational learning emphasizes the structures, routines, systems and procedures of an organization that strongly influence learning and, thus, the knowledge integration of an organization. Weick (1991) argues that organizations tend toward patterns of means-end relations, which are consciously constructed to give the same routine answers to different stimuli, problems or possible innovation, and, therefore, do not learn in a traditional manner. Learning in organizations is, from his perspective, fundamentally different from individual learning and, therefore, needs non-interchangeable, differential conceptualizations (Weick 1991). Argyris and Schön (1978) add that organizations often learn different things than their members do. Although some authors assume that learning actually takes place in the minds of individuals, the content and extent of knowledge is still depended on what knowledge already exists in the organization. In this light, not only the information that exist in an organization but also the knowledge of other organizational members is important for organizational learning (Simon 1991, p.125). Organizational learning is, therefore, conveyed by learning through individuals and is intended to be an interaction between the cognition and action of them (Ellström 2010). The learning outcomes within organizations are often reflected in innovative products or production routines, thereby increasing the organization's competitiveness (Porter 2000). Moreover, existing literature assumes that organizational learning includes individual learning, but not the other way round (Ellström 2010), as this tends to attribute human characteristics to organizations that they do not actually possess (e. g. Cook and Yanow 1993; Weick 1991; Weick and Westley 1996). A further differentiation lies in the different knowledge content acquired by individuals and organizations, since the organization cannot always acquire or absorb all the knowledge that the individual may hold (Argyris and Schön 1978, p. 9). The learning of organizations would, therefore, not correspond to the learning of individuals (Weick 1991).

The recent developments of *interorganizational learning* has evolved in the wake of environmental transformations, leading to the breaking down of organizational boundaries and a rethinking of organizational collaborations (Mendez 2003). New organizational forms, like clusters, joint ventures, project work, innovation networks, multinational cooperation, etc. bring new conditions that influence the way organizations learn (Ellström 2010). At present, only a handful studies have dealt with the interorganizational level of learning, why it is not well known how learning actually takes place in a collaboration between organizations (Crossan et al. 1995; Easterby-Smith, Lyles, and Tsang 2008). Some authors emphasize the process character of interorganizational learning in which network actors commonly work to create new collective knowledge (Dyer and Nobeoka 2000; Holmqvist 1999). Other authors describe this form of learning between organizations as external learning (Lane 2001) and refer to it as a proactive cooperation (Crossan et al. 1995; Easterby-Smith et al. 2008). Another attempt to deepen insights into interorganizational learning is to focus on its reciprocity. Thus, mutual learning between different organizations is described in other studies as interactive learning (Lundvall et al. 2002) as well as cross-learning (Schmickl and Kieser 2008). Hedberg and Holmqvist (2001) refer to the notion of an "imaginary organization" in which a shared knowledge base is created through interorganizational learning. This collective knowledge is carried out through the continuous development and transformation of individual to interorganizational knowledge (Holmqvist 2001). Likewise, Nonaka and Konno (1998) assume that knowledge is bundled and integrated in a common space and activated as a resource for creating innovation. What becomes clear is that a special attention is paid to the shared knowledge base that is repeatedly emphasized in the interorganizational learning approaches. In this sense, Grunwald and Kieser (2007) argue that interorganizational learning is central for building the common knowledge base necessary for the successful implementation of innovation. Overall, interorganizational learning appears to be a complex phenomenon with several research directions that have not yet been fully explored. In contrast to other forms of learning, interorganizational learning focuses on the design of knowledge and learning as a series of social and physical methods in its specific material surrounding (Araujo 1998). Organizations are, therefore, not knowledge repositories, but compilations of different imbricating knowledge systems, which are embedded within a wider occupational alliance (Araujo 1998). Learning between organizations and their respective knowledge base is, therefore, increasingly central to heterogeneous networks characterized by social and material ties that transcends or bypasses company boundaries (Araujo 1998). Hence, the particularity of interorganizational learning lies in the heterogeneity of the organizations coming together to create a shared knowledge base. Arguably, therefore, it is more important than ever to study interorganizational learning between organizations and to develop a better understanding of how knowledge is integrated between different organizations to establish innovation.

3.2.2. Interorganizational learning in a project-based environment

To further explore the process of interorganizational learning, a more explicit reference to project work is highly promising, as projects provide the frame for collaboration between different organizations in this study. In project-based interorganizational learning, some peculiarities occur, which are explained in this chapter. Lubatkin et al. (2007) assume that interorganizational learning processes take place when describing knowledge integration in innovative projects (Lubatkin et al. 2007). Interorganizational learning in projects is usually associated with the development of work assignments that are completed in a time limited manner in order to achieve the prearranged performance goals and to enable individual as well as group learning (Smith and Dodds 1997). In this sense, interorganizational learning is not only based on resolving actual problems in their work environment (DeFillippi 2001), but also aims at creating complementary skills in order to build a common knowledge base between the organizations (Schwab and Miner 2008). This image underlines that projects are sites for organizing knowledge-intensive work (Mendez 2003) and for structuring innovative actions. Projects link the essential processes of knowledge generation and knowledge sedimentation and act as the interface between organizations, networks and institutions (Scarbrough et al. 2003; Schwab and Miner 2008). Likewise, learning in projects is influenced and reflected by the extent of heterogeneity, both in terms of the technically different knowledge, on the one hand, and the social cooperation between heterogeneous internal and external actors, on the other hand (Grabher 2002). Dwelling on this aspect, Wenger (1998) and Brown and Duguid (1991) suggest that project-based learning can be thought of as *community of practical tradition*. Learning would, therefore, take place through the participation of members in social communities and the identity structure that emerges within them. Among these social communities, specific brokering roles are established to enable a deeper learning, which is undertaken through the interaction at the intersection of multiple communities (DeFillippi and Arthur 1998).

It is interesting to note that interorganizational learning in projects is characterized by transdisciplinarity and transience, which is responsible for the success of project-based learning (Amin and Cohendet 2004), but can also present challenges to learning. The organization of transdisciplinarity involves the risk that the knowledge obtained in the project will be scattered by the dissolution of the project team, as each specialist returns to the traditional workforce and is assigned to other duties and teams (DeFillippi and Arthur 1998; Prencipe and Tell 2001). Although projects are well suited for combining diverse knowledge, there is still the problem that the knowledge is quickly forgotten once the project is completed (Morris, Pinto, and Soderlund 2012). This phenomenon is also described as “organizational amnesia”, which has attracted awareness from the unique organization to a broader social context in which projects are integrated (Brady and Davies 2004; Cacciatori 2008; Hobday 2000; Prencipe and Tell 2001; Sydow, Lindkvist, and DeFillippi 2004). Project-based learning is often thought to require project members to be reflective so that they can see how the nontraditional combination of different areas of knowledge brings new ideas and experiences into view. This makes it easier for members to transform their tacit knowledge into something they can meaningfully articulate (DeFillippi 2001). After this overview on interorganizational learning in projects, it is necessary to take a deeper look into the specifics of knowledge that is actually learned between the organizations.

3.2.3. Type of knowledge to be interorganizationally learned

In general, organizational knowledge differs from the knowledge of individuals as it is not self-contained, but highly context-dependent and unevenly distributed across different individuals (Tsoukas 1996). A reciprocal interference becomes evident between the organizations that encompass and link the totality of all individual knowledge, and the individuals, who have additional knowledge, but which is shaped by the organizational frames. While individuals within a company act on the basis of their own knowledge and values, these must cohere with the wider institutional practices of the organization. Thus, through social interaction, individual and collective knowledge structures co-evolve, influence each other and lead to a unique knowledge structure at the enterprise level (Nonaka and Takeuchi 1995). Since in this study, knowledge is shared across organizational boundaries, interorganizational knowledge tends to be more complex and decentralized. Likewise, most organizations do not have a common knowledge base when entering into a collaboration. Hence, the actual knowledge learned relies on the constellation of these different organizations (Monteiro, Arvidsson, and Birkinshaw 2008). It is, therefore, necessary to dig a little deeper into the knowledge characteristics between the different yet collaborating organizations. Nevertheless, not only are there few concrete approaches to what knowledge is actually learned in an interorganizational context, but the existing approaches often intermingle the nature of knowledge between the different levels.

Beginning with the characterization of knowledge to be learned interorganizationally, the terminological overview of knowledge in chapter 2.1 made a first venture with the distinction between a tacit and explicit part of knowledge. Since both parts of knowledge are central to the underlying processes and nature of interorganizational learning, they will be revisited. Chapter 2.1 elaborates that the explicit part of knowledge is mostly codifiable and easy to write down, which makes it readily transferrable to other organizations. In contrast, tacit knowledge is strongly anchored in an individual who is bound to the organization, resulting in a difficult transfer of knowledge (Martin and Moodysson 2011a). As tacit knowledge is very context-specific and tied to individual experiences, it is not easy to write down (Martin and Moodysson 2011a). While explicit knowledge can be codified and takes the form of documents, databases etc., tacit knowledge is mostly intuitive and rooted in contexts, experiences or practices (Nonaka 1991).

Tacit knowledge is often captured in the form of expertise that is both interpersonal as well as inaccessible know-how to the conscious mind (Polanyi 1966; Walczak 2005). This tacit knowledge in form of expertise is seen as interorganizationally promising because it provides economic advantages, such as control mechanisms, the construction of artifacts and desired outcomes, as well as its usefulness in decision-making and reasoning. Lundvall and Johnson (1994) anticipate that interorganizational learning and the development of innovation is strongly dependent on specialized knowledge and expertise, especially for organizations that are characterized by sharply rising learning curves, expanding markets and fast-declining costs (Lundvall and Johnson 1994). Generally, expertise is addressed in an interdisciplinary area of research, engaging in polarizing debates about its nature, influences and accelerators (Ward et al. 2019). According to Ward et al. (2019), studies on expertise focus on finding out how individuals perform at a high level of proficiency in complex environments and socio-technical systems. A widely used definition derived from Ericsson and Smith (1994) who highlight a task-centered perspective to expertise, which is a *"reliably superior performance on representative tasks"*. Although some tasks can be standardized and simulated under controlled conditions, other tasks can hardly be evaluated in terms of their performance due to their complexity of the domain. As a result, there are some domains where hardly anyone is able to reflect all of their expertise, making performance measurement to be a difficult endeavor. Other definitions focus on goal achievement and its associated attitudes, skills and knowledge. For example, cognitive skill competences are seen as central for achieving specific performance goals in a team (Rosendahl Huber et al. 2020). Other authors assume that expertise consists of skills and knowledge aimed at generating new knowledge and meeting or exceeding present standards (Feldon, Jeong, and Franco 2019) or define expertise as the ability to demonstrate and apply appropriate knowledge and skills with competence and confidence (Chrichton, Moffat, and Chrichton 2019). The difficulty in using and learning expertise at the interorganizational level is that the tacit knowledge components can be difficult to articulate, to transmit it to others and to apply it in the form of concepts and documents. Projects, therefore, need the derivation of generalizable principles to enable others to learn the knowledge as well (Scott 1992).

3.2.4. Process of interorganizational learning

In order to gain further insights into interorganizational learning, possible processes of knowledge acquisition across organizational boundaries are presented. Larsson et al. (1998) argue that organizations can learn on an interorganizational level by changing their interorganizational routines or creating a repertoire of potential common activities. Interorganizational learning can, therefore, be characterized as the joint acquisition of knowledge between two or more organizations by constructing and adapting their interorganizational environment, their regulations and policies as well as their work options. Contrary to organizational learning, interactions in interorganizational learning create learning synergies that require positive interaction between organizations (Larsson et al. 1998). In this vein, interactive learning processes, which take place at various interfaces inside and outside the company (Nonaka and Konno 1998), are necessary for the development of innovations and the survival of organizations (Lundvall and Johnson 1994)

According to DeFillippi (2001), learning between organizations is based on a combination between theoretical knowledge (explicit knowledge) and spontaneously arising questions based on the interpretation of experiences (tacit knowledge). In theory, tacit knowledge is seen as challenging to transfer over long distances as it is strongly bound to the respective individuals (Martin and Moodysson 2011a). The authors argue that despite globalized channels for communicating, the transfer of knowledge remains localized as it needs interactions that are collocated in space and time (Martin and Moodysson 2011b). This entails that the closer the two actors are located to each other, the higher the probability that both actors can access localized knowledge flows and tacit knowledge can be exchanged for the development of innovation (Martin and Moodysson 2011a). This suggests that innovation is primarily based on codified knowledge that does not require a strong proximity of actors to share their knowledge (Gertler 2008; Gertler and Levitte 2005). Nevertheless, there is little empirical evidence that the transfer of tacit knowledge takes place almost completely at the local level. Some studies imply that tacit knowledge flows more often when there is a rather low level of local knowledge exchange (Gertler and Levitte 2005; Hagedoorn 2002; McKelvey, Alm, and Riccaboni 2003). These authors consider that a high extent of local knowledge flow is codified (Martin and Moodysson 2011a). Other authors argue that both the tacit and explicit part of knowledge play a role when transferring knowledge. Accordingly, the tacit and explicit knowledge is viewed as complementary and not as substitutes for each other. Consequently, the simultaneous transfer of tacit and codified knowledge is not excluded in research (Johnson, Lorenz, and Lundvall 2002; Polanyi 1966).

A more systematic approach that addresses the different transformation processes of knowledge is addressed in the work of Nonaka and Takeuchi (1995). While their model of knowledge management was developed for knowledge transformation within the organization, many aspects are likely to be similar between organizations. Therefore, their model for knowledge transformation processes is applied to the interorganizational level of learning at this point. Nonaka and Takeuchi (1995) describe four modes of knowledge conversion, namely the socialization (from tacit to tacit knowledge), the externalization (from tacit to explicit knowledge), the internalization (from explicit to tacit knowledge), and the combination (from explicit to explicit knowledge) of knowledge. While socialization has emerged from the analysis of group processes, the combination derived from information processing and the internalization is strongly related to corporate learning. Only externalization of knowledge has received scant attention in theory. Nonaka and Takeuchi's (1995) four forms of knowledge transformation are briefly elaborated below.

To begin with, socialization is the transformation of tacit to tacit knowledge. The key factor for this transfer of knowledge is the physical conversation between experts, which can be achieved, for instance through face-to-face experiences (Nonaka and Konno 1998). Accordingly, the learning of tacit knowledge takes place through experiences, observations, imitations or practices. It is worth noting that in most cases the exchange of information only makes sense within the corresponding context of experiences, which requires the individuals to put themselves in a particular position. In this vein, the mutual tacit knowledge transfer enables the actors to put themselves in the knowledge world of the others. An open organizational culture promotes such direct encounters between individuals (Nonaka and Konno 1998). For the transformation of tacit to tacit knowledge, mental models are often used, which presuppose interpersonal skills, such as memory, a composure of assertions, reality perception or problem solving (Johnson-Laird 2010).

On the contrary, combination is the process of linking different elements of explicit knowledge into one set of explicit knowledge (Nonaka and Takeuchi 1995). The process of combining connects different explicit concepts from a particular area of knowledge. In other words, existing information is recomposed with the help of sorting, adding, classifying, or combining in order to create new knowledge. A common strategy for the combination is to exchange explicit knowledge through documents, meetings, telephone conferences, or by other digital communication networks. Databases and computer networks facilitate the form of knowledge transformation. An important role here plays the codification of information and knowledge to assist in the articulation and creation of new concepts. However, the combined knowledge is often even more systematic and complex than the separate elements (Nonaka and Takeuchi 1995).

Externalizing is the process of transforming tacit knowledge into explicit knowledge (Nonaka and Takeuchi 1995). Externalization plays an important role in the creation of new knowledge, as it attempts to cast tacit knowledge into explicit concepts. These explicit concepts are a common method to promote the dialogue and reflection of knowledge with images and linguistic expressions. They often combine deductive with the inductive approaches. For externalizing tacit knowledge, metaphors, analogies, models or hypotheses are common means of articulating tacit knowledge (Nonaka and Takeuchi 1995). Indeed, metaphors and analogies are particularly good at increasing creativity as figurative ideas are used for understanding tacit knowledge. Metaphors especially form the interconnection between concepts and models. However, metaphors are not always sufficient to actually represent the complexity of tacit knowledge. Clearly, no logical analysis is used for building explicit knowledge but a new interpretation of experience is generated. In this process, new meanings deriving from the tacit knowledge can be recognized, linking abstract concepts with concrete ones. Finally, models can be used that coherently and systematically address the concepts and statements (Nonaka and Takeuchi 1995).

Internalization intends to transform explicit knowledge into tacit knowledge and, along with the externalization, one of the most challenging transformations. The internalization is, therefore, decisive whether concepts or models or experiences from the socialization, externalization or combination are also internalized. According to Nonaka and Takeuchi (1995), it is only at this point that new knowledge emerges and becomes a valuable asset. For the internalization of knowledge, documents, manuals or oral narratives are particularly supportive, through which the explicit knowledge can be conveyed and internalized more effectively. Internalization is also very similar to the learning-by-doing concept. Nonaka and Takeuchi (1995) note that knowledge can only be exploited when it becomes explicit to the company. Innovations can, therefore, only be developed when tacit and explicit knowledge work together (Nonaka and Takeuchi 1995).

Wiig (1993) developed a model to distinguish the different degrees of internalizing tacit knowledge, which separates between five different stages of knowledge internalization. At the first level, there are the so called “ignorants or beginners”, who are not or barely aware of a specific knowledge or how it is linked to a situation or consideration. At the second level, the “advanced beginners” have little complex understanding of the knowledge, but recognize where and how knowledge can be found and used. At the third level, the “competent or proficient performers” know about and apply the knowledge in a rudimentary way using external knowledge bases. At the fourth level, the "proficient performers or experts" know the knowledge, retain it in memory, apply and are able to justify with the knowledge. At the fifth level, the "masters or grand masters” have a fully understanding of the knowledge, have completely internalized it and, thus, have a broad understanding of judgements, consequences and values (Wiig 1993). However, since this transformation of knowledge, especially the internalization of new knowledge, never takes place in a vacuum, but external factors have an impact on interorganizational learning, influences and requirements are considered in the next chapter.

3.2.5. Influences and requirements for interorganizational learning

Interorganizational learning depends in part upon external influences, social relations and other conditions that affect the process. A closer look is taken at the concepts of power and trust that impact how interorganizational learning occurs and is experienced – both of which are powerful drivers and barriers to learning (Thornburg 2021).

To pave the way for examining the influence of trust and power on interorganizational learning, it is necessary to consider the social arrangements, including the broader market relations of the organizations in their project surrounding. A salient aspect here is that cooperating organizations often operate in the same market and are in some form of competition with each other. Due to general market liberalizations, competition is changing from a purely national phenomenon to a pan-European one (Mattes 2010). This creates a tension in so far as the cooperating organizations are sharing learnings and innovation in one context, but act as competitors with potentially conflicting interests in another. It is apparent that cooperation and competition are going hand in hand (Harrison 1992) and reveal a dichotomy between engaging in a relationship and releasing knowledge, as well as managing the risk of knowledge leakages to competitors (Braczyk and Heidenreich 2000). Competition, therefore, arises from the fear and the subsequent striving of the actors to be more successful on the market than others. Hence, competition often implies a power relationship between actors in a market.

Although the theory of power is universally known, it is not only conceptually diverse, but also difficult to grasp. Since interorganizational learning always takes place between different organizations, power is seen as the basis of organized action between two or more actors. According to Crozier and Friedberg (1979), power is always referred to as a relationship and never an attribute or characteristic of an actor. Actors are always in a state of co-dependence as they have specific personal interests for achieving a common goal. Power, thus, thrives on exchange or interaction between actors, whereby actors must show explicit commitment. Similarly, it is argued that power is always linked to negotiation and, therefore, it is an exchange or negotiating relationship (Crozier and Friedberg 1979). Crucially, this relationship is typically unequal, as one of the actors usually benefits more from the relationship than the other. However, power does not signify that one actors is at the mercy of the other, since power always provides a free space that promises the relationship room for maneuver (Crozier and Friedberg 1979). In the context of interorganizational learning, power can take on a significant role, as expertise or specialized knowledge in particular can lead to an advantage in a collaboration, thus enabling the expert to set the learning direction or innovation implementation through a high wealth of experience (Crozier and Friedberg 1979).

Power imbalances can also take the form of knowledge retentions. Indeed, the risk of knowledge leakage in collaborations is high when selfish partners appropriate valuable knowledge in order to gain an extra advantage over a competitor (Jiang et al. 2013). Hence, competition characterizes the agenda of many organizations, leading to restricted knowledge integration. For interorganizational learning, this creates the risk and dilemma that some organizations take more knowledge than they are willing to give in return (Larsson et al. 1998). This unwillingness to share knowledge leads to a general decline in knowledge, which at the same time means a potential loss of market share for all concerned parties. Cooperation can, therefore, lead to a competitive strategy between organizations aimed at gaining more power and knowledge compared to the other, more collaborative organizations. However, the only effect such strategy brings is a decrease in joint learning processes and, thus, innovation (Larsson et al. 1998). Interorganizational learning is, therefore, based on the shared decisions of interacting organizations and their ability to be both transparent and receptive (Larsson et al. 1998). The willingness to share knowledge is, consequently, an indispensable prerequisite for interorganizational learning.

Finally, unequal power relations or the exploitation of them can also hinder the development of trust, which is an essential part for learning in collaborations (Vangen and Huxham 2003). Generally, trust can be summarized as a willingness to enter into a state of vulnerability based on positive expectations regarding the purpose or behavior of others (Rousseau et al. 1998). However, the term has a multi complex character and is, therefore, defined differently in various research disciplines (Rousseau et al. 1998). Whereas economists focus on the institutional (North 1990) or calculative (Williamson 1993) character of trust, psychologists assess trust according to the characteristics and internal insights from the engaging in trust (Rotter 1967; Tyler 1990). Sociologists see trust as a socially embedded element of relationships between human (Granovetter 1985) and their relation to institutions (Zucker 1986).

However, the sociological definition conceals a multitude of possible forms and focalizations that social relations of trust can take. For example, McKnight et al. (1998) define trust at an interpersonal level based on the willingness of an individual to make oneself dependent on others and thereby feeling relatively secure, despite the risk that the trust could be misplaced (Mcknight et al. 1998). The definition assumes that trust involves risks (Luhmann 1991) or at least an uncertainty (Gambetta 1988) based on the interdependence between the persons to be trusted. Another attempt of enhancing the insight into the term trust is the distinction between initial and gradual trust (Nilsson and Mattes 2015). While initial trust assumes that partners have little information about each other when they first meet(Mcknight et al. 1998), gradual trust relies on repeated interactions that occur over time from personal experience (Nilsson and Mattes 2015). Initial trust is perceived as rather fragile compared to experience-based, gradual trust because it is very impersonal and does not come from a direct personal interaction between the trustor and the trustee (Mcknight et al. 1998).

Another strand of research in trust is *dispositional trust*, which focuses on the situation- and person-spanning variable within its definition (Harnett and Cummings 1980; Wrightsman 1991). Dispositional trust, therefore, arises when a person has a consistent propensity to trust across a wide range of situations and people. Dispositional trust is especially proven by two arguments: 1) advocates of the approach argue that other people are usually trustworthy and 2) people who trust each other will achieve better results even if they do not have as much knowledge and skills (Mcknight et al. 1998). In contrast to dispositional trust, the decision to trust is an *intentional construct* that refers to trust that is granted in a specific situation. Intentional trust is manifested in the willingness to trust others, based upon to those intentions and individual cognitive beliefs about others (Bromiley and Cummings 1995; Gabarro 1978;

Rotter 1967). This leads to the development of an individual emotional certainty about those beliefs and, thus, about the judgements made. These two aspects, namely cognitive beliefs and emotional certainty are able to build a person and situation-related construct that is called *trusting beliefs*. Trusting beliefs are characterized by personal attributes, such as predictability, honesty, competence, as well as benevolence and assume that an individual believes in the trustworthiness of another person or particular situation (Mcknight et al. 1998).

Trust may take place at the individual level for the first instance, but becomes embedded in a new system through interorganizational collaboration, such as in projects. Trust is, therefore, considered to have positive characteristics, such as the creation of cooperative behavior, the development of adaptive forms of organizations, the reduction of conflicts or the fast creation of working groups (Meyerson, Weick, and Kramer 1996; Miles and Snow 1992). To this end, it is also useful to look into the trust of systems. System trust is based on the belief in the right structures that define the respective roles within in a system (Mcknight et al. 1998). These impersonal structures enable the formation of new relationships and create a secure feeling for the future (Luhmann 1991; Shapiro 1987). Impersonal structures can be protective measures, such as regulations, promises, contracts or guarantees that aim to reduce uncertainty in a changing environment. In contrast to the cognitive beliefs model, system trust is situation-dependent rather than person-dependent (Mcknight et al. 1998). Transparency is essential in order to build trust. This is particularly relevant when partners from potentially different organizations collaborate. Generally, it is noted that the more transparent the partners are in their actions and behavior, the more likely they will trust and learn from each other (Hamel 1991; Kale and Singh 2000). Hamel (1991) defines transparency as an expression of the degree of openness and accessibility of the partners. This degree is strongly related to the degree of protection that each of them gives to the other partner.

To sum up, trust is seen as an important factor for learning and an efficient knowledge transfer (Janowicz and Noorderhaven 2014). As has been repeatedly emphasized in the different processes of knowledge transformation as well as in the prerequisites for interorganizational learning, a common knowledge base between the actors is expected to emerge, depending in particular on the willingness to share knowledge (Larsson et al. 1998). The state of research on the common knowledge base will be highlighted in the next chapter.

3.2.6. The creation of a common knowledge base

A shared knowledge base is considered as a result of interactive learning between organizations (Grunwald and Kieser 2007; Holmqvist 2001; Mattes 2010), which increases the likelihood of a successful knowledge integration in a collaboration (Lubatkin et al. 2001). The knowledge base can be identified as one of the main characteristics of interorganizational learning and is, therefore, seen as a general condition of strategic alliances or projects. From what has been outlined so far, the knowledge base is the sum of the knowledge to be transferred between the partners in the interorganizational learning process. According to Wiig (1993), a knowledge base contains all the domain knowledge of the system that is used to reason about the system. While in a more technical sense, the knowledge base is often equated to a database represented in a standard format, in the sense of this study, the knowledge base is rather related to a knowledge-based repository from which the actors can extract, assemble and synthesize the different knowledge formations.

In an organizational sense, knowledge bases are considered as local, specific and not generalizable entities (Mattes 2010). Project structures can be thought of as local frameworks for the development of a knowledge base. Creating a common knowledge base requires in-depth learning processes such as cross-learning and the combination of heterogeneous knowledge (Mattes 2010; Schmickl and Kieser 2008). According to Lubatkin et al. (2001), knowledge bases consist of the "know-what" and "concrete know-how". The authors argue that the absorptive capacity and, thus, the ability for mutual learning is influenced by the similarity of knowledge bases of the partners as well as by the institutional behaviors and routines (Lubatkin et al. 2001). In order to create the knowledge base, it is necessary not only to learn by oneself, but also to learn jointly and to expand the acquired knowledge and collectively transform it into new knowledge. This new knowledge, in turn, makes the actors independent of each other (Lubatkin et al. 2001, p.1354). However, Lubatkin et al. (2001) prioritize to provide some key requirements for achieving successful mutual learning, rather than acquiring specialized knowledge as much as possible. Developing a shared knowledge base through learning requires recognizing and valuing the proprietary knowledge of the other partners. It also requires that the partner organizations already have a basic awareness of the semantics and a shared articulation of the decisions rules for causes and effects in terms of the partners' knowledge structures. In their opinion, a common knowledge base would, therefore, require a (1) common *awareness* about semantics, consequences as well as cause-and-effect relationships, (2) a *common language* including proprietary knowledge about the technologies and, lastly, (3) a *similar thinking and behavior* between the partners (Lubatkin et al. 2001). Therefore, a common awareness, language, and behavior in particular play a significant role in the shared knowledge base.

Despite these findings of the two forms of knowledge, the transformation of knowledge and finally the discoveries from the knowledge base, the field of interorganizational learning nevertheless contains limitations. This is mainly due to the fact that the knowledge of individual person always contains a variety of associations and connections to other areas of understanding. These connections are not only fractured and comprehensible to a small extent but it is also unknown how knowledge is really organized interorganizationally. Consequently, despite all efforts, studies on interorganizational learning and the emerging knowledge base reveals less concrete representation.

3.3. Knowledge bridging - as the underlying process of knowledge integration

This work aims to investigate how and to what extent Smart Grid actors integrate specialized and distributed knowledge for developing innovation in Smart Grid projects. For this purpose, the underlying process is to be investigated in order to understand how knowledge is integrated between the organizations in Smart Grid projects. Given the assumption that interorganizational learning is effortful and challenging, knowledge bridging is explored as an alternative for integrating knowledge in collaborations.

3.3.1. Knowledge bridging as an alternative to learning in collaborations

Knowledge bridging is identified here as the underlying process of knowledge integration. As specialization is increasing in most fields of work and project tasks become more complex, today's project environment requires flexible and dynamic handling for integrating knowledge. This complexity is producing a second stream of research in the field, namely of knowledge bridging, which has evolved under the premise that learning between project partners becomes even more difficult and arduous in collaboration.

The term "knowledge bridging" is not well established in sociology because few researchers have studied and defined the term. Nevertheless, the sub-concept "bridging" is widely used in sociology and a known phenomenon, for example, when bridging cultures, disciplines or perspectives between different people or groups. According to Mattes (2010, p. 65) *"knowledge* *bridging provides a means of spanning the gap between two individuals who, at the same time, remain solitary experts in their own field"*. Mattes (2010) suggests knowledge bridging as a means connecting two individuals or experts in their particular area, with the aims of bridging or bringing together different fields of expertise. In contrast to learning, they do not share a common knowledge base, but bridge the relevant knowledge for the development of innovation (Mattes 2010, p. 65). Knowledge bridging is the expedient and short-term exchange of the particular part of knowledge necessary to achieve a more or less stable bond between two different and independent parties. This connection is needed for linking different organizational actors in order to overcome obstacles between them. Schmickl and Kieser (2008) see knowledge bridging as a type of interorganizational learning characterized by reciprocity, in which only limited knowledge is exchanged. This equates that partners combine the knowledge relevant for the common interfaces, which is necessary for bridging the different knowledge areas. However, this does not affect the core competences of the partners. Through this process, a high degree of modularization can be achieved (Schmickl and Kieser 2008). In a similar way, Grunwald and Kieser (2007) describe knowledge bridging in their study as transactive organizational learning (TOL), whereby knowledge is shared across the interfaces of the different modules. Individual modules are to be connected in order to bridge knowledge gaps (Grunwald and Kieser 2007).

Despite this attention to the reciprocity, knowledge bridging is also described as a strategy, which intends to prevent the outflow of knowledge by competitors and to protect the core competencies of knowledge in organizations. This draws attention to the competing interests of the organizations involved, assuming that cooperation is not always the first choice of organizations (Braczyk and Heidenreich 2000). In this sense of interpretation, the project structure is based on the division of work, through which the exchange of knowledge is avoided as far as possible. The division of labor ensures that the various modules are developed independently of each other. Despite the less intensive exchange of knowledge, innovations are still created (Krüth 2018). In this vein, knowledge bridging is deliberately used to retain central know-how within the company. According to Krüth (2018), knowledge bridging aims primarily at increasing efficiency, which means that basic assumptions are accepted and not necessarily investigated further.

Another attempt to capture knowledge bridging can be seen in single-loop learning (Argyris and Schön 1978; Mattes 2010). Single loop learning assumes that an organization corrects errors when they are discovered, but the organization itself continues to adhere to the previous policies and goals that caused the error. Therefore, single-loop learning contributes to new competencies and capabilities of the organization but without necessarily changing the fundamental nature of the organization's activities (Dodgson 1993). Fiol and Lyles (1985) distinguish between the two levels of learning: a lower-level learning and a higher-level learning. Fiol and Lyled (1985) characterize the lower-level learning by surfaced and temporary knowledge that is based on replications of short term former behaviors and has no fundamental impact for the organizations. The knowledge comprises only of selected parts of the organization, why low-level learning is related to single-loop learning. In contrast the higher-level learning comprises an overall understanding of causation and associations of relevant actions and the involvement of complex rules (Fiol and Lyles 1985). Dodgson (1993) argues that most organizations fail when it comes to higher-level learning because of inhibitory loops, provoking individuals to reinforce failures due to entrenched organizational cultures

The concept of exploitation and exploration by March (1991) can be seen as another approach to describe the process of knowledge bridging. The concept envisions that organizations in a collaboration can use existing technologies and thus exploit them, which does not need intensive interorganizational learning (Koza and Lewin 1998). Along the same line, Grant and Baden-Fuller (2004) argue that learning new knowledge is less important for certain collaborations compared to exploiting existing knowledge formations more efficiently. However, exploitation is often favored by a stable and homogeneous network with hierarchical mechanism (Dittrich and Duyster 2007), while exploration is often associated with flexible forms of organizations (Weick and Westley 1996).

An even more extreme way of looking at knowledge bridging is suggested by Senge's (1990) concept of *"non-learning"* as a challenge to organizations that have lost any dynamism of learning in teams. Senge (1990) justifies the non-learning approach of organizations with different learning barriers, such as defense routines and argues that learning requires awareness and openness from team members and their leaders. In fact, if teams are to transcend "non-learning", reflexivity must be an integral part of their work-based culture. In this sense, reference can be made to the challenges of knowledge integration (chapter 3.1) emphasizing further that collaboration and learning are not a matter of course and do not always run smoothly. However, according to Schnauffer (1999), there are also situations in which learning is insignificant and not mandatory. This is the case, for example, if much irrelevant and unreflexively information is accumulated, leading to a loss of identity and the focus for a common vision, both of which arguably block innovation. Although economic studies propose a certain basic understanding or prior knowledge for learning, this basic understanding is often present in varying degrees. Accordingly, if the prior knowledge in terms of absorptive capacity by the team is too low, the feeling of information overload develops. At this stadium of information overload, adequate assimilations (or single-loop learning) are not possible, resulting in inconsistent perceptions of the mental models, which represent processes or objects in the person's mind. In the absence of reflection, mental models cannot serve as a representation of reality and do not provide a mental path to a solution. In contrast, by absorbing too much knowledge, it is no longer possible to refer to the validity of the mental models. This cannot only influence the quality of decision-making, but also creativity, which is based on a completely contradiction-free assimilation. Similarly, learning can lead to introjection of knowledge, which means that learning material is swallowed without consciously understanding it. In short, non-learning as well as learning can entail opportunity costs (Schnauffer 1999). Finally, it should be noted that non-learning is often not a conscious decision, but is often accompanied by learning barriers, which will be discussed further in chapter 3.3.4.

To summarize, knowledge bridging stems from different research directions, making a concrete definition almost impossible. In the spirit of this research, knowledge bridging is seen as an alternative for learning between organizations and is intended to bridge the knowledge gap required for innovative projects. However, the process is conducted in such a way that enables two or more actors to interact and communicate within a project without explicitly having to learn an alternative body of knowledge that a partner organization may bring to the project. The subsequent chapters will provide an overview on the type of bridging knowledge, its actual process, influences and requirements an alternative to interorganizational learning.

3.3.2. Bridged knowledge – a different type of knowledge?

Drawing on the discussion in the previous chapter, current research provides only little guidance on what underlying type of knowledge ought to be bridged. A gap in the theory appears as researchers have been torn apart about what and to what extent knowledge is being bridged in this approach. At this point, two possible understandings of bridged knowledge are presented.

Firstly, some authors emphasize that knowledge bridging is justified with *specialized expertise* in the project team. Following Nonaka and Takeuchi (1995), this expertise entails a large scale transfer of tacit knowledge that is bridged. According to the previous elaborations in chapter 2.1, this tacit knowledge would require a deep understanding in order to integrate it and shift it into a new context (Bennet and Bennet 2008). Expertise in form of specialization in projects is, therefore, strongly linked to a person and is difficult for partners to learn.

The second understanding of bridged knowledge implies *that intensive learning is not necessary* for developing innovations and suggests that knowledge bridging is sufficient for cooperating in strategic alliances. For this approach, not all interactions are equally profound and some are, therefore, restricted to superficial interfaces, which is often all that is actually required to collaborate. The degree of knowledge actually exchanged, thus, varies from partner to partner in a cooperation and can remain unproblematically at a level of basic understanding (Mattes 2010). In this sense, knowledge bridging is referred to as a weak form of learning, with a lower-level transfer of knowledge. According to Nonaka and Takeuchi (1995), this refers mostly to explicit knowledge that is easy to transfer and does not require a high level of understanding. The depth of penetration of the knowledge that is bridged can be examined, for example, by using the internalization approach by Wiig (1993) again. According to Wiig's knowledge internalization, it could be possible that the bridged knowledge is internalized to a lesser extent, since it is a more basic understanding of the knowledge. Hence, the partners are aware of the knowledge but do not deeply internalize it. At this point, the question arises again to what extent the knowledge is actually internalized, as it is exchanged on a basic level. Hence, the extent to which the bridged knowledge is actually internalized is, therefore, not yet given in the attempts for describing knowledge bridging. Presuming that there is an exchange between the partners, it is open to question how deeply the partners delve into and understand the knowledge to be bridged.

Wiig (1993) summarizes four types of knowledge that can be used to approximate the nature of bridged knowledge in this study. The distinction was made between factual knowledge, conceptual knowledge, expectational knowledge as well as methodological knowledge. In this design, *factual knowledge* includes concrete and realistic details, known causal chains or measurements that are based on relatively stable mathematical or procedural models. It is this initial semantic knowledge that is related to a specific knowledge domain and can thus be placed in a specific context. The factual knowledge is generally recovered from memory and used for explanations. For this purpose, it is codified from the external knowledge bases. *Conceptional knowledge* can occur in the form of perspectives, concepts or systems, which are meta-models needed for describing complex situations. The conceptual knowledge is derived from observations or other factual information and data. *Expectational knowledge* is the overarching term for judgements, working hypotheses, associations or beliefs. This knowledge aims to assess how to deal with knowledge integration in complex as well as simple situations and contain associations and impulses for thoughts to achieve possible conclusions and interpretations. Concepts, confirmed data or facts as well as perspectives build the basis for working hypotheses and expectations. Finally, *methodological knowledge* relates to decision-making methodologies or techniques, judgements or hypotheses and provides the meta-knowledge for arguing and reasoning in specific situation and context. It, therefore, uses the background knowledge (Wiig 1993).

The third assumption of knowledge bridging as "non-learning" implies a complete lack of mutual exchange of knowledge. This assumes that neither tacit nor explicit knowledge is bridged, since no direct form of interaction between the partners takes place. Returning to Nonaka and Takeuchi's approach of tacit and explicit knowledge (Nonaka and Takeuchi 1995), we can see directly here the theoretical limitations because it is not clear what specific part of knowledge needs to be bridged. Again, both parts of knowledge are generally available, but it is not clear which part of knowledge is actually important for knowledge bridging. Finally, the question remains of whether knowledge is actually shared at all, as knowledge bridging can also be accomplished without direct exchange among each other.

3.3.3. Process of knowledge bridging and possible mechanisms

With all of the above ambiguities continuing to characterize the theorization of knowledge bridging, I turn to Grunwald and Kieser (2007) who attempt to examine the process of knowledge bridging in more detail. Without explicitly using the term knowledge bridging, Kieser and Grunwald (2007) have investigated the appearance of knowledge bridging in their approach to "Transactive Organizational Learning (TOI)". Grunwald and Kieser (2007) argue that a joint interpretative framework could be designed, which serves as a coordination of knowledge and not as a whole spectrum of technological possibilities. TOl enables an expert in an innovation cooperation to use the knowledge from other experts without passing on its own knowledge to them (Grunwald and Kieser 2007). Their central argument is that learning does not have to be interactive (Grunwald and Kieser 2007). TOI assumes that learning between project partners can be minimized without negatively affecting the cooperation. This is made possible by the four TOI mechanisms "modularization", "knowledge storing in artifacts", "localization of knowledge" as well as "prototype knowledge integration". *Modularization* stipulates that architectural innovations that build on the technical knowledge of partners and are reflected in products, processes or organizational components are broken down into smaller and less complex units during modularization (Baldwin and Clark 1997). These architectural innovations can be handled independently by specialists or experts, enabling a decentralized production process (Schilling 2000). Modularization, therefore, assumes that teams of experts redesign, rearrange or recombine products or processes at their home location (Galunic and Eisenhardt, 2001; Sanchez, 2000). This increases the capacity for innovation through loosely coupled teams (Sanchez 1999).

The second mechanism assumes that *knowledge is stored in artifact*s. These artifacts or the knowledge contained in them can be used or learned by people without knowing exactly how the artifact is constructed (Grunwald and Kieser 2007). For example, two specialists can design different modules on a common product without understanding every detail the other expert knows about the new product. One specialist only needs to know the interfaces between them. Therefore, they only need the functions of the other expert's module to build their own and do not need to know how the other expert developed this function of his module. The specialists in knowledge storage in artifacts, hence, concentrate on adapting their module to the input-output requirements with which their modules interact (Grunwald and Kieser 2007).

The third mechanism is the *localization of knowledge* that is not present in the project team as a whole. Accordingly, it is assumed that organizations in the innovation development process, particularly in information technology, often know what specialized knowledge is needed, but not necessarily where to find this knowledge (Kaffashan Kakhki et al. 2022). Again, it is assumed that not every knowledge is relevant for every project partner. A knowledge management system or a board of directories can be used for the knowledge localization, which describes where specialized knowledge can be found, either by internal members of the organization or by external partners who have the required knowledge (Grunwald and Kieser 2007).

Last mechanism is the *prototyping*, which is based on the verification of errors in several attempts to find solutions for tricky problems. Prototyping is based on the assumption that specialists who learn modules from other experts can only acquire this knowledge imperfectly (Gaimon and Carrillo 2022). Although specialists create descriptions of their modules, it is often difficult for other specialists to understand their thought processes of other specialists in the creation process of the module. In fact, specialists from other fields can ask questions, the individual knowledge modules are based on such different theories and terminology that it is difficult to create a common understanding (Grunwald and Kieser 2007). Especially during the finalization of the modules and the necessary testing of the interaction between the modules, the specialized knowledge is often not shared to a larger extent between the actors. Modules are to be continuously improved with each additional prototype round and tested for their compatibility and functionality for the end product. To this end, feedback loops and reflexivity are vital (Grunwald and Kieser 2007).

The mechanism showed that deep learning between different specialists is not always necessary in order to jointly develop innovation. Nevertheless, the approach assumes that even if learning in cooperation can be greatly reduced by these mechanisms, joint knowledge and cross-learning is still needed in an interaction and cannot be completely neglected. Grant (1996) describes that knowledge sharing influences the effectiveness of knowledge coordination. Grant (1996) divides the common shared knowledge into two types, namely the knowledge for coordination purposes and knowledge for content or design purposes. Common coordination knowledge refers to the coordination of different specialized bodies of knowledge in order to facilitate the interaction and exchange between actors and to increase the effectiveness of coordination activities. Common content knowledge refers to colliding specialized knowledge for new product design, whereby specialists exchange their knowledge about technical specifications of components. One of the most important elements of coordination knowledge is a joint natural language to communicate with cooperating partners. In software engineering teams, for example, it would make sense if the cooperating partners speak a common programming language, which contributes to a more effective coordination of the partners and facilitate the cooperation by common definitions and interfaces (Sommerville 2001).

Grant (1996b) seeks to connect coordination and content knowledge and claims that shared content knowledge often increases interaction and coordination capabilities between the involved actors. However, a paradox arises: on the one hand, the better the partners know the other partner’s specialized knowledge, the less positive effects can be achieved by integrating knowledge of the other partners; on the other hand, the fewer similarities in their knowledge base with other partners exist, the higher the degree that partners integrate new knowledge only at a low level (Grant 1996b). The distinction between content-related and coordinating knowledge is not assigned to the TOI concept, because the TOI mechanisms reduce the necessity of cross-learning and, conversely, the need for coordination (Grunwald and Kieser 2007).

3.3.4. Upstream reasons of non-learning as arguments for knowledge bridging

The preliminary explanations show that the conditions surrounding the process of knowledge bridging need to be reconsidered and readjusted, as the working conditions in today's environment are changing tremendously. Although few concrete prerequisites or influences for the knowledge integration process are identified in the literature, interesting aspects can be derived from the "non-learning" literature. It is argued in this sense that learning is by no means a matter of course and that there are many reasons and influences why learning may not take place between organizations – all these aspects lead to a recourse to knowledge bridging, which becomes vital for tackling these influences (1990).

First, it is argued that learning requires a lot of effort in form of practice, which is not always possible in current project collaborations. This practice of joint learning is often missing in modern organizational forms because it is intensive in terms of human resources (Senge 1990). He suggests an equal dialogue between the partners for facilitating learning, but this presupposes that the partners respect each other and create a positive atmosphere in order to allow vulnerability. However, today's project environment is not only fast-paced, but also focused on efficiency, which means that the common practice for learning is almost impossible to achieve. Likewise, today's collaborations are much more sophisticated and, therefore, face new challenges, especially regarding the increased specialization of the experts (Tell et al. 2017b). Due to the time constraints, difficulties can arise for creating an atmosphere that allows a valuable dialogue between the partners to develop (Senge 1990). The parties of the project have had little prior contact and only meet for a short period of time (Niedergassel 2011). As a result, there is rarely any practical experience between the project partners, so it is not always possible to acquire each other's expertise.

The occurrence of defensive routines can also produce the conditions for non-learning and thus for the underlying process of knowledge bridging. Defensive routines arise, for example, when employees are dissuaded from contributing their ideas by the overly dominant behavior of some team leaders (Senge 1990). The defensive behavior is justified, for example, when managers do not seriously address criticism and pretend as if they things under control. Team defense routines can create walls or mental barriers for collective learning (Senge 1990). The stronger the defense routines in the team, the more these existing problems produce non-learning as an unintended outcome. In such collaborations, learning is hardly possible, which can impact the use and effectiveness of knowledge bridging.

The complex interaction between project partners and their leaders, including relations of trust and respect, place high demands on the expected learning outcomes, which cannot always be met. These aspects are also closely related to power and control in such collaboration. Both can impact the common knowledge base and lead to a lack of learning and recourse to knowledge bridging. The trust necessary for learning is also presented as difficult in practice between different organizations. As was also made clear in chapter 3.2.5, trust is often associated with effort, which requires personal contact, at least at the beginning of a project. This cannot always be guaranteed under the new conditions of project work.

To conclude, collaborative learning requires many practical prerequisites for it to take place at all. There are many reasons why learning in current collaborations cannot take place as originally envisioned in theory. Thus, learning is confronted with high challenges of the actual project world, suggesting that knowledge bridging is a viable alternative for dealing with expertise. Overall, it can be stated that the arguments against learning can be in favor of knowledge bridging as an alternative. However, this is rarely explicitly mentioned in the literature.

3.3.5. Summarized distinction of both processes

Both underlying processes of knowledge integration are not easily distinguishable and, therefore, no consensus on the two processes has developed on the two processes. In short, the literature review revealed that neither the specific characteristics of interorganizational learning nor the nature of knowledge bridging has been more profoundly researched and substantiated. In particular, knowledge bridging has been identified as a somewhat fuzzy process and was hitherto not even considered by all researchers as an independent process but rather treated as a face of interorganizational learning. In this matter, the literature review showed that the concept of knowledge bridging is rarely applied, while learning takes on a completely different dimension and is much more investigated. It has been argued that learning has been theoretically prioritized in the context of collaborative projects despite the problematic and effortful nature of learning. The same applies to innovation development in projects, for which learning is often seen as a prerequisite. These fuzzy processes are now being brought to the fore because collaborative work between organizations is characterized by heterogeneous actors and their different specialized, technically complex knowledge, which is able to impede the underlying process of knowledge integration.

The two different approaches of interorganizational learning and knowledge bridging are shown in the figure 4 below. This figure shows how two exemplary organizations interact with each other. On the upper part, the organizations learn from each other, thus create a common knowledge base. In this sense, learning is often associated with greater effort and communication. While the lower part of the figure 4 shows the two organizations bridging knowledge and passing on only that part of their specific expertise to fill the respective knowledge gaps. In this case, it is unknown if the organizations require a basic understanding of the expertise of the other partner or if they fill the knowledge gap without knowing the specific area of expertise.

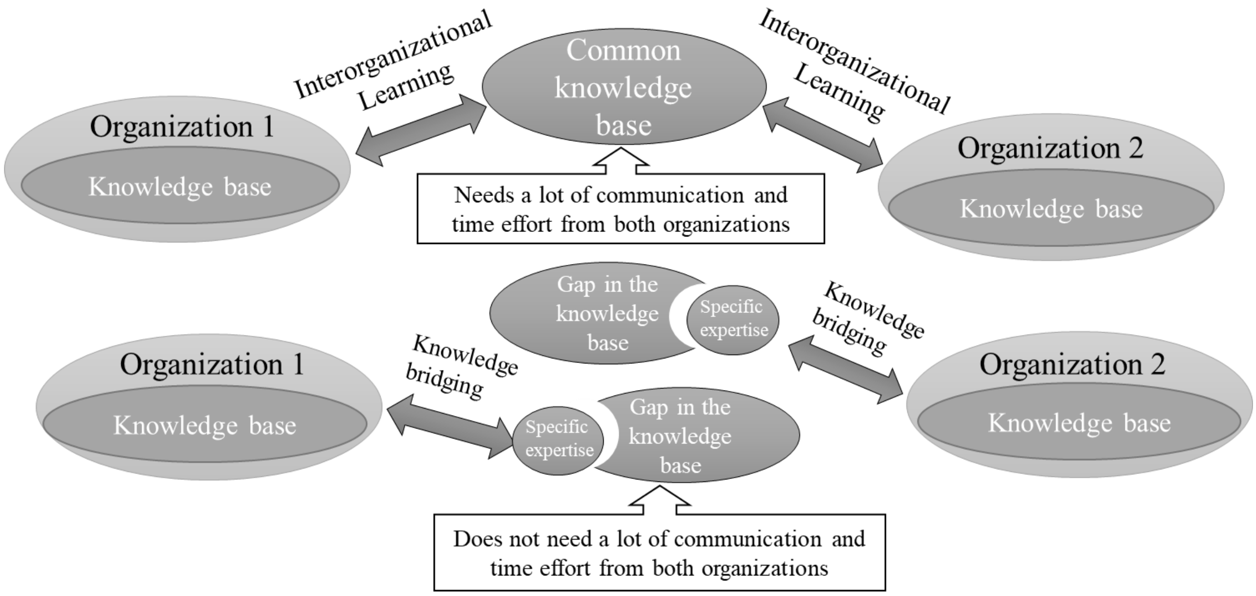

Figure 4 Interorganizational learning vs. knowledge bridging (Köhlke 2019a)

In the following chapter, “boundary objects” are invoked to offer a conceptual means to bridge the knowledge gaps that the respective organizations bring to project work. While there is a consensus that a shared knowledge base emerges because of interorganizational learning, this research offers boundary objects as a more efficient, practical and potentially less resource intensive outcome of knowledge bridging. Since the result of knowledge bridging has not been explicitly studied in the literature so far, a new conceptual approach to boundary objects as the outcome of knowledge bridging will be presented here.

3.4. Understanding the concept of boundary objects

In my conceptual approach to knowledge integration in Smart Grid projects, I argue that boundary objects can be the result of knowledge bridging. The main concern of boundary objects in my concepts relates to their role in knowledge integration and their potential as a heuristic tool for bridging knowledge in Smart Grid projects. To this end, the concept is described in more detail below.

3.4.1. Origins of the concept and its terminology

The original concept of "boundary objects" was first introduced in 1989 by Star and Griesemer (1989) in their book *"Grenzobjekte und Medienforschung"*, in which the authors analyzed the nature of cooperation in the non-existence of consensus. This was followed by research such as *"Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology"* (1989) and a paper from 2010 entitled *"This is not a Boundary Object"*, in which the concept was further refined. According to Star and Griesemer (1989), a boundary object describes how diverse actors can be involved in a cooperating project, although they have different and in many cases conflicting interests. More recent studies analyzed the role of boundary objects in network operation (Harrison et al. 2018), as an approach for explaining innovativeness (Huang and Huang 2013) and educational transfer (Kopatz and Gessler 2017), its usage as ecosystem services (Abson et al. 2014), for the success of new technologies (Fox 2011) or in regard to resilience (Brand and Jax 2007). In the energy domain, boundary objects were used to explain the cross-domain stakeholder alignment of different energy actors using the LEGO®SERIOUS PLAY® method (Köhlke et al. 2021). Although boundary objects have been used in more recent studies, most of these studies refer to the fundamental approach for developing boundary objects by Star (1989). Star (2010) even criticizes that other studies of boundary objects often misleadingly adopt her approach. Since it is a complex concept, I focus on the original meaning and use boundary objects according to the former approach.

Star (2010) analyzed the nature of projects and found that they often lack a basic consensus leading to debates and conflicts. The core element of the concept envisions that partners in collaborations only share the relevant information necessary for building the boundary object. In fact, partners involved in a collaboration only share particular viewpoints upon a common object, implying that actors already select what knowledge needs to be shared (Star and Griesemer 1989). In general, the term "boundary objects" is used for scientific objects that are located and established in different social worlds, in which they meet different information needs (Griesemer 1990). Boundary objects are, thus, in the position to adapt to the local requirements as well as to the constraints of the collaborating parties. A common identity in different places can be created that makes the boundary object robust. Another important aspect is that boundary objects can be abstract or concrete (Griesemer 1990) and have the component of interpretive flexibility. Subsequently, boundary objects can have different values and meanings for different groups that derive from different sources of data, thus boundary objects weaken the need for the complex processes required to produce interorganizational knowledge integration. Accordingly, boundary Objects are characterized as an agreement, which enables different actors to operate together - even if there is no consensus between them (Star 2010).

The basic assumption of Star and Griesemer (1989) is that collaboration is fundamentally challenging. Arguably, challenges arise in cooperative projects primarily when different worldviews of actors clash in the joint design process for new (technical) solutions and innovations (Star and Griesemer 1989). New innovative technologies, objects and methods can have contrary meanings in various knowledge fields and research directives. Thus, actors have to bridge these divergent viewpoints if cooperation is to be achieved (Star and Griesemer 1989). For this purpose, the authors suggest that empathy, i.e., putting oneself into the perspective of another social world, is necessary when developing innovation. By reducing local uncertainty for a specific time without risking the stability of the cooperation, actors should be able to easily immerse themselves in the viewpoints of others (Star and Griesemer 1989). In this process, Star and Griesemer (1989) describe that a passage point has to be reached, which must be defended against other opinions for finally achieving an agreement. In the actor-network theory developed by Callon, the obligatory passage point (OPP) is described as a narrow end of a funnel that puts pressure on actors to agree on a specific issue (Callon 1986).

Having presented the origins of the concept, the terminology origin and meaning should further illuminate the conceptual peculiarities. According to Star and Ruhleder (1996), the term "boundary" is understood as an edge, margin or periphery of something, such as a geographical, political or administratively limited area. The term is, thus, used to define a shared space that outlines the precise confines of "here" and "there". In this sense, boundary objects should depict common objects between groups that are characterized through interpretive flexibility and commonly used structures (Star and Ruhleder 1996). Initially, Star wanted to call her concept "marginal objects" because marginal points include more strongly the vision of a periphery and the assumption of a center, but she decided against it. Indeed, marginality is originally used in sociology to describe groups that are pushed to the edge of society, belong to two or more groups or that are of mixed racial heritage. In the end, Star chose the term "boundary" as a compromise (Star and Ruhleder 1996). The term "objects" is originally defined as a "thing", which Star uses in a computer sciences, material and pragmatists meaning. Objects can be used for something a human can act with or in contradiction of it. In a material sense, an object is not a prefabricated thing or a “thing”-ness, but it is something that comes from an action. However, an object can be embodied, voiced or named, but it is only a boundary object when it is used between different groups (Star 2010).

3.4.2. Core characteristics of boundary objects

From the late 1980s onward, research on cooperation has in most cases been conceptualized with the idea that agreement must be first reached before the actual work in the collaboration can begin (Star 2010). However, Star experienced in her own fieldwork that an analysis of heterogeneous groups consisting of different institutional actors are able to work together, without the necessity of first building a consensus. Moreover her field data strongly indicates that consensus does not exist in real life projects (Star 2010). Even when a heterogeneous group managed to achieve a (fragile) consensus, they often simply continued to work without problems and without much reference to the consensus. This dynamic provides the core characteristics of a boundary object. Boundary object that are a kind of a work arrangement are material and procedural at the same time (Star 2010). Firstly, a boundary object is located and structured in different social worlds, in which they should fulfil different information requirements. Secondly, the object can be edited by local groups that adapt it for local use in a social world, but it still maintains its vague identity. In general, this phenomenon explains, thirdly, why groups that cooperate without consensus, go back and forth between the different forms of the object. However, this back and forth between them enables the boundary objects to transform to standards, infrastructure, things or processes that have not yet been fully researched (Star 2010).

The most established characteristics of boundary objects are its *interpretive flexibility*. According to Star (2010), such interpretive flexibility is always given in any object. For explanation, she provided the example of a road map with a way to a campground, which could have a different meaning for each group in regard to their worldviews and intentions. Star (2010) assumes that the different views of the map derives from different sources of data that are present at the individual group members. The interpretive flexibility is also described in the book *“Sorting things Out: Classification and Consequences”* by Bowker and Star (1999). They claim that boundary objects are concurrently based on a specific action, are of temporal nature and can change according to the subject of reflection. Likewise, they ascribe to them characteristics, such a high adaptability to the localities and a broadly distribution capability (Bowker and Star 1999).

Another aspect of boundary objects, which is not as often used as interpretive flexibility, is the *material and organizational structure* of diverse forms of boundary objects. These forms differ in scale and granularity (Star 2010). The form of work between these actors is not randomly chosen and is, therefore, a significant organic structure, which is a result of "information needs". Star adapted her concept of information needs to "information and work requirements" as it is used locally and by actors that want to work together (Star 2010). Boundary objects, thus, provide insights on how language is used in order to work together (Becker 1986).

Originally, Star (2010) described the form of such object to be a *repository* consisting of a range of modular things. In a repository, things can be removed individually without breaking or modifying the entire structure. Such repositories, for example, libraries, arise from the needs of compiling things that are iteratively designed (Star 2010). Moreover, a repository produces heterogeneity between its internal actors without creating confrontation between them. The enclosure of inner units is the heuristic advantage of a repository, such as the external layer of a book that contains the internal pages (Star 2010). In order to conduct private research and to monitor the nature of statements and discussions between them, instance-based work and the repository ontology are appropriate for this purpose. However, this iterative process preserves details in contrast to a formal work process, which omit details. Other forms of boundary objects vary, for example, by their vagueness (Star 2010).

3.4.3. Detecting boundary objects in project collaborations

For the detection and observation of boundary objects in collaborations, Star (2010) presents several ways to identify anomalies that enables a faster triage of these boundary objects. During her fieldwork, she advised her students to look for two things in collaborations. Firstly, they should monitor if a particular language or vernacular is used in a particular location, such the use of metaphors or some specific words or phrases, or if the group uses some confidential codes. Secondly, the students should watch out for things that are considered weird, anomalous or strange. Finding this exceptional nature that embedded in the language, is the most difficult lesson to learn in this kind of fieldwork (Star 2010).

Star (2010) argues that five anomalies can identify the structure and emergence of boundary objects. The first anomaly is "invisible work", which was found in documentation of a clinical brain experiment. *Invisible work* describes the gap between the formal representation, including publications of a research and the unreported back stage work. This gap shows an important site of analysis. The notion of invisible work is used for computer systems and originally aims to investigate the materiality that is connected with the dissemination of presentations. Invisible work subtly affects the design of boundary objects, in keeping with the comprehension of local tailoring as a type of work invisible to the entire project group. Invisible work shows how a common representation can be very vague and very useful at the same time (Star 2010).

Another anomaly was also detected in the clinical brain study in England, which was about nervous disorders, such as epilepsy. In the nineteenth century, family members of these patients were asked to write down information about the symptoms of the disease and its timing. The investigation of these notes showed that the edge of the documents have been filled with unrelated, scribbled messages, like “Had too much hot soup yesterday” or “Rode alone in a Carriage” (Star 2010). These *edge messages* were discarded as unimportant and were lost in the files of the patient. This problem showed the difficulty of coordinating, gathering and disciplining distributed knowledge. However, this also raised questions on how delegated duties work between the family members as research assistants and the medicines administered and how delegated work influences the data quality. This also led to the question of how forms of data collection could be shaped in order to coordinate the research and restrict it to required information. In the following years, Star and Lampland further investigated the conflict between the forms disseminated by the World Health Organization and the traditional system of knowledge in medicine in an analysis of standardization. From these results, Star connected boundary objects as inseparable from standards (Star 2010).

Another indication for the discovery of boundary objects was the “platonic” form, which was explored from a set of comments and reports about a paper that David Ferrier published and which gained considerable attention. In the paper, he explained his experiments with monkey’s brain function, which differ in size, shape and function. He developed an eye field brain map of the monkeys, marked the functional areas of the brain, and transmits them directly onto the map. Star compared this method with drawing a specific path in a Paris subway map, transmitting the same way to the Cleveland subway map and expecting the infrastructure to be the same as in Paris. The research served as foundation for discussion and research into the area of exchanging data and pointing to things without defining any real territory. Star indicated this class of arrangements as a “tacking” functionality when using boundary objects (Star 2010).

The forth anomaly is related to the things that do not fit in any category. Star detected the anomaly when she looked into a piece of reports and receipts from an expedition to Mojave, which was conducted to detect gopher behavior (Star 2010). When she opened the reports, a dead and totally desiccated bluebird felt out of the reports including a notice for a researcher with the question “what kind of bird could this be”. Star assumed that the biologist who found that bird could not categories it into the existing species. For the biologist, this bird was, therefore, meaningless without having a proper label or the records of its habits. However, the bird was placed into a file folder where it was kept. This experience showed that boundary objects could also relate to things that *do not fit into a standard or category*. The marginality or “otherness” of objects can still be a problem that are necessary to analyze (Star 2010).

The last and fifth anomaly derived from an ethnographic study of a biology community, which had the task to sequence the genome of a nematode. In this project, Star was involved to ensure that a virtual lab for data sharing would match the biologist’s research in order to create collaboration between the scientists (Star 2010). When she started her work, Star noticed that a sort of communication tangle appeared, because when she asked for an introduction to the computer system the anomalous answer was that they were just about to use it. The concealed messages that were sent from the developers of the system were not understood by their users and vice versa. As Gregory Bateson’s work suggests, this was called “double binds” (Star 2010). This anomaly showed that it was obvious that the user and the developers did not speak the same language. The conclusion is that if something is clear to someone, it can be a mystery to someone else. Star assumes that this was a problem of the infrastructure in which the heterogeneous team was working. She, therefore, designed a list with Karen Ruhleder to develop important characteristics for a reliable infrastructure (Star and Ruhleder 1996).

To summarize, boundary objects are an interesting starting point to describe collaboration between heterogeneous and conflicting actors, but the concept is complex and interpretatively open. As Star (2010) already indicates, various authors have used the concept and cast boundary objects in different forms that develop from the original concept (Star 2010). These different proposals span from textbook, to computer operating systems, to performances or different design aspects. For my study of boundary objects, I use Star and Griesemer's original concept in order to preserve the unique idea of boundary objects. It is, hence, central in my own approach in order to address my research question and examine knowledge integration. The interplay and new combination of these concepts applied to Smart Grid projects show the originality of the study. In the following chapter 3.5, the three outlined hypotheses are developed from the theoretical concept, which aim to reveal concrete answers to the research questions.

3.5. Hypotheses

Having reproduced the individual theoretical concepts that form the conceptual framework, it is now the turn to link them together, make new connections between them and use them coherently for decoding knowledge integration in Smart Grid projects. The hypotheses are, consequently, derived from the theoretical conceptual design, which together aim to better answer the research question of the thesis.

The first hypothesis connects the theory of heterogeneity in the different dimensions of proximities with the knowledge boundaries. The hypothesis assumes that heterogeneity between project partners is one of the main reasons, why misunderstandings and difficulties in the collaborative work arise. Hypothesis 1 (H1) assumes that**:** *The heterogeneity of project partners is a knowledge boundary that prevents the integration of knowledge in Smart Grid projects.* The hypothesis suggests that heterogeneity must be reduced in order to overcome knowledge boundaries and enable knowledge integration. Accordingly, it is presumed that the relationship between the two variables proximity and knowledge boundaries influences knowledge integration, which will be tested by the hypothesis.

The second hypothesis links the two concepts of interorganizational learning and knowledge bridging and aims to find out which processes are taking place for knowledge integration in Smart Grid projects. As shown in the literature review, it is not clear what exactly organizational learning and knowledge bridging is, nor how it takes place. Linking the two processes of interorganizational learning and knowledge bridging is intended to highlight the particularities and their distinctions. My own approach starts by investigating the actual processes of knowledge integration by finding out how deeply expertise from the different specialized project partners is integrated between the organizations. The hypothesis aims to provide information on whether and at what point partners learn in collaboration or whether they merely bridge they knowledge gaps. Hypothesis 2 (H2) stipulates: *The individual project partners do not need the expertise from all the other partners in the innovation cooperation. Therefore, knowledge bridging takes place in Smart Grid projects instead of real learning.* The hypothesis assumes that the expert knowledge is so complex and specific in Smart Grid projects that the project partners are not able to learn all expertise from the other members in the short time available to the particular projects. Aquiring knowledge from other project partners may not be necessary, if knowledge bridging proves to be a successful integrated knowledge practice. In this way, the project partner only need to fill the missing knowledge gap in order to develop innovation. By sharing only the knowledge that is absolutely required, partners remain within their individual area of expertise and thus to not have to undertake the learning of fields of knowledge.

Lastly, hypothesis 3 (H3) relates to the concept of boundary objects as a part of knowledge integration in innovative projects. The hypothesis aims to broaden the concept and ascertain its significance for Smart Grid projects. Essentially, the hypothesis aims to establish the influences and variables of boundary objects as a possible construct for the knowledge integration. The hypothesis seeks to trace the process of knowledge bridging and its influence for innovation development in heterogeneous collaborations. The hypothesis builds on the two other hypotheses and aims to find out 1) where in the integration of knowledge boundary objects occur, 2) which different forms boundary objects could take, 3) how they are capable of overcoming knowledge boundaries, and 4) how boundary objects are connected with knowledge bridging and interorganizational learning. The following H3 should be addressed: *Boundary objects serve as a heuristic tool, which allows the actors to overcome knowledge boundaries and to develop innovation without learning. Actors, therefore, do not strongly integrate external knowledge.* The boundary object is used to ensure that despite limited knowledge and little time, innovative solutions can be achieved. The hypothesis, therefore, assumes that boundary objects enable the actors to overcome knowledge boundaries.

The following chapter clarifies the methodological approach. For this purpose, the chapter provides a general overview of the case study approach, elaborates the tailored research design for this work and describes the process of its implementation.

4. The methodological design for disentangling knowledge integration in Smart Grid projects

This work aims to delineate new insights into the knowledge integration process in Smart Grid projects by combining different sociological concepts. In order to disentangle the knowledge integration process, this study addresses the research question: *How and to what extent do heterogeneous Smart Grid actors integrate specialized and distributed knowledge in order to develop innovation in Smart Grid projects?.* To explore this research question, a deeper understanding of the heterogeneous influences and underlying processes of knowledge integration is required.To this end, I follow a case study design in my dissertation as advocated by Yin (2018), as his approach to case study modeling is widely used and accepted,. In general, case studies investigate simultaneous events that take place in the real world, keeping in mind that the objects of analysis often melt with their environment and cannot be clearly separated from it (Yin 2013). According to Gerring (2004), case studies can be defined as an *"intensive study of a single unit for the purpose of understanding a larger class of (similar) units"*. At the same time, not all topics of the real (project) environment can be investigated as most of the objects of analysis are too complex to be presented in a holistic manner. Therefore, my own approach is based on the different theoretical concepts shaping the selection and collection of data used for the case study. This data is particularly important to ensure the quality of the study and gain valuable results that illuminate the actual knowledge integration process. The selected case study is considered to be representative and a proxy for other Smart Grid projects in order to draw general conclusions to knowledge integration in Smart Grid projects.

To provide a deeper insight into the methodological design of this study, chapter 4.1 describes the approach of qualitative research including the concerns and quality criteria. Chapter 4.2 provides the case study research design, explaining how the selection and assessment of the case study was undertaken and offers an overview of the sample, in this case the surveyed partners of a Smart Grid project. Chapter 4.3 covers the process of data acquisition and evaluation, paying particular attention to the design of the interview guideline, the process, the data evaluation and interpretation and limitations. After a brief summary in chapter 4.4, the subsequent operationalization in chapter 4.5 transforms the theoretical conception into empirically measurable characteristics. Based on this design, the empirical analysis is conducted in chapter 5.

4.1. Methodological view on case studies

Although mainly five different research methods exist in social science, such as experiments, surveys, histories, archival analysis and case studies, this dissertation uses a case study research design. Especially due to the complex and fluid character of the knowledge integration process, the case study research design enables an extensive comprehension into the routines and practices of knowledge integration in Smart Grid projects. A case study within a qualitative research design is, hence, used for answering the research question and illustrating the actual knowledge integration process in a Smart Grid project.

Yin (2018) defines case studies in a twofold way that evolved and expanded within six versions of his book “Case Study Research and Application”. The first part of the definition concerns the scope of case studies and assumes that case studies refer to a real phenomenon that includes contextual factors and conditions relevant to the particular case. In particular, they can be used when the phenomenon may not be clearly delimited by the context. The first part is also used as a rationale for the use of case studies, which will also be discussed later in this chapter (Yin 2018). In the second part of his twofold definition, Yin (2018) assumes that case studies can handle a lot more interest variables than data points and, therefore, take advantage from an earlier development of theoretical concepts, such as a theoretical design, the data collection or a guidance for the analysis. As a result, case studies depend on several sources of empirical evidence whereby the data is merging in a triangulated manner. The twofold definition covers the scope and characteristics of a case study and shows that case study research involves an all-encompassing mode of investigation (Yin 2018). In this vein, case studies have an individual design logic, a specific data acquisition technique and particular approaches for the data analysis (Yin 2018). Accordingly, case studies are more than just a data collection methodology or a design feature (Stoecker 1991); they are about understanding "the case" in terms of the kind of case and the functions in its actual contextual framework (Yin 2018). Many researchers characterize a case by a number of variables that could also be described as microelements, such as the demographic profile. Although variables are very important in the investigation, cases should not only be described by single variables, but should be observed in their holism and, thus, beyond a mere collection of microelements (Yin 2018).

The decision for the case study research design as a methodology is based on the following arguments. Starting with the nature of research questions, case studies are particularly suited to research questions that address “how” and “why”. As the study is dedicated to find out how exactly knowledge is integrated between heterogeneous actors in innovative Smart Grid projects, why knowledge boundaries develop in this process, as well as how boundary objects develop in this process, case studies fit the research question addressed. Since such questions are generally more explanatory, case studies, historical research, or an experiment is the preferred methodology in literature. Likewise, these questions are not concerned with frequencies or incidences, but with the tracking of operational processes over time. This process level can also be found in the investigation object of the dissertation. Especially the fluid character of the knowledge integration process, which cannot be examined without the context variables, is another indicator for a case study as a suitable approach (Langley 1999). Hence, knowledge integration comprises of complex interrelations between the project partners that have to be considered in their different external environmental factors. A quantitative analysis on a numerical basis would not be sufficient to take into account the complexity and the holistic nature of the investigated object. The decision against experiments or histories as a research method was based on the condition that there is no or little control over behavioral events. While histories are used when research is concerned with the "dead" past and thus, direct observation of the event is not possible or no relevant people are alive, in social or field experiment, scientists play a key role in treating whole groups of people in different ways. Experiments, therefore, require an investigator who can manipulate behavior directly, precisely and systematically, which is often done in a laboratory environment by focusing on one or two isolated variables. In this dissertation, neither experiments nor histories are appropriate methods because the Smart Grid project under study is a real event currently underway. Finally, the research examines a contemporary event. In this sense, case studies are preferred when the behaviors relevant to the research cannot be manipulated and the event is current. The contemporary phenomenon examines the object it in its realistic context (Yin 2018).

For the conduction of a case study research, Yin (2018) assumes that five components should be respected. These components range from the case study question, a proposition, the definition and bounding of the case, the logical connection between data and the propositions and finally the criteria for interpreting the data found (Yin 2018). The research question as the first component was already mentioned above. Although the case study questions provide a first indication of what is to be researched, “how” and “why” questions alone often do not get to the heart of what is to be investigated. Thus, only with the help of propositions, the case study user can head in an appropriate direction (Yin 2018). For this purpose, the dissertation defines three hypotheses in chapter 3.4, along which the case study is oriented. By way of example, a proposition can be seen in (H1), which assumes that the heterogeneity of actors leads to knowledge boundaries in Smart Grid projects. This proposal not only reflects an important theoretical question, such as whether heterogeneity in form of proximities influences knowledge integration, but also advises what exactly is being looked for and can direct the questions to that end. Without including such propositions, the risk could arise that unimportant details will be studied leading to a loss of focus (Yin 2018). The third component is the definition and bounding of a case. For defining the case, I have to find a suitable case to be investigated, which is often seen as a challenging part of case studies. While some researcher investigate individuals in the case study, other researchers use small groups, organizations, communities, projects, relationships, partnership or decisions as their object of case study investigation (Yin 2018). The definition of the case is especially important due to the fact that these events or processes, which have to be investigated, do not have a starting or end point and depend on the perspective of the actors and components involved in the process (Yin 2018). To counter this challenge, the bounding describes the lacing of the case study in terms of the rationale for why certain individuals from a group are selected for the study or in terms of setting temporal boundaries, such as the start and end of a case study design (Yin 2018). Hence, the bounding specifies the scope and tightens the frame of the case study investigation object. For this study, a clear definition was made for the case and for the bounding, given that a specific Smart Grid project should be investigated. In the project, one to two partners from each organization should at least be included in the case study in order to get a comprehensive picture of the knowledge integration process. While the interviews were conducted from halfway through to the end of the project, this allowed to portrait the entire project period. Thus, the project partners were already able to give a good assessment of the knowledge integration process throughout the project. Finally, the case study design is completed and anticipated by establishing the logical connection between the data to the hypotheses and by defining the criteria for interpreting the results (Yin 2018). These criteria for the measurability were later defined in chapter 4.5.

Looking deeper into the case study approach, Yin (2018) distinguishes between a single case study and a multiple cases study approach based on the purpose of the study. Hence, prior to data collection, a selection should be made to answer the research question. Whereas the single case study calls for intensive data collection in one case, the multiple case study examines many different cases. According to Yin (2018), the single case study is justified by specific circumstances to be investigated in the phenomena. First, the case pertains to a critical testing of the existing theory. From this point of view, the single case study is capable of making input to knowledge and theory formation by validating, questioning or expanding the theory. This applies to my dissertation in which knowledge integration is still undertheorized, although it is critical to project work. Secondly, the case of objective is an extreme or unusual case or, thirdly, it is a common case, which has a revelatory or longitudinal function (Yin 2018). This common case should grasp the situations and conditions of an ordinary event and is interested in breaking down social processes theoretically. Ordinary scenes are, thus, supposed to provide conclusions about existing theories and interconnections. In this dissertation, a project that represents an ordinary Smart Grid project is appropriate, which is very revelatory and can serve as a proxy for other Smart Grid projects. A single case study can also be justified if it is an instructive case. Therefore, a single case study should be used when a widespread phenomenon can be detected that has been inaccessible from a social science perspective. The single case study, therefore, has a revelatory character and provides information about previously hidden theoretical statements. A justification for a single case study is the longitudeness. Longitude cases are carried out at different time frames, enabling the research to look at conditions or processes that could change over time. Finally, single case studies have the advantage of a fast and intuitive adaptation of the data collection to new conditions and circumstances during the data analysis. This enables the finding of new, as well as appealing patterns. Such kind of adaptation is much more difficult with multiple case studies, since consistency between cases must be maintained. In my dissertation, a single case study was chosen here it is particularly capable of contributing to knowledge and theory formation by confirming, questioning or expanding the theory. Such a study may even help to reorient future investigations in an entire field. Based on the theory, three hypotheses were formulated for this research. Accordingly, the theory was used to define a clear set of circumstances under which its statements are assumed true.

Another distinction can be made as a single case study can include units of analysis or can be examined as a whole (Yin 2018). Based on these considerations, an embedded case study that includes several subunits for analyzing knowledge integration in a Smart Grid project is appropriate for my study. Although the Smart Grid project is considered as a whole, different relevant theories formed the subunits that were investigated within the project, such as proximities, knowledge bridging and interorganizational learning or the identification of boundary objects. Subunits, therefore, provide new glimpses into the single case study (Yin 2018)..

To sum up, the single case study is a valuable methodology for this study in order to constitute all dependencies and causalities between the project partners for integrating knowledge. This qualitative method can illuminate the underlying processes in order to gain a deeper understanding. Nevertheless, risks can occur during the application of a case study, such as concerns about the uniqueness or artifactual conditions adjacent to the case. These criticisms and its peculiarities in data collection will be discussed in the following chapter.

4.1.1. Concerns of a case study approach

The previous chapter already alluded to the fact that prejudices about case study research still exist. Accordingly, some researchers reject the methodology and prefer other quantitative or qualitative approaches. Although case studies are an effective research method for understanding real phenomena in their context, the most common criticism is usually the rigor of the methodology. This is often referred to the fact that researchers work too sloppily or do not follow systematic procedures (Yin 2018). From this angle, the concern exit that ambiguous evidence and subjective interpretation by the researcher can influence the direction of the results and conclusions of the study (Ruddin 2006). The subsequent chapter clarifies how exactly these concerns need to be addressed for this case study.

To begin with, a common concern relates to the confusion that often arises from lumping together different non-research case studies with the case study methodology in social science. First, there are pedagogical case studies that exist in different varieties and do not follow an explicit research purpose and method. These pedagogical cases, such as from business, law or medicine (Ellet 2007; Garvin 2003) are often mistaken and mixed with the social science case studies. Such teaching cases do not have to address conventional social science procedures. The same applies to case studies in the media or in "popular" literature, where the quality of case studies is equally questionable (Yin 2018). Case studies presented as a magazine article or as a video run the risk that scholars from non-social science fields may form an inappropriately view of case study research based on these case studies. Finally, social science case studies are also confused with case studies that appear as case records, such as medical records or other case files (Vertue 2011). For a proper methodologically well-founded justification, confusion with other non-research case studies must, therefore, be avoided.

A different concern refers to the generalizability of case studies, especially in the case of single case studies. Indeed, generalizations in the natural sciences rarely result from single experiments, since they are usually based on a large number of experiments reproduced the case under different circumstances (Yin 2018). Nevertheless, case studies can be generalized to the hypotheses developed from the theories and not to populations or universes (Yin 2018). The generalizability is, hence, limited only to the investigated object and its propositions in the case study that is illuminated under specific circumstance. Since my dissertation opted for the single case study approach, the case study serves as a proxy for other Smart Grid projects but is still linked to the specific conditions and circumstances of the case. The goal of a single case study is to find generalizations and to broaden theories in an analytical way, rather than to quantify statistical probabilities (Lipset, Trow, and Coleman 1956). Even if generalizations are assumed in a particular case, experimental research fluctuates or is revised over time and replaced by new approaches.

Another concern refers to the unmanageable level of effort meaning that case studies can possibly take too long for its completion because of a massive amount of data collected. The critics often assume that undecipherable documents develop through which the researchers can hardly penetrate (Yin 2018). Indeed, case studies can generate a lot of effort and time, but they do not have to. This mainly depends on what kind of data collection method is used in the case study. For instance, if ethnographies are used, the majority of case study take a lot more time as they consist of detailed observations and are dependent on a longer stay in the field (O'Reilly 2012). The same relates to participant observation that also require a high effort and time in the field (DeWalt and DeWalt 2011). Therefore, a data collection method should be used that allows to estimate the expenditure approximately. This is often a thin line between having not too overwhelming data and obtaining detailed information to be used for meaningful statements.

Lastly, case studies are criticized due to their poor comparability in contrast to other research methods. Particularly in the first decade of the 21st century, a devaluation of case studies was observed, as they have been deemed that they would not adequately answer the question of effectiveness (Yin 2018). 'Real experiments', such as randomized controlled trials (RCT) studies were often preferred here, as they primarily aimed at determining the effectiveness of different treatments or interventions (Jadad and Enkin 2007). Nonetheless, case studies cannot be replaced because they represent aspects that could not be represented in experiments. Having examined the different concerns to case studies, the explanations show that the method is not only well received, but there are also a lot of prejudices. Although most concerns can be pried open, it is important to figure out how to deal with these different concerns in my case study, which is outlined in the following chapter 4.1.2.

4.1.2. Quality criteria for the research design

In the light of the previous discussion, this chapter defines criteria to maintain the quality of my case study and avoid the concerns mentioned above. The research design should be conceived in such a way that a coherent set of statements can be derived from it. To deduce such valuable conclusions and ensure the quality of the research design, the case study should be evaluated using specific logical tests. Four tests are commonly used in social sciences: Construct validity, internal validity, external validity as well as reliability (Yin 2018).

Construct validity plays an important role in the data collection process. The aim is to identify correct operational measures for the concepts being studied. The test is, therefore, intended to counter the common criticism of case studies, which refers to the lack of an adequate operational set of measures, leading to a subjective judgment. In order to ensure construct validity in my case study, several sources that proof the findings are necessary as well as key informants, who revise the case study. Construct validity mainly plays a role in the phase of data collection and composition (Yin 2018).

Internal validity is important for explanatory or causal studies that look for causal connections, whose concerns usually relate to adverse effects (Yin 2018). Hence, it plays a major role when case study users try to explain interrelationships, e.g., how or why an event led to a specific other event. This could lead to the risk that a causal relationship between two events will be suspected without taking into account a third event involved. Another problem of internal validity within case study research is often the inference, e.g. if an event cannot be directly observed and yet an interference is drawn from it. Although the statement could be based on interviews and case study documents, some questions still remain, such as whether the statement is correct, whether all competing explanations and opportunities have been excluded, or whether the evidence is convergent (Yin 2018). Internal validity is in particular important in the phase of data analysis. For the sake of internal validity in my case study, Yin (2018) suggest to perform pattern matching, to build explanations, to use rival explanations, as well as to develop logic models.

In contrast, external validity refers to the generalizability of the findings of a case. Generalizability may already be determined by the form of the original research questions, which may foster or impede the search for generalizations within the study. In this sense, case studies should include an urgent "how" or "why" question. For instance, “what” questions that ask to document a specific situation can, therefore, make analytical generalization difficult.

Arguably, the research question should be clarified during the phase of research design. In order to create generalizability in my case study, first, a suitable research question had to be found and settled in the design phase and, second, an appropriate theory had to be identified for deriving hypotheses in a single-case study (Yin 2018).

Ultimately, reliability represents the final test for operating a case study. Reliability is essential to reduce errors in a case study and ensure that the results are robust. Yin (2018) assumes, that researchers who repeatedly perform a case study using the same methods and procedures as the researcher of the first case study should arrive at the same results. This should ensure a minimization of errors and biases in a case study. The reliability test, therefore, assumes that the re-examination of the same case should lead to the same results based on the assumption of the same methods (Yin 2018). For accomplishing reliability in my dissertation, it is important to document the procedure that I follow in my case study. This can be done by using a case study protocol or a case study database, ensuring that research is conducted as explicit as possible.

Concluding, chapter 4.1 provided the theoretical framework of case studies, highlighted their challenges and concerns, as well as presented possible strategies for handling them. The adherence to and application of these suggested quality criteria is critical to deriving valuable conclusions from my case study and, thus, obtaining relevant research findings. While the theoretical frame for my case study design was presented in this chapter, the next chapter 4.2 shows the empirical set-up by selecting and assessing case study and especially the persons interviewed.

4.2. Case study research design

For the development of the case study design, first, I needed to sharpen my theoretical approach to the point where it aligned with my research question and second, I looked at how the theoretical framework could be coupled with the case study approach by Yin (2018). The goal was thereby to empirically analyze knowledge integration in Smart Grid projects within the scope of a case study. As was made clear in the preceding discussion, despite its challenges, the single case study approach was deemed particularly appropriate for answering the research question.

Yin (2018) assumes that the case study research design is not a rigid process, but lives from feedback loops and constant adjustments to the theoretical framework and the case study set up. This leads not only to a sharpening of the research idea and its implementation, but also to the achievement of coherent and valuable research results. The detailed methodological preparatory work is, therefore, particular important at this point. The next two chapters will discuss the selection and assessment of the project as well as the choice of the interview partners to further demonstrate the research design for the case study.

4.2.1. Selection of the case study project

Since knowledge integration is a common but vital process that arguably takes place in every Smart Grid project, a single case study with in-depth interviews of experts operating within Smart Grid projects was chosen. The focus is, therefore, on the detailed and comprehensive analysis of one Smart Grid project rather than a broader analysis over several cases. Although the results of multiple case could have been replicated, it would not necessarily have been possible to go into the depth in each case for disentangling knowledge integration. Therefore, it was rather more important for me to interview all partners in a project to get an all-encompassing view into the project and to actually understand the underlying knowledge integration processes between the partners.

The Smart Grid project used for the case study was not chosen randomly, but was picked according to certain suitability criteria for my study. These criteria were particularly established on the basis of my theoretical approach and should enable the reflection of the proximities of actors, their learning and knowledge bridging process, as well as the investigation of boundary objects. Hence, the case study project seeks to capture how the partners actually interact, dependencies exist and consequently, how theoretical concepts can be investigated. The project has to ensure that the heterogeneous partners actually communicate and exchange knowledge in the project. For answering the research question, the aim of the case study project needs to be a common development of an innovative solution between heterogeneous actors in a Smart Grid project. With the preferred attributes of a case study project just outlined, this question should be able to be tested and empirically underpinned.

The chosen Smart Grid project is a European project from the Horizon 2020 program that aimed at the development of new ICT tools, such as a data exchange platform. The project partners all come from the energy sector, within which they can be distinguished between distribution system operators (DSO), transmission system operators (TSO) and research organizations. The duration of the project lasted three years, from 2017 to 2020. I began the interviews at the halfway point and conducted the last interview at the end of the project. This allowed the partners to look back and tell where and how they had integrated knowledge from various project partners. The assessment of the innovation development was only possible at the end of the project in terms of the outcome of it. Likewise, the project was particularly interesting as a case study from various more perspectives. First of all, the project had a medium to smaller project size with about 30 active project partners. This allowed all partners directly involved to be interviewed. The Smart Grid project aims at developing and designing new ICT techniques, processes and tools. These serve to create scalable and secure information systems and to establish data exchange between DSO and TSO. The ICT tools and techniques have taken the form of a common data exchange platform for DSOs, TSOs and other market players, involving the basic building blocks of scalability, security and interoperability..

The project involved partners from different countries and, thus, enabled an interesting geographical mix of project partners. In this sense, partners from Central, Western, Southern, Northern and Eastern Europe were involved, each bringing a different context in terms of energy markets, with some much more focused on the integration of renewable energies. This introduces how boundaries occur and reflects the different ideologies held by the participants regarding future energy systems. This balanced mix of nation-based organizations provides a comprehensive picture of the European situation with regard to the DSO, TSOs and research institutes in the energy system.

Valuable comprehensive insights into the project structure and processes were gained due to the proximity to the project itself and the partners. This proximity and the existing contact with the partners also made it comparatively easy to gain consent for the interviews. This allowed me to directly approach and contact the partners for the case study, who were eager to support my investigation. This ease in dealing with the partners and the openness and willingness of the partners gave me a privileged access to the case study project. Hence, I could gain insights into the development of the tasks, the project meetings, and I was able to look into various deliverables and other documents that were uploaded to the share point. Actually seeing the partners in action demonstrated the uniqueness of investigating this case study project, allowing for entirely new insights into their behavior of the partners in the project. All in all, an encompassing picture of the overall collaboration was enabled due to this project proximity. In addition to the formal interviews, I was able to conduct ad hoc “talk” with the partners and, thus, gain deeper perceptions into their work. These conversations were particularly relevant to supporting triangulation of data in order to achieve a holistic view of the knowledge integration processes. In a nutshell, I was able to benefit from insider information of the project.

To conclude, the project was selected as a case study as it particularly fit to illuminate knowledge integration between heterogeneous Smart Grid actors and promised to provide significant potential as well as extraordinary research access. In this regard, I was able to collect all relevant data outside and within the interviews. The next chapter provides a deeper understanding of sectors and regions of the partners and, therefore, continues from the whole project to the organizational level and the individual level of the interviewed partners.

4.2.2. Case study actors, their role and location in the energy sectors

The chosen Smart Grid project serves as an interesting case study for disentangling knowledge integration in Smart Grid projects. In order to examine more deeply the structure of the project, this section considers the organizations involved, including their inner structures and their external circumstances in which they operate. The case study project involves the three functional partners of the energy system, which are the DSOs, the TSOs and the research institutes. The main interest is to identify their function in the energy system and their fields of knowledge that are touched. In addition to the organizational structures, location specifics are described, offering a better understanding of the actors and their role in the case study project.

Since the entire case study is set in the energy sector, some special characteristics of the sector should be highlighted at this point. Although most of the European energy system is dominated by a few larger TSOs and DSOs with enormous market power, it is becoming apparent that market structures are increasingly increasingly broken up in the course of liberalization and deregulation and a heterogeneous actor landscape is emerging (Aichele and Doleski 2014). While the TSOs are responsible for the high-voltage (HV) transmission lines over long distances from generation to the DSO, the DSOs are responsible for the medium-voltage (MV) and low-voltage (LV) and in some cases high-voltage (HV) lines up to the consumer (Silva et al. 2021). However, as the influence of renewable energies is changing and decentralized energy is increasingly injected into the distribution grid, a higher need for coordination and exchange between DSO and TSO is required. Similarly, most actors of the energy sector operate at the international arena, e.g. in supply, trade as well as in project work (Fischer and Häckel 2014). Hence, DSOs and TSOs are particularly suitable for the investigation in the area of knowledge integration because not only do they play a central role in the energy system, but also operate on an international level, as well as face the challenges of the integration of renewable energies and the inclusion of new players. As DSOs and TSOs are one of the key actors in the energy system, the subject of investigation becomes even more relevant.

DSOs and TSOs are generally dominated by electrotechnical engineering knowledge due to the electrotechnical grid operation within the energy system but are increasingly acquiring knowledge in ICT through digitalization (Stefan 2019). DSOs and TSOs are typically very traditional and established groups that have been operating in the market for a long time and have, therefore, developed their market dominance over many years (Hirschl 2008). By contrast, the research institutes of the case study are not directly involved in the generation or operation of energy per se but have evolved to search for designs the energy system more efficient. The research institutes were mostly smaller to mid-sized companies that tend to be newer to the market relative to the DSOs and TSOs. By highlighting their relevance for the energy transition, research institutes have received high financial and political investments in the past years (Dorsman, Gök, and Karan 2014). The research institutes are based in the IT energy sector and, therefore, contribute to the new fields of knowledge in the high-technology sectors. Thus, they are characterized by incremental and radical innovation development (Mattes 2010; OECD 2007). The differentiation between DSO, TSO and research institutes reveals that different worlds meet here: Traditional DSOs and TSOs with established organizational structures, but often slower innovation cycles, as well as more recent emerging research institutes from the IT sector aiming to dissolve old structures of the energy system. Overall, it can be stated that the large IT focus of the project indicates a high-tech project. Especially in IT as a high tech sector, innovations and knowledge exchange are of high importance, which is why the project again seems extremely suitable for the case study.

First, three of 13 organizations, a DSO, a TSO and a research institute come from one country in *Eastern Europe*. The country has a very varied landscape with an alpine mountain region and valleys with many rivers. In recent years, the industrial sector of the country has been particularly responsible for increasing electricity consumption. The country has limited indigenous resource of fossil fuels and, therefore, imports natural gas. Renewable energies in the form of solar energy, geothermal, wind or biogas are, consequently, rather little used. Energy production is generally depending on the liberal market, only some ancillary services, which are important for the TSOs, are regulated. The TSO in the country is 100 % state owned and a public company. The TSO and the research institute are spatially close as their buildings are in the same city, while the DSO is located slightly outside from the city.

Four project partners are coming from a S*outhern European* country, a DSO, a TSO and two research institutes. The countries landscape is very mountainous, while the southern part of the country has many prairies. The climate is mostly dry and stable during summer as well as wet and volatile in winter times. In recent years, wind energy has become an increasingly important factor for the energy supply of the country, while photovoltaic electricity generation is surprisingly rather insignificant. The TSO, DSO and one of the research institute are spatially close as they are located in a common larger city. The TSO of the country is not completely state owned and foreign companies have shares in it. The other research institute is located in another city.

Two project partners, a DSO and a TSO come from two different *Western European* countries. Both countries have very diverse landscapes, ranging from flatlands to mountainous and riverine regions. Likewise, both countries have coastal regions. While one country mainly invests in renewable energies in the form of biomass, solar and wind energy, the other relies on offshore wind power and photovoltaics as renewable energies but also on the integration of nuclear power. While the TSO organization is an association, the DSO is a group dominating large districts for the distribution of energy in the country. Both organizations operate on an international level and are based in the respective capitals.

Two partners, one research institute as well as one TSO come from two different *Northern European* countries. While one country consists of lowlands with some mountainous regions, the other countries' landscape dominates of mountain ranges and barren plateaus. Both countries have a large coastal areas leading to a large investment in onshore and offshore wind resources, accounting for the largest share in renewable energies. While one of the countries still has fossil energies involved in the electricity mix, the other country has switched most of it to renewables involving wind and hydropower. The TSO is also state owned and the sole TSO in the country. Both, the TSO and the research institute are based in the capitals of their respective countries.

Two project partners come from the same *Central European* country. The country is divided into the plains region in the North and mountains area in the South. The country is located in a moderate climate zone with frequent changes in weather, which means that precipitation occurs throughout the year. The country is active in hard coal and lignite mining; the large lignite fields, but also iron ore deposits, the rock salt deposits and the potash fields. Both research institutes carry out application-oriented research and development work inICT. Both institutes are located in different smaller cities in the country.

The interview partners also had different positions in the case study project. From the project partners working in R&D, eight interviewees were research associates, three of them had a higher position as a senior researcher and a project leader as well as one interviewee was a professor. By looking at the positions in the economic enterprises, it became clear that six interviewees were project manager, four interviewees had a higher person as project leader, and one interviewee was the director of the strategic innovation department of the company.

The following table 2 summarizes the organizations of the project partners involved. In total, partners from seven different countries were interviewed. The interview abbreviation starts with the interview number, which has been marked with X in the table. Two research institutes were involved in each of two countries, which were also marked with numbers. This is followed by the function in the power system, whereby RD stands for research and development, DSO and TSO for the particular system operator. In two countries, two research institutes were involved in each case, which were also still marked with numbers. Finally, the countries are abbreviated as Central = C, West = W, South=S, East=E and North= N.

Table 2 Actors interviewed in the case study

Function in sector	Region Europe	Organization size in employees	Amount interview	Interviewees position	Organization's expertise	Interview abbreviation
R&D	Central Country 1	~ 250	3	1 sub-project leader ; 2 researcher	Computer sciences and standardization, architecture modeling	IX[1]_RD1_C1
R&D	Central Country 1	~242	3	1 sub-project leader; 2 researcher	Computer sciences	IX_RD2_C1
DSO	West Country 2	~ 152000	3	1 sub-project leader, 2 employees	Computer sciences; electrotechnical engineering	IX_DSO_W2
TSO	West Country 3	~200	2	2 higher positioned employees	Electrotechnical engineering	IX_TSO_W3
R&D	South Country 4	~50	2	1 project task-leader; 2 researcher	Electrotechnical engineering	IX_RD1_S4
TSO	South Country 4	~684	1	1 higher positioned employee	Electrotechnical engineering	IX_TSO_S4
DSO	South Country 4	~12000	3	1 higher positioned	Electrotechnical engineering	IX_DSO_S4

[1] X = Interview number

				employee; 2 project manager		
R&D	South Country 4	~1100	4	1 project manager; 3 researcher	Computer sciences; electrotechnical engineering	IX_RD2_S4
TSO	East Country 5	~550	2	1 department manager; 1 employee	Electrotechnical engineering; business administration	IX_TSO_E5
DSO	East Country 5	~273	2	2 Employees	Electrotechnical engineering, computer sciences;	IX_DSO_E5
R&D	East Country 5	~80	4	2 higher positioned researcher; 2 researchers	Electrotechnical engineering; computer sciences;	IX_RD_E5
R&D	North Country 6	~980	2	1 sub-project leader; 1 researcher	Computer sciences	IX_RD_N6
TSO	North Country 7	~1,500	1	Employee for expert panel	Computer sciences	IX_TSO_N7

4.3. Process of data acquisition and evaluation

While the previous chapter displayed the case study research design including the selection of the case study and the description of the involved case study actors, this chapter further elaborates on the process of data acquisition and evaluation. For answering the research question, I conducted 32 expert interviews with partners from the chosen case study Smart Grid project. These semi-structured interviews (Galletta 2013) based on an unstandardized interview guideline (Gläser and Laudel 2010; Lamnek 2016) enabled the project partners to speak freely about their experiences in the area of knowledge integration within collaboration. Their answers facilitated drawing conclusions about their earlier actions and enabled a reconstruction of former situations in the common project work. Representing a holistic account (Patton 1990: 388) of the study was of particular importance to me, as I spoke with all of the project's main partners. The interviews allowed me to add another piece of the puzzle each time in order to reach a holistic view of the research study. The following chapters provide further insights into the interview guideline and the actual data collection process.

4.3.1. Interview guideline and data collection process

The process of data acquisition and collection has been conducted by means of semi-structured interviews with an unstandardized guiding questionnaire (Galletta 2013; Gläser and Laudel 2010; Lamnek 2016). According to Galletta (2013), semi-structured interviews include open-ended as well as more theoretically oriented questions. The information needed for the creation of the questions mainly based on information through existing constructs of the theory as well as on the participant experiences. Guided expert interviews are unstandardized, which means that the questionnaire implies the detailed elaboration and formulation of questions as well as their precise determination of the sequence in the guideline, but still uses the principle of openness and allows a deviation from it (Gläser and Laudel 2010; Lamnek 2016). The unstandardized nature of the guiding questionnaire enables the building of a formal structure but allows to remain flexible and react spontaneously in the interview. Especially for the investigation of complex research objects, unstandardized interviews can adopt to the situations and course within the conduction of the interview (Lamnek 2016).

For my case study, the questions were modeled rather open-ended, but still understandable and close to the interviewees. This especially required sensitivity to choose questions as openly as possible in order to create space for the answers of the interviewees while still being able to draw conclusions for the theory. The individual questions were combined into super categoriesthat directly engaged in my theory (Galletta 2013). Given the abstract nature of the theoretical concepts, a simpler language was used here and the questions were more colloquial. Principally, the formulation of questions and their arrangement needed time, as each question should have carried a clear purpose for my research. With this in mind, trial and error methods were undertaken within the case study to make adjustments within the conduction of the case study (Galletta 2013). Finally, the thoughtfulness in designing the guiding questionnaire shows the significance for the exploration of the phenomenon under study.

My theoretical concept of knowledge integration has, therefore, given a rough scheme for the central topics to be covered and the sequence of questions in the interview guideline, which can be found in the annex of the dissertation. The core topics of heterogeneity, knowledge boundaries, interorganizational learning, knowledge bridging, and boundary objects provided an initial orientation, which had to be poured into appropriate questions. For a first overview of the interviewees, the questionnaire initially covered organizational and communication-related topics. Hence, questions regarding their position in the project, their tasks and their general communication in the project were asked at this point. This was necessary to find out with whom and how often communication took place, how tasks were distributed and what expertise existed in the project. Afterwards, the topic of heterogeneity was addressed by covering the questions of their differences and proximities in the project. To identify knowledge boundaries, challenges in the project work were asked, as well as how the interviewees handled them. To approach the topic of knowledge bridging and interorganizational learning in the project, questions have been developed regarding the knowledge that was needed for task development, sourcing new knowledge from partners and innovation development. In total, 19 questions were previously defined for the different core categories of the guideline. All these questions of the questionnaire can be found in the annex of the dissertation.

The interview partners did not receive the questionnaire beforehand and, thus, had to answer my questions spontaneously. This often led to a spiral in which one question was followed up by further questions (Patton 1987) and allowed to go even deeper into a topic. The interview guideline was, therefore, used flexibly to allow for specific topics to be explored in more depth, but still have assistance to help ensure that the most important topics and related questions were not forgotten and left out in the interview (Patton 1987). After the preparation of the questionnaire and some test runs, e.g. with regard to the time frame needed for the interviews, the process of conducting the interviews was started.

As many interviews as possible were conducted on site. For this purpose, project meetings were used, for example, where I was able to meet most of the project partners in person. In total, 19 interviews were conducted at project meetings, which took place every six months in one of the project partners' countries. Most of the interviews were prearranged. However, a small number of interviews occurred spontaneously. Before the interview started, rights were explained that the interview is voluntary, that the recording will be used anonymously, only kept for the research purpose and deleted afterwards. Talking to the interviewees face-to-face enabled me to build a comfortable and confidential atmosphere. Likewise, trust could be built up even faster, which was important to get the partners involved in the topic and talk freely, particularly for describing also difficult situations in the project. Five more interviews were also conducted during a conference stay. For these interviews, a location was sought where it was possible to talk undisturbed. Due to the Corona pandemic, the remaining eight interviews took place via online video conference room. However, since I already knew the interviewees from previous meetings, the online interview did not result in any significant changes to the face-to-face interviews. The interviews were carried out between the middle to the end of the project, so that the project partners already knew each other well and a basis of trust could be built up between them. Therefore, the initial sniffing of the interview partner was not necessary to the extent that it might have been necessary with foreign interview partners. Due to the easy access to the partners, I was able to discuss my research topic with the research partners beforehand and was, thus, able to enter directly into the topic with the specific questions without having to explain my research relevance and topic again. Many of the interview partners were able to answer my questions relatively precisely, why the interviews lasted from about 30 minutes to 75 minutes. Most of the interviews were conducted in English, which was not the native language of most interviewees. This has led the project partners to reflect on their wording and phrasing. During the interviews, reflections and demands of the interviewee statements were made in order to ensure that the interpretation was valid and accurate (Lamnek 2016). I also took many notes, which I completed and revised on the same day. I followed the 24-hour rule so that the interviews would not be forgotten (Eisenhardt 1989). As the transcript alone cannot represent the non-verbal communication or how something was said, the notes were used to check the transcript and possibly add gestures or facial expressions. After conducting the interviews and collecting all necessary data, it was necessary to evaluate and interpret them, which will be explained in more detail in the next chapter.

4.3.2. Data evaluation and interpretation

The difference between natural sciences and social sciences is the "explaining" of the nature and the “understanding” the social behaviors (Rohracher 1976). While quantitative science seeks to derive more general principles or law-like principles, the qualitative science strives to understand why groups or individuals act in a specific way. According to Mayring (2015), the qualitative understanding approach attempts not only to analyze objects in its specific contexts or processes, but to relive it and to emphasize with the object of investigation, experience and delve deeper in its understanding. To gain such an understanding of the case study object, the evaluation and interpretation of the interviews is crucial for the empirical part of the dissertation. The interviews, therefore, build the data basis for the subsequent evaluation.

For the data analysis of the interviews a “content structuring content analysis” according to Kuckartz was chosen (Kuckartz and Rädiker 2022). Kuckartz's method provides a procedure for category formation, coding and analyzing the data from the interviews. For this purpose, it is important that the data material is adapted to the concrete object of research. The transcribed interviews serve as the basis for the content structuring content analysis. To ensure the anonymity of the interviewees, I gave the interviews numbers and obscured names of persons and organizations (Mayer 2009). For the content structuring content analysis, different phases were defined for the process of category formation and coding, which are defined in the following (Kuckartz and Rädiker 2022).

To begin with, the first phase of "initiating text work, memos and case summaries" is about carefully reading the text sections of the interview and marking particularly important text passages. In this phase, special features of the text may already be noticed and initial ideas for evaluation may emerge (Kuckartz and Rädiker 2022). In the second phase, “development of main categories,” main categories are generated from the data. These main categories do not emerge completely independently, but are derived from the research questions in particular. The theoretical basis of this study guided this process of category formation in order to be able to finally draw conclusions about the theory again (Yin 2018). In this sense, I searched the interviews for the same characteristics, patterns and similarities, but also for differences and contradictions between the interview partners in order to build main categories. However, categories can never be strictly divided inductively or deductively (Kuckartz and Rädiker 2022). The third phase “coding data with main category” begins with the first coding process in which the data is assigned to the main categories. After this initial coding, phase 4 "formation of inductive sub-categories" further differentiated the assignment to the main categories and subdivided the coding into subcategories. The subcategories, hence, derive from the inductive category formation of the material. The next phase 5 “coding data with subcategories,” the second coding process begins, which requires a re-run of the encoded material. In this coding, I took special care to ensure a comprehensive and accurate understanding of the interview statements in order to properly reflect the context and background information. Phase 6 uses the codes from the main and subcategories for "simple and complex analysis". Various forms of analysis can be used here. For the analysis, it is important to retain the originality of the interviewee’s verbal contributions in order to interpret the interview results as objectively as possible and to position the statements into the right context. In order to interpret the coded text, important quotations and findings from the interviews were highlighted and systematized according to the respective important dimensions of the analysis. My analysis was conducted “category-based along the main categories” which aims to find out what has been said about a certain category. The analysis was conducted along the categories related to my conceptual theoretical approach. In the final phase 7, results are written down and procedures are documented. In order to write down the analysis results, I used my own concept and the corresponding hypotheses.

In order not to make the description of the results seem too lengthy, I have gone into the hypotheses after the respective descriptive empirical part. For example, H1, which is based on heterogeneity and knowledge boundaries, was answered after the elaboration of the statements to these topics. The statements and their assignment to the categories, therefore, provided the basis for the interpretation. In addition to the interview statements, other methods for data collection are also included so that an overall picture can emerge. I also found this more conducive for the reading flow than the variant that the hypotheses are all answered at the end. Overall interpretations on the process of knowledge integration take place in the discussion chapter, where a new perspective on the approach is also thrown.

The evaluation was software-based with the tool MAXQDA, which is widely used for qualitative data analysis. The software tool supports in speeding up the traditionally lengthy process of evaluation but is arguably not only more timesaving, but also more objective. It also facilitates to form a scheme for the categories and enables a clear presentation of the codes and sub-codes, connecting the different interviews in one file. My code system and the code trees for the empirical investigation can be found in the annex of the dissertation. The interviews were also supplemented by additional subsequent discussions, which took place in person or through inquiries in telephone conferences. The data from these later inquiries was also integrated into the interviews and allowed for a further review of the results. All in all, this allowed an iterative procedure between the theoretical and empirical parts of the work (Glaser and Strauss 1967). Likewise for the evaluation and for the preparation of the interviews company documents, project documents, as well as information from articles or web pages were consulted in order to deal with hard facts within the interview.

4.3.3. Managing sample limitations in a single case study

Despite trying to overcome all methodological challenges in my research, this dissertation uses a single case study of a Smart Grid project as a case study object and is, therefore, limited to 32 interviews. This dissertation does not claim to make a generalizable statement that can be universally applied to any social order, nor is the empirical data here strictly replicable. . Especially more fact or evidence-based natural sciences aim to verify their results in repeated experiments. However, in my research no hard statement are intended that consider something to be right or wrong, but different statements are collected and interpreted related to this Smart Grid prototype project. Hence, the empirical model is a sample project to test the concept of knowledge integration and to investigate its underlying processes. Therefore, no judgement is intended with the study but it aims to show a picture of knowledge integration in innovative project work. As already mentioned, it is more about getting deep insights into the project, which can be better guaranteed with a single case study. The single case study is characterized in particular by exclusive access to high-ranking experts from powerful energy companies and, therefore, offers the opportunity to gain comprehensive insights into a Smart Grid project. Generalizability, then, relates to the similarities of the interview statements of this particular project. All in all, the wide-ranging view of such a project enhances the relevance of the case study - for other projects as well.

4.4. Brief methodological summary for disentangling knowledge integration

In a nutshell, for the methodological implementation of this research, a single case study is conducted according to Yin (2018). The case study takes as its research object a Smart Grid project involving DSOs, TSOs and research partners. These partners are not only different in terms of functionalities in the energy system, but are also geographically very distributed in Europe. For data collection, expert interviews were conducted (Gläser and Laudel 2010), using an unstandardized guideline (Lamnek 2016). Overall, the difficulty is that in the interviews individuals are asked about the knowledge integration processes, but the study of knowledge integration takes place at the interorganizational level. Therefore, I aggregate the individuals who belong to an organization. I assume that the individual interviewees act as representatives of this organization, and therefore, in a figurative sense, also bear the characteristics of the organizations. Based on that, the data analysis is conducted using category formations and various coding stages (Kuckartz and Rädiker 2022). Finall, these are interpreted along the hypotheses and overall conclusions for knowledge integration are derived (Lamnek 2016). The next chapter considers the measurability of the study, building the bridge between the theoretical concept and its empirical implementation in the case study.

4.5. Measurability of the own concept

The operationalization in this chapter aims to build a relationship between the theoretical constructed concept including its terminology and the observable facts generated from the empirical data. The aim is to make the observation in the case study measurable on the basis of selected criteria. In this sense, the meaning of the terms is examined beginning with the defined indicators, which are described in a uniform and precise manner. The operationalization is especially necessary for this study because theoretical terms can often be interpreted ambiguously. Therefore, it should be clarified in advance what meaning they have in my case study. An indicator is used for the measurement of the latent variables. For the measurability of my case study, the quality criteria objectivity, reliability and validity are used, which should ensure a good and exact examination. Overall, it can be seen that there are several ways to operationalize certain terms, since they contain many different properties, not all of which can and should typically be tested. My own approach merged the different sociological concepts described in chapter 3. These build the basis for the operationalization and the derivation of criteria for the theoretical terms of the case study. The following figure 5 shows the indicators constructed to interrogate the interrelationship between heterogeneity and knowledge boundaries. It shows what is meant by the different variables and provides an approach on how the theoretical concepts will be measured in my study. The bullet points indicate what is meant by the different variables and provide an approach on how the theoretical concepts can be made measurable in my study. While heterogeneity is represented using the different proximity levels, knowledge boundaries are examined using the syntactic, semantic, and pragmatic levels.

<table>
<tr><th colspan="4">Indicators first research sub-question</th></tr>
<tr><th colspan="2">Heterogeneity</th><th colspan="2">Knowledge boundaries</th></tr>
<tr><td>Organizational</td><td>• Organizational size
• Formality
• Hierarchy, control & decision-making
• Autonomy & flexibility</td><td>Syntactic</td><td>• Mother tongues
• Technical terminology
• Data bases</td></tr>
<tr><td>Institutional</td><td>• Law systems & regulation
• Working method & processes
• Institutional conditions
• Work culture & ethical background</td><td>Semantic</td><td>• Interpretation of technical terms
• Technical depths
• Processing and understanding of information</td></tr>
<tr><td>Cognitive</td><td>• Absorptive absorption & externalization
• Knowledge fields
• Personal positions</td><td rowspan="3">Pragmatic</td><td rowspan="3">• Different energy infrastructures and architecture
• Political and legal regulations
• Hierarchies, bureaucracy and organizational boundaries
• Project objectives
• Working practices and habits
• Power relations
• Confidentiality and feasibility of data sharing
• Interpersonal boundaries & communication</td></tr>
<tr><td>Social</td><td>• Social bond
• Communication
• Trust and friendship
• Reliability & commitment</td></tr>
<tr><td>Geographical</td><td>• Physical meetings & face-to-face communication
• Intracountry communication
• Regional influence</td></tr>
</table>

Figure 5 Indicators for first research sub-question

Following figure 6 provides an overview on the indicators that are used for answering the second research sub-question. Both analyses examine the knowledge type, the process, the influences and requirements, the usage and the outcome according to the stated variable.

Indicators second research sub-question			
Interorganizational Learning		Knowledge Bridging	
Knowledge type	• Tacit knowledge • Explicit knowledge	Knowledge type	• Tacit knowledge • Explicit knowledge
Learning process	• Socialization • Externalization • Internalization • Combination	Mechanism and process	• Modularization • Knowledge storing in artefacts • Localization of knowledge • Prototype knowledge integration
Influences/ Requirements	• Trust & confidentiality • Power & competition	Influences/ Requirements	• Trust & confidentiality • Power & competition
Reasons for usage in collaborations	• Evolved in environmental transformation of organization • Rethinking of organizational forms	Reasons for usage in collaborations	• Scarce resources and time • Flexible and dynamic handling • Filling the knowledge gap is sufficient for collaborations
Common knowledge base	• Local entities • Repository for assembling the knowledge • Consists of a common semantic	Boundary objects	• Located and adapted in different social worlds • Fragile consensus • Interpretive flexibility

Figure 6 Indicators for second research sub-question

From the derivation of these variables, codes were created based on the particular variables that were derived during operationalization to each theoretical concept. Therefore, a rough code tree was first created. With the review of the interviews and the actual coding, this code tree was revised and constantly adjusted. Slight deviations to the original operationalization, therefore, occurred during the empirical work. The code trees and an overview table including the codes can be found in the appendix.

5. Empirical analysis

The theoretical foundation showed that knowledge integration is not only complex and fuzzy, but also undertheorized. Various influences, therefore, do not allow a concrete picture to be derived for knowledge integration in Smart Grid projects. Especially since the energy system is facing an enormous transformation and new actors are entering the market, new knowledge constellations are to be expected. An empirical investigation of knowledge integration in Smart Grid projects is, therefore, indispensable. The framework for the empirical investigation starts with the particularities of Smart Grid projects. This is followed by an empirical analysis of the concepts of proximities and knowledge boundaries, which are linked for discussing the first hypothesis. Further on, the concepts of interorganizational learning and knowledge bridging are empirically examined and analyzed in terms of the second hypothesis. Finally, using innovation development as the site for investigation, the concept of boundary objects is empirically reviewed and the data used to explore the third hypothesis. The results of chapter 6 provide the basis for the discussion within chapter 7. Using the descriptive interview results in conjunction with the findings of the hypothesis testing, the knowledge integration process is uncovered, a new perspective on knowledge integration is drawn, as well as implications for future Smart Grid projects are presented.

5.1. Specifications of the Smart Grid project

As a starting point for the empirical findings of this dissertation, the context conditions of collaboration in Smart Grid projects are provided at this point. Consequently, my research analyzes the specific characteristics of the case study as a Smart Grid innovation project that needs to be considered in the process of knowledge integration. This chapter takes a closer look at the Smart Grid context and its changes in terms of networks, collaboration, standardization and increasing information exchange. Building on this, the project structure and tasks, the actor constellation and expertise, as well as the general communication culture in the project are presented in order to gain a more detailed insight into the background of the case study project.

5.1.1. Smart Grid context

Smart Grid projects are designed to analyze new innovative solutions and business models for a rapidly changing energy system, change that is triggered by the process of energy transition. This change not only affects networks, as new distributed resources are increasingly connected to the grids, but also leads to the need for new flexibilities. The interviews revealed that DSOs and TSOs are particularly affected by these changes and need to coordinate much more with each other in order to tackle the evolving challenges. As more distributed energy resources are connected to the DSOs, electricity generation is shifting to the distribution system operators' territory and is no longer generated only by larger power plants connected to the TSOs. For this new DSO-TSO coordination, new tools are necessary, which are developed within the Smart Grid projects. This specific need for new technical coordination mechanisms was strongly emphasized in many of the interviews conducted by DSOs, TSOs and research staff.

> *Nowadays, there is a changing paradigm and a changing environment in the distribution networks because there are more and more distributed energy resources, such as wind parks connected to the distribution grids and because of that there is a need of coordination with the upstream operator that is the transmission system operator. Nowadays, the distribution system operators need to have a coordination with the transmission ones, since in the past there was not this need because the power flow was unidirectional. There was a lack of tools, which support this cooperation. The tool that I developed within the project was specific on this topic. So basically, it designed the maximum and the minimum limits of power flow that could be exchanged between the transmission networks and the distribution networks […] Flexibility can be of several types from curtailment of wind power, mobilization of flexibility provided by energy consumers, on-load changes, energy consistence and so on. (I31_RD2_S4)*

Likewise, the interviewees emphasized that the energy industry suffers from very old structures, as the networks and organizations have hardly changed over decades. My empirical data showed that the project partners are challenged to rethink their organizational structures because the demands of the energy transition are growing rapidly and the structures no longer fit their purpose. The DSOs and TSOs in my case study have not only grown historically, but have long held a position of power through their control of the grids and, therefore, have had comparatively little pressure to implement technological innovation rapidly. A DSO partner from the Southern European country described that not only are new flexible and agile concepts increasingly necessary, but also new requirements must be placed on the IT architecture within and between organizations *(e.g. I29_DSO_S4)*.

As the energy industry is changing, the interviewees stated that new types of data are needed. Against this backdrop, ICT is seen by the interviewees as an enabler for increasing data exchange and knowledge sharing. For example, it is used for forecasting future challenges in the grid, for activating flexibilities or validating new markets. A research project partner from the Eastern European country considered ICT as a key technology, which is one of the most important resources to share information in the future energy system *(I1_RD_E5)*. However, my empirical data showed that knowledge from ICT cannot be built up in one fell swoop, but must grow and be constantly adapted over a period of years. This suggests that new data exchange processes are not fully established and, as *(I29_DSO_S4)* states, Smart Grid project partners must be prepared for the new Smart Grid requirements and cannot expect to catch up with the knowledge growth and exchange on an ad hoc basis.

> *The most important thing is to know how to operate a distribution network and have the right mind-set to see how to improve it, like by changing information with the TSO. So, it is about where we can improve it and what do we need for the future. Because the networks that we are operating now are not the networks that we will have in 10 years from now. It will be much different, especially if the electrotechnical vehicles will live up to the promise of being even more of an option regarding mobility. The DSO and the TSO think that we will need to have more interaction of information and this information will be crucial for the DSO side. That's my opinion. We need to use that information, so that we can forecast problems, activate flexibilities or validate markets. If we don't have some upstream information, we won't be able to do that officially. Also from the TSO point of view, as generation is being co-simultaneously connected to the distribution side; they will need more information to maintain systems stability, balancing and all these things. (I4_DSO_S4)*

An interviewee from a Northern European TSO explained that all project partners have to slowly adapt to the new project conditions in Smart Grid projects and catch up with new ICT knowledge. However, they must also recognize that the rigid structures of DSOs and TSOs cannot be dissolved all at once *(I9_TSO_N7)*. The project shows how rapidly and comprehensively this change is perceived by the partners. In particular, project partners are called upon to face new challenges and to build a common understanding of certain interrelationships in the energy system. The interview data indicated that, in this sense, DSOs and TSOs would have to deal with new issues, such as the dealing with the observability area. Both should develop a common understanding to clarify future tasks in the area of observability, but also in relation to other ICT matters. The interviews show that this knowledge cannot be built up in one year, but must grow over time. Therefore, one interviewee from a Central European R&D institute concluded that organizational actors should prepare for the new requirements, as the organization cannot catch up with the knowledge on an ad hoc basis *(I22_RD1_C1)*.

> *I think some of the challenges are how to come up in a way that it will work, like adapting to new challenges; because as you getting new production and network changes, the challenge will change […] For instance, this will be clear on what is the observability area […]. And to help you do that, you need to have more IT systems. I mean, another thing is that we have people, who have been working a long time and they are in retirement now. They have understood that this [energy system] was built from the 70s. Then, you cannot say after one year of training that you now have all that experience. So, what we are trying to do now is to find out how we can build that experience that is needed for the IT system (I9_TSO_N7)*

The interviews also exposed that new flexibilities and distributed resources are increasingly bringing new actors with different business models to the market. Smart Grid project connect these new stakeholders, which often involve a substantial flow of information and communication between them in an international arena. However, the exchange of information and data is not self-evident and standards must be established to achieve an interoperable information exchange. As energy systems evolve, standards are, hence, needed throughout the system, especially for designing interoperable tools and compliant services to different organizations *(I14_RD2_S4)*. Synergy effects are assumed by *(I19_TSO_E5)*, e.g. when project members make progress in standardization and this progress spreads to other members and states. Accordingly, research in one countries could have positive effects for other countries in the EU. However, not all possible scenarios created in the European projects, can actually be developed. Thus, a good selection of new business scenarios that show potential for future data exchange in the real environment should be considered for development *(I27_DSO_W2)*. Summing up, the standardization process to ensure interoperability continues, resulting in new standards being developed and existing ones revised.

> *I would stress the point of standards, which have developed here. Once we achieve some progress in one of our member states, this progress can be easily transferred and prolonged into other areas. This is the big advantage of these standardized solutions for data exchange. But my concern is always that the protocols have to reflect the real business environment and we cannot develop everything in advance. We have to see what is coming. We have to wait for the real services. Once we see where is the predominant area of services, which will be important in the future, we might even need to further enhance data exchange standards and protocols in those areas. This parallel development of data exchanges standards and services has to go on all the time. We must not oversleep these interactions, as there is no finished work. So, we are just making progress. We are still quite far away from that. (I19_TSO_E5)*

This image underlines the main idea of standardization, that is, to connect all technical elements in the Smart Grid. This plug-and-play phenomenon suggests a seamless connection between two or more different systems. Interestingly, some interviewees stated that the standards are still not yet sufficiently implemented and used today, as other individual solutions are still being deployed, for example, by partners from the Southern European country. As *(I31_RD2_S4)* explained this change takes time in order to convert the old systems and introduce the standards across organizations.

> *[…] The problem is first, that this did not happened in the past and even nowadays, many of the operators still do not use these standards. And if you have, for example, the demonstration of a year and a half, you need at least half a year to adapt your tool in the way that it is possible to provide information to the operators. Nowadays, we need to adapt […]. The perfect world would be, if we go to one place or another, you simply plug and play your tool and everything works. I understand, of course, that the operators have internal systems that were born 40 years ago. So, it is difficult for them to adapt, but in my perspective, we lost a lot of time doing this. Lot of that could be saved, if we had those standards working properly." (I31_RD2_S4)*

Summing up, Smart Grid projects are seen as a starting point for developing new standards in order to increase information exchange in the energy system. Smart Grid projects, thus, aim to share information that was previously only used within their own organization. This was summed up well by a Southern European DSO partner, who described that information, such as on forecasts or real-time data, is becoming increasingly important and essential for coordination between DSOs and TSOs *(I4_DSO_S4).*

5.1.2. Project structure, tasks and project-related challenges

The Smart Grid project was structured in five work packages (WPs). In the first two work packages, the requirements engineering tasks focused on what the project partners expect from a mutual exchange of data and information on a common platform and how this exchange could be designed. For this purpose, individual use cases were defined by the partners, which were located in different areas and mapped in particular future scenarios. The first work package mainly focused on the development of use cases concerning DSO and TSO interactions. In addition, the requirements for information exchange, such as network data models and profiles for the testing of the use cases were defined in the first two work packages as stated by *(I6_RD2_C1)*.

> *In WP1, we were involved in two tasks. In these tasks, we had to check the data model and we had to verify if the data model cover all information that should be exchanged in the use cases defined in WP1. This means that we looked at the data model in detail, checked whether the data could be covered by the information and if not, we considered which classes and attributes should be added to the data model (I6_RD2_C1)*

The interviews revealed that use cases related to DSO to market interaction, services,as well as roles and rights to access the data exchange platform were developed, as well as the technology readiness was assessed. Finally, the overall architecture including exchange processes and use cases was visualized in Smart Grid Architecture Model (SGAM). Thus, many different partners had to work closely together to develop the use cases, as the systems and new interactions of the DSOs and TSOs had to be described in detail. The IT architects in the project, ultimately, had to model these systems in a Smart Grid architecture model *(I22_RD1_C1).*

> *But from what I've done, I would say that my tasks tend to be in the field of Smart Grid architecture modeling with SGAM and the use case methodology. I would say that I have the role of architecture development, modeling and assessment in the project. (I22_RD1_C1)*

By elaborating the use cases within WP1 and WP2, the project partners had to familiarize themselves with different themes of the Smart Grid. One R&D research partner from Southern Europe explained that use cases were developed in the area of short circuit operation, generation forecasting, or fault locations for which the partner-needed knowledge of how to protect systems and what type of data needs to be exchanged within the use cases *(I11_RD1_S4)*. Although some experts for requirements engineering in IT system were involved in the projects, all partners worked together on these tasks in the project, even the industry partners who were mainly responsible for the later implementation in the demonstrations. Hence, the expertise of DSOs and TSOs partners was mainly needed for the description of their systems in the requirements engineering part. Here, the interchange between DSO and TSO was already important in order to jointly create Smart Grid scenarios *(I12_TSO_S4)*.

The requirements engineering part in WP1 and WP2 and the demonstrations developed in WP4 enabled the merging of the different results in the phase of WP3, which aimed at the development of a common platform design. For this purpose, the interviewees explained that new data access and resources in the energy system were described. Subsequently, the use cases were defined with regard to the levels of portal access, as well as existing platforms were examined with regard to their extensibility. One TSO partner from a Western European country explained that specific TSO data exchange platforms were taken into consideration. These already involve information from the TSOs about electricity generation, load, balancing, outages, congestion management, system operation as well as transmission in order to facilitate transparency in the market *(I8_TSO_W3)*.

WP4 used the identified requirements to conduct demonstration on data exchanges between DSOs and TSOs. According to the interviewees, one demonstration took place with the organizations from the Southern European country, another between organizations from the Eastern European country and one with the partners from the Western European country. Within WP4, information exchange was tested between DSO and TSO with the open standard Common Information Model (CIM) and Common Grid Model Exchange Specification (CGMES). Both standards are used for the management of IT systems and aim to ensure data exchange in distributed applications *(I1_RD_E5)*.

Lastly, the interviews showed that there were various coordination and management tasks in the project. A distinction can be made between the coordination tasks within the individual organizations that participated in the project and between the different partner organizations. Regarding the coordination between the project partners, one research organization was in charge of ensuring that the various work package tasks were merged into deliverables and submitted on time. WP3 ensured that the partners pursued the same goal and that the results developed in all deliverables were harmonized with each other. The coordination task was particularly in finding one equilibrium between the two worlds of DSOs and TSOs, which was seen as one of the most interesting parts of the project *(I2_DSO_W2)*. For example, interviewee *(I28_RD_N6)* stated:

My tasks were mainly in the work package 3. They were actually related to making sure that there is a harmonization between the outputs from different partners [...] I was overlooking what other project partners were doing and I was making sure that the outputs were corresponding to, first of all, the work package plan and, also that they were harmonized, meaning that they actually were coherent with each other and they were achieving the final goal of the project. (I28_RD_N6)

In addition to the coordination of cross-tasks, the interviews revealed that coordination within the organizations was necessary in the Smart Grid project. My interview data showed that, for this purpose, each organizations had a team leader, who had the role of coordinating the activities at the top level and assigning tasks to the respective project members in the organization. As interviewee *(I4_DSO_S5)* stated, this person was also often more responsible for ensuring that the project accurately represented the organization's overall position and that the organization's goals were unified with the project goals.

I was more doing the collaboration inside [TSO W3] and I was making sure that we have the groups, that give their expert opinion and that we take on board the position of [TSO_W3], when going through the work in the project. And [name] was more the interface and leader in terms of collaborating with partners. (I26_TSO_W3)

In addition to the team leader within the organization, who was often responsible for external communication, most organizations also employed an expert with additional technical or scientific know-how in a particular area. However, the number of active project participants per organization was limited to between two and six working regularly on project tasks (I1_RD_E5). Particularly in the case of industrial partners, such as DSOs and TSOs, employees often have several projects going on at the same time, which means that EU projects are often added on top for them. This was summarized by the interviewee *(I29_DSO_S4)* as follows:

Our role is to engage all the people from other departments to participate in this type of project. And it's not easy, because typically in our model in [DSO_S4], we have a very small team for the European projects. And we need to engage the people from other departments to participate in this project. So they have additional work, because they have their daily tasks and need to participate in the European projects. I would say that one of the responsibility is to engage people from other departments and to coordinate their resources. Besides the coordination and management of that work package or task that we are leading, it is necessary to interact with other European partners and also to manage the work to achieve the goals that are proposed at the beginning of the project. (I29_DSO_S4)

The interviews revealed many peculiarities in EU projects that led to collaborative work being challenging in general. First, the number of deliverables and their scope were considered by the intervieweed to be quite high and extensive. In addition, the deliverables had to be written at very regular intervals, which led to high content expectations regarding implementations and developments in the project. Moreover, interviewee *(I30_RD2_C1)* stated that appropriate contributions were needed from all partners in time, which sometimes led to "hassles". Equally, the intellectual engagement to a deeper understanding of the deliverables, consideration of the project goals and avoidance of redundancies placed a high demand on the project partners *(I17_RD_E5)*.

> *Challenges are about the time and it is a really comprehensive project. And we also have many deliverables and many meetings. So the number of deliverables and the number of meetings is above the average for the project. And these deliverables are quite large, especially work package 1. This is also very challenging. (I13_RD_E5)*

In order to verify that the common goals have been pursued, the project partners were required to conduct reviews of the deliverables in order to comment on the content and provide feedback. This review was also conducted by non-experts. The interviews showed that for the development of the deliverables intensive collaboration was needed. Therefore, coordination between the actors was considered as very important in the interviews. In this sense, *(I23_RD1_C1)* stated:

> *[…] And apart from that, getting the tight deadlines and providing the deliverables [is difficult]. You also work in a distributed manner; you have to handle, so that everyone goes along with the project aims. You have to plan the reviews in terms of time. I think these are the big challenges in an EU project. (I23_RD1_C1)*

As the previous statements revealed, high coordination between the project partners was necessary. This resulted not only from the open description of the project objectives, but also from the geographical distance and the high proportion of virtual communication between the partners. The interviewees described that the development of a common project vision and story that runs through each task is critical to EU projects. However, the realization was all the more challenging, as it required a lot of time and communication effort. This was summarized by *(I14_RD2_E5)* as follows:

> *[…] The project is not really clear in some aspects and some goals that we want to achieve. So when you read the tasks, it is very broad and it is very difficult to understand the comprehensive objective. It has not been precise in the description of the action and the tasks […] what the overall objective is. Sometime it leads to the partners are not being so coordinated. It can also be a problem, if you don't see how you contribute for instance for other work packages and just focus on the job at hand. And then people are telling in other work packages that they don't really know how to use this information to contribute ahead. I guess there is no common objective that everyone is seeing. […] I had the opportunity to talk to [RD_N6] and they said that we need to improve the storyline of the project to get everyone on board. They mainly said that it was their job to create the story and they would be working on it as the project leaders. (I14_RD2_E5)*

Another challenge was seen in the general access to resources within the project. While some large industry partners, such as DSOs and TSOs, had access to many intraorganizational resources, other research partners had to arrange with fewer resources to achieve their goals. Even organizations with same role in the energy system showed problematic differences in terms of data, material and equipment in their facilities. The interviewees of my case study argued that this would make comparability between organizations in EU projects difficult.

> *Another aspect was the availability of material. For example, if you are a DSO then you can run the payment, because you already have the data, the material or the kit. However, for example, in [DSO_W2], we don't have access to this. So we need to set up the payment of the laboratory. So it is more difficult to compare results. For example, I think the [DSO&TSO_E5] results are more robust, because they were performed in the real network. For us, we could only use the computers in the laboratory. (I27_DSO_W2)*

Having described the general project structure, tasks and their challenges, the next chapter takes a closer look at the actors involved and their expertise. In order to approach the question, it is, therefore, necessary to clarify what expertise is available in the organizations and how general communication took place.

5.1.3. Expertise of actors and general communication

The interview data identified that the majority of the project partners came from the field of electrotechnical engineering or computer sciences in the power sector. Knowledge of electrotechnical engineering knowledge was especially used to conduct the demonstrations in the project. Special attention was paid to the grid management and communication, such as with SCADA systems *(I5_DSO_S4)* and to the optimization of the market and the grid operation with regard to the corresponding standards *(I21_RD2_S4).* Some of the project partners with electrotechnical engineering background have furthered their education in the field of informatics for power systems, which resulted from the work shift towards an increasing need for ICT in the energy system *(I28_RD_N6)*. The experts from the field of electrotechnical engineering mostly worked at the industry partners, such as DSOs and TSOs. According to interviewee *(I16_RD_E5)*, partners with a background in electrotechnical engineering often gained new experience in computer sciences, such as communicating with Extensible Markup Language (XML), service-oriented architecture (SOA) or the use of common information model (CIM). Consequently, electrotechnical engineers increasingly integrated more knowledge in the IT field. As interviewee *(I25_RD2_S4)* stated:

> *I am an electrotechnical engineer and specialized renewables energy. But I am also good with computers and programming. So, they managed to hire me for both areas. (I25_RD2_S4)*

Equally, computer scientists were increasingly employed in the field of power systems *(I17_RD_E5)*, bringing with them expertise in programming languages, communication tools, hardware and software knowledge, data models or systems processes. Further categorizations have been made among computer scientists, e.g. System of Systems (SoS) engineers or system architects, who required high expertise in standardization. While SoS engineers had the task to test and validate the system, the IT architects focused on the requirements management and systems architecture. IT architects were involved in the use cases creation, as well as in the definition of functional and non-functional requirements for the different system components *(I23_RD1_C1)*.

> *My specific expertise is the standardization. I worked back with the standardization groups, standardization meetings at [TSO W3] and also with data exchange. So I have a participation with a communication standard subgroup through [TSO W3]. I am the contact person at [TSO W3] for this group. So this is my specialization. (I8_TSO_W3)*

Next to the electrotechnical engineering and computer sciences knowledge, individual expertise was evident in the fields of physics, math, or business administration. Interestingly, most of the partners studied or earned a doctorate in their specialist field. This once again confirms the depth of knowledge of the experts.

Communication between the Smart Grid project partners

Most communication in the case study project was conducted via a particular project management platform "Basecamp" to which all involved partners had access. This platform was used to create messages for the individual tasks in the work packages, to upload documents, to organize online meetings or receive daily summaries. The platform provided the fundamental basis for an online get-together of the project partners *(I27_DSO_W2)*. Regarding the use of digital media, communication took place with a time lag, meanings that a lot of synchronous and asynchronous communication has actually been a permanent part of the project *(I23_RD1_C1)*.

> *[Communication took place] most of the times online with tools, such as Skype, phone calls, e-mails, also through our platform Basecamp. We use Basecamp to upload, download and send files, send information, schedule appointments and the meetings. (I3_RD_N6)*

The main reason the interviewees cited for the intensely document-based communication was that partners could not simply meet or run into each other, but were limited to the biannual consortium meetings *(I23_RD1_C1)*. This required that the communication platform and all documented activities be tightly integrated into project work. The interview data showed that the deliverables were mainly co-authored and shared with each other by uploading and storing them in Basecamp. Likewise, the interviewees described that the documents also served as a pre-agreement between the partners *(I31_RD2_S4)*. The deliverables often formed the basis for externalizing new knowledge, and for using it for further exchange. This was stated by interviewee *(I31_RD2_S4)* as follows:

> *So, we started a deliverable, since we are the owner of the tool. We define the best way of how the data would be sent to us, but then we discuss this with [DSO_S]: "What do you think about providing the data in this format and in this way?" Based on this, there is a pre-agreement, but the final output is the deliverable (I31_RD2_S4).*

In addition to the shared deliverables via Basecamp, communication was also conducted via video conferences, phone calls or e-mails. Most of the partners, however, explained that they followed the messages on Basecamp on a daily basis. Participation in telephone conferences was rather less frequent, at two to three times per month *(I1_RD_E5)*. The interview data revealed that, throughout the project, emphasis was placed on ensuring that all messages were written on the communication platform. Issues that had previously been discussed via e-mail were then uploaded to Basecamp, creating a high level of transparency as every partner could access all information. Likewise, minutes were used as a formal instrument, which were uploaded to the platform after conference calls.

> *[…] Mainly through Basecamp, because there was a need to have a visibility and accessibility. For example, when I send an email to the partners, the task leader asked me to repost them on the Basecamp. (I27_DSO_W2)*

Many interviewees stated that the communication also took place in parallel or occurred informally between the partners *(e.g. I6_RD2_C1)*. Discussions also took place at the consortium meetings and subsequent casual meetings. These were not always about specific content, but also about milestones in terms of what still needs to be done or how tasks will be set up *(I5_DSO_S4)*. This was also confirmed by interviewee *(I31_RD2_S4):*

> *Sometimes, we had the discussions after the consortium meetings. Then we stayed a little bit more, we discussed a little bit more about some topics that were necessary and that particularly related to us […]. (I31_RD2_S4)*

Due to the geographical distance, EU projects are characterized by online communication with external partners. The interview data revealed that it was, therefore, not always possible to arrange face-to-face meeting *(I23_RD1_C1)*. Likewise, the interviews showed that communication mainly took place within the organizations. In this regard, the interviewees stated that they hold daily or weekly meetings in order to exchange information about the project status and work together on tasks *(I1_RD_E5)*. According to the interviewees, door-to-door meetings were often possible in the organizations, which greatly facilitated communication *(I25_RD2_S4)*. Likewise, a lot of talking to each other developed especially at the beginning of the project, which decreased over time *(I2_DSO_W2)*.

> *It also depends, because in the beginning, we organized meetings every week and internally we worked together more or less every day in the week and at least 2 or 3 days in the project. Now we talk internally one time a week or sometimes maybe 15 days because we are already in the demonstration. (I2_DSO_W2)*

Similarly, the interview data showed that communication was firstly conducted internally within the organizations and then communicated to external partners *(I14_RD2_S4)*. Project managers or leading partners communicated mainly with external partners, while the rest of the internal project team remained in the background, largely communicating on an ad hoc basis *(I31_RD2_C1)*.

Summing up, the interviewees of the Smart Grid project required high technological know-how to drive the energy transition and develop new coordination tools for DSO and TSO. The interviews showed that the communication took place on multi-level channels based on simultaneity. Although online communication offered a high level of transparency and a quick way to interact, it became apparent that personal and internal communication was still needed between the project partners.

5.2. Knowledge boundaries between heterogeneous Smart Grids actors

This chapter empirically analyzes the influence of heterogeneity on knowledge boundaries in the project. As described in my conceptualization of knowledge integration, heterogeneity is explored by the proximity concept and the related dimensions in order to identify the coordination and social relations in the collaboration among the project partners. These dimensions serve as a basis for discovering knowledge boundaries in the project.

5.2.1. Proximity relations between Smart Grid partners

To address the first sub-question, on *which boundaries of knowledge integration develop in Smart Grid projects due to heterogeneity*, it is first, necessary to find out how heterogeneity is traced in the Smart Grid project and second, to identify how the different dimensions lead to knowledge boundaries. The first hypothesis, namely *"The heterogeneity of project partners is a knowledge boundary that prevents the integration of knowledge in Smart Grid projects"* is rooted in the assumption of conflict between heterogeneous actors cooperating in Smart Grid innovation projects and aims to unravel what impact heterogeneity has on knowledge boundaries. Connecting these two strands of research sets the stage for the knowledge integration processes in innovative Smart Grid projects in chapter 6.3.

Organizational proximity

Prior to addressing the specific organizational aspects in this case study, it is important to note that the organizational structures had a great influence on the organizations' behavior in this Smart Grid project. First, the organizations involved in the project were structured very differently. A significant role was played by the size of the organization, which varied widely among the project partners. For example, the research institutes tended to be small to medium-sized organizations with 50 to 250 employees. There were only two larger R&D organizations with about 1000 employees, divided into smaller energy departments. TSOs were mostly medium to large sized enterprises with a number of employees ranging from about 200 to 1500. Only one TSO was an interconnected organization of other companies. The DSOs in the case study were mostly large corporations with up to about 150000 employees. Roughly summarized, the organizational structure of the partners in the Smart Grid project involved large global players, such as energy suppliers, as well as smaller sized research institutes.

In the interviews, the difference in organizational proximity was evident in the fact that the relations of smaller organizations were often much more loosely coupled. In particular, the collaboration between research institutes with a smaller number of employees was seen as more frequent and informal. The interviews showed that the hierarchies in research institutes were often flatter and decision-making paths were therefore shorter. The same was also evident in the smaller Eastern European DSO, which also showed flatter, less hierarchical structures *(I2_DSO_W2).* Individuals working in these flatter organizations often knew each other very well, which resulted in an easier communication. But also in the relation among organizations with smaller organizational structures, communication was described as very direct and personal, producing a quicker general understanding between them. For example, *(I2_DSO_W2)* stated:

> *I think it depends on the size of the company. In [Eastern European country], for example, I think in the case of DSO, it is much easier because it is a small company and the people can understand each other. I think it is more direct between the people that have the idea, that have the knowledge and the people that make the decisions. It is easier to communicate. (I2_DSO_W2)*

The interview data showed that the scope for decision-making and implementation was often wider in research than among the industrial partners. In particular, the research institutes in the project often showed a start-up-like atmosphere of trial and error *(I28_RD_N6).* At the same time, research partners often spent more time finding the best decision and strategy for the project. Similarly, the interviewees explained that the rationale for decisions at industry partners sometimes appeared unclear to the remaining organizations, while decisions in the research institutions were often very carefully weighed up and examined before being implemented. This was summarized by *(I28_RD_N6)* as follows:

> *[...] In a research-based institution, compared to an industrial institution, it is more difficult to see the justifications for decisions than they can in industrial establishments; For us in the research domain, we always have more critical thinking and we are justifying our solutions; while in industry you see that they come up with an idea and they say: "Ah that sounds good, let's roll with it." And then you have to dig more in order to see the real justifications. (I28_RD_N6)*

The interviews showed that more loosely coupled organizations tended to have a higher degree of flexibility and organizational distance between each other. This allowed organizations to more easily integrate information and knowledge from other smaller organizations by incorporating a higher number of mutations and novel solutions. In particular, the comparatively smaller research institutes shared information more easily with each other *(I3_RD_N6; I22_RD1_C1)*. This assumes that a certain organizational proximity fostered the transfer and exchange of knowledge and increased the capacity for innovation development between them. However, it became apparent that while this flexibility of organizations facilitated exchange of new knowledge, it also entailed the risk that organizations quickly changed their goals and strategies in the project, especially if the tasks were very person-bound. This change of mind was evident, for example, in the adjustments made to exchange data between the partners *(I22_RD1_C1)*. Thus, too much flexibility increased the risks of uncertainty and opportunism in the process of creating new knowledge between organizations.

In contrast, the interview data elicited that relations between large industry partners were more strongly coupled, which was especially apparent in the coordination of partners. Given the more hierarchical and formal structures of the organizations, decision-making and responsibilities were often pre-determined, so that organizational members represented and aligned with the goals of the organization. In this sense, the interview data showed clearly that in tightly coupled systems between hierarchical organizations, decisions were made over several stages and under the strict auspices of the project leaders. This was deemed time consuming, resulting in a smaller, less effective task development *(I27_DSO_W2)*.

> *[…] But we also have some internal processes. For example, I know that at [DSO_W] we maybe have a longer delay to answer some questions, because we need to have some validation from the first chief, then from the second chief and so on and so on. So maybe it is a quicker process for some smaller companies or some academic institute. (I27_DSO_W2)*

The high degree of control exercised by the project leaders as well as the overtly hierarchical structures of large organizations produced strongly coupled systems. Here, the processes and the scope of action were described as much more tightly controlled. Difficulties in decision-making processes between very hierarchical companies were seen as a hindrance for knowledge exchange in the collaboration. Some interviewees indicated that this resulted in unanswered inquiries and lengthy requests, causing tasks to fall behind schedule. However, despite the challenges posed by organizational structures, the need for integrating knowledge was still recognized, leading to organizational structures opening-up *(I11_RD1_S4)*.

The interview findings also showed that asymmetrical relationships were present. The asymmetric organizational structures, such as different hierarchies and decision-making processes, as well as different levels of autonomy and control, have had an impact on the direct interaction of the actors. The interview data revealed that the more distant the organizational structures, the more difficult it was to collaborate. Strong control mechanism paired with long decision-making paths led to the situation where the necessary information was sometimes provided months later to the research institutes *(I21_RD2_S4).* Asymmetric organizational relations were also evident in the fact that hierarchical organizations were more rigid in pursuing their goals and their project partners were often less flexible in adapting their strategies and aims. This stands in contrast to partners from research institutes with flatter hierarchies. The finding of common compromises and solutions was particularly influenced by this. Proprietary solutions that were already in place at the facility were often enforced and followed through in the collaboration between project partners *(I23_RD1_C1)*. Different approaches to formalities have also influenced the asymmetrical relationship. While meetings were held more informally and spontaneously in organization with flatter hierarchies, this same patter often proved to be more challenging for hierarchical organizations due to stricter processes of the organizations. This was well summarized by *(I22_RD1_C1):*

> *My experience is that there are huge differences. As soon as a company gets bigger, you simply have the problem, that they have their strict processes. Companies can move very little outside these processes and that's the way they work. […] while smaller organizations or companies are often more agile, when it comes to cooperation. Especially in research projects, where you often do not know in advance, what the current phase is. Of course, this is often difficult – that's when you notice the problems. (I22_RD1_C1)*

To conclude, the case study has shown that the involved organizations in the Smart Grid project have very different organizational structures in terms of hierarchy and decision-making, as well as autonomy and control. The relation of the organizations, thus, ranged from loosely coupled systems between flatter organizations to strongly coupled systems between hierarchical organizations. Particularly in loosely coupled systems, it was found that actors behaved more agilely and flexibly, for example, in the conduction of meetings. Likewise, research institutes tended to be more open with respect to their research and goals, while DSOs and TSOs often adhered more closely to their organizationally based structure. However, the project also showed that too much flexibility and leeway in flat hierarchies also carried the risks of changing goals and implementation strategies, and that organizations could get stuck in the trial-and-error phase without enough decisions being made. Regarding this risk, more strongly coupled organization displayed a positive influence on bringing more structure and rigor to the project.

All in all, organizational proximity could be established more quickly in organizational structures that were set up in a similar way.

Institutional proximity

Three distinct groups of institutions were identified that have particular patterns of behavior, namely the DSOs, the TSOs and the research institutes. This division was made by their coordination of actions through their formal and informal structures and processes – both should provide stable conditions to enable interactive learning. Considering formal structures and processes, the interview data showed that the participating institutions were subject to different laws and regulations. All of the institutions were subject to strict EU regulations and laws, such as General Data and Protection Regulation (GDPR). The interviews revealed that DSOs and TSOs in particular are even more tightly regulated due to the protection of their system-critical networks *(I5_DSO_S4)*. In particular, TSOs are not only highly regulated by national committees and EU regulations, but also by ENTSO-e, which is an assembly of 38 TSO members in Europe. TSOs that are ENTSO-e members must apply certain technologies and standards and are bound by jointly agreed regulations *(I8_TSO_W3)*. These strict safety regulations are justified by the fact that TSOs have a high level of responsibility for the long-distance energy grids.

Although there is an EU association of DSOs, the large number of DSOs makes it much more difficult to harmonize them all. In fact, DSOs often follow their own individual rules and are not immediately under the umbrella of a superordinate association. Both involved DSOs and research institutes must abide by the GDPR, national regulations and confidentiality clauses of the organization and projects, but are formally more independent than the TSOs. In particular, TSO partners are formally strongly bound to the regulations and common standards for information exchange by ENTSO-e. *(I16_RD_E5)*.

> *[…] TSOs are more strictly regulated by ENTSO-e; by all these regulation committees, but also national regulation committees, whereas DSOs are not so strictly regulated and they have a different use of the technology. […]. I mean the TSO must of course provide transmission with a high level of security. Everything is strictly regulated and the DSOs, on the one hand, have far more complex structures, network models, which are more difficult to model, on the other hand. And, therefore, we have not been digitalized to such an extent yet as this is far more complex. But it is inevitable and it is going that way […] with this project. So these are the first steps we are making. This merger between the two worlds. (I16_RD_E5)*

Regarding the formal institutional proximity, differences in regulation lead to comparatively less institutional proximity among project partners. Therefore, the strict regulations had an impact on collaboration, particularly with regard to standardization and data exchange. While it was perceived as beneficial that research institutes had fewer institutional constraints and could, thus, talk about everything more easily, DSOs and TSOs were perceived as more closed to sharing information due to all the regulations *(I5_DSO_S4)*. Against the backdrop of fewer regulations, the research institutes were perceived more flexible in coordinating their activities.

Regarding the *informal institutional perspective*, the interview data identified common working habits and routines between the same types of institution. A shared working method and similar processes significantly facilitated cooperation. Even if the common institutions had not previously worked together or did not all came from the same countries, informal conditions often brought the same type of institutes closer together. A partner from an Eastern European country research institute explained that the cooperation with a research institutes from another country worked very well, as both used similar working methods and had a set of common habits *(I17_RD_E5)*. This led to a culture in which project partners helped each other and everything flowed more naturally, because there were no superfluous questions. Likewise, challenges were addressed similarly, which shows that the working methods and processes between the same institutional forms were often very similar *(I17_RD_E5)*.

> *[…] but if I compare [R&D2_C1] and us, we work on the same part at this time. Maybe, we actually don't have many differences, which I like. We have a similar approach to work. I think that's what makes us such good partners and helps us to work very fast because we work in the same way. Thus, there are not too many questions. Usually, we agree very fast. I think we don't have very big differences […] We work now with the same tools and what I like is, for example, that [name] and I have a similar approach to problems. We kind of think alike in that part. And when I told them that I worked in a specific way, it is usually that they did the same things. We had luck to be parallel in that way. (I17_RD_E5)*

Another interesting point was that the institutional framework for working conditions varied widely between DSO, TSO and R&D partners. In this sense, some institutions of the project had a high staff turnover, for example employees in research institutes who worked at the beginning of the application phase but were later no longer part of the project. Frequent personnel changes were especially common in research institutes because of temporary contracts. Based on these considerations, the risk emerged that the tasks and goals described by the responsible person in the project application process could not be correctly understood, as these individuals already left the organization. This also had an impact on learning among the institutions *(I23_RD1_C1)*.

> *Other partners are involved and don't even know why they are involved, because the internal organizations and the project partners have changed since the project application. (I23_RD1_C1)*

Ethical values represented another strand of informal institutional proximity in the case study. The interview data revealed that institutions from the same country often share similar cultural or ethical values. These ethical and cultural similarities between them were also often closely tied to its geographical location, which often shaped them. For example, one interviewee from the Southern European country explained that these informal aspects equally influence the interaction between them *(I5_DSO_S4; I4_DSO_S4)*. In this sense, the culture of the partners from Northern or Central European countries was perceived as very strict, focused as well as more distant in regard to partners from the Southern European country. An interviewee from a Southern European DSO provided the following example for ethical and cultural differences in the project *(I5_DSO_S4):*

> *I would say the [Central European] partners… (Let me choose the correct words) are I would say more strict to the point. A little bit less human contact regarding the Latin cultural aspect. In that way, they are a bit colder, if you put it that way. Then the Latin culture is a culture of doing things as time goes by - not having a strict plan as the [Central European]. (I5_DSO_S4)*

The Latin culture within project work was described by the same interviewee from a Southern European DSO as a culture of "doing things as time goes by" *(I5_DSO_S4)*. Therefore, some partners from the Southern European countries saw differences in the work culture, for example, in comparison to the Central European work culture, which was perceived as rather stricter. Moreover, most of the Southern European interview partners emphasized the importance of the human aspect in such international project work. Overall, the interview findings showed that the same culture connected the organization from the same European regions, not only because of the same way of working and thinking, but through the same languages, which led to a better understanding and often a faster emotional connection between them. The differences were highlighted in the following quote from *(I10_RD1_S4):*

> *For example, I can talk about [Central Europeans]. I feel that they are very focused and very structured in the way that they should work and they take about all the steps very well structured and that is very, very nice. […]. That's my feeling - very good people to work with. (I10_RD1_S4)*

Likewise, the interviews showed that partners with the same ethic-cultural background often worked together more intensively than partners from different cultures (I10_RD1_S4). Stronger institutional ties between these partners from one country were evident, as in most cases these partners had already collaborated several times before the case study project. This allowed for a better appreciation of the informal realities of the organizations and facilitated collaboration. The impact of informal institutional proximity on the ultimate communication between the partners is described by *(I10_RD1_S4):*

> *In this case of the [Southern Europe] demonstrations, there was, of course, much more communication between the [Southern European] partners, but we also have the exchange with the work package leaders and this kind of stuff; just to assure that everything that we do is what they expected from us. It's much more of a way to do that. (I10_RD1_S4)*

Some interviewees stated that cultural differences affected the collaboration, but tended to become less relevant to project work over time and with increasing experience in international projects *(I28_RD_N6)*. Similarly, partners from one country sometimes behaved very differently, so the organizations could not all be lumped together. In this vein, one interviewee explained that cultural differences did not play a major role, as the partners already knew each other from other projects and have already worked together.

> *When it comes to the multi-culture of it, of course the fact that we are all coming from countries means that we had some cultural differences. However, now because we have been doing research for some time now with international partners, I started to blend them out. I am not really seeing cultural differences anymore, if that makes sense. (I28_RD_N6)*

Taken together, the project structure showed a clear differentiation of the institutional forms of DSO, TSO and R&D institutes, which are subject to different formal conditions, such as laws and regulations, but also have different ways of working, cultural norms and ethical values. The interview data showed that institutions that had similar working conditions were more likely to establish common structures of collaboration through institutional proximity. In contrast, strong institutional differences often led to a lack of institutional proximity, as the laws and regulations, but also cultural norms and habits could act as a barrier for cooperation between them.

Cognitive proximity

The interview data exposed that different knowledge bases existed between the organizations in the Smart Grid project, leading to a different cognitive proximity. A distinction between the knowledge domains of the DSOs, TSOs and R&D organizations were identified, delineating their knowledge-based relationship to each other. Although basic energy knowledge was present in each type of organization, different emphases emerged in the case study. Accordingly, the expert systems, networks and responsibilities at DSOs differed from the TSOs and vice versa, which strongly affected the way new knowledge was absorbed. As a result of the different interests and positions in the system, knowledge was also adopted from different research directions. An interviewee from a Western European TSO added that specialized project partners would bring varying degrees of technical knowledge to the common project work *(I26_TSO_W3)*. All in all, differences in the knowledge base of the organizations affected the relationship on a cognitive level.

> *First of all, there are different types of partners. Thus, the researchers and the utilities, which do not have at all the same stage in the project. There is also a big difference in terms of how deep the partners could go into the technical details or the technical implementation of the project. […] Then within the different categories of partners, like system operators, the TSOs and the DSOs, or*

research, they do not have the same position on everything. Most of the time, the DSOs were maybe promoting some way and then the TSOs some other ways […]. (I26_TSO_W3)

The various knowledge fields were also attributable to the circumstances of the different countries specifications *(I27_DSO_W2).* Consequently, the partners had different technical systems that required different knowledge. For example, *(I11_RD1_S4)* mentioned that each national grid would have different technical requirements and, therefore, different challenges to solve in the common project work. In this way, specific knowledge about the respective technical implementations in a given country of the project partners was identified. *(I27_DSO_W2)* described this as follows:

We don't have the same technical difficulties because each national grid has a different situation. For example, the [DSO_W2] voltage for the distribution is not the same as the [DSO_S]. So, we don't have the same difficulties. Of course, in some case, you have only one big DSOs […], but in other countries, you have many DSOs. So, it is a different demand in the countries. […] A concrete example is the additional requirements. Maybe a country needs to have the data in less than 20 milliseconds and for another country, it is not recommended at all. (I27_DSO_W2)

Other interviewees summarized the DSOs and TSOs to industry partners and compared them with research partners. While the industry partners often included more practical applied knowledge, the research partners often contributed more theoretical knowledge to the research project *(I28_RD_N6).* For example, applied knowledge from industry focused on achieving business goals, whereas research partners operated within the framework of scientific methods used to seek and analyse new solutions. The difference between both types of knowledge was also evident in the fact that the research partners appeared to be more open in their search for new knowledge, as they often used unconventional approaches that facilitated the adoption of new knowledge *(I17_RD_E5; I1_RD_E5).* On the contrary, industry partners tended to have a more incremental approach to knowledge production, which was dependent upon the organization's standard practices *(I28_RD_N6).* The interviews showed that the search for knowledge was more flexible in research institutes, leading to the possibility of changing directions and exploring new perspectives. For example, *(I28_RD_N6)* stated:

Usually in the research, we are using a lot of simulation and we are doing more theoretical research, while in industry, they are doing more practical oriented research. That's a difference, which is our advantage this time, because we are a bit more open, while in industry the research is very incremental. You have a solution, for example, a tool, as you said, and you are trying to develop that further. While for us, it is easier to say: "Okay we are scrapping this tool, we are changing direction and we are developing the new one from a different perspective." (I28_RD_N6)

A further distinction of knowledge fields emerged from the interviews that were shaped by the technical expertise of the participants. The interview data revealed that DSOs and TSOs tended to involve more employees from the field of electrotechnical engineering, while organizations in research often had more knowledge in the field of standardization, architecture modeling or computer sciences.

> *For example, the DSO of course involves electrotechnical engineering aspects of knowledge, other partners have computer sciences knowledge and other partners are modelers and have knowledge about new relevant standards (I27_DSO_W2).*

However, most interviewees indicated that their organizations increasingly incorporated new knowledge in the field of computer sciences. The interviewees explained that technical terms and approaches were often similar between partners with a common knowledge background, making it easier to acquirenew topics *(I11_RD1_S4)*. Similarly, cognitive differences emerged through the different personal positions, for example, between the *managers in the project* and the *content-related scientists*. According to the interviewees, these two differing roles influenced the knowledge-based relation between organizations. The different locations, with the managers and the content-related scientists showed that knowledge was brought in and developed in different places of the project. In this vein, communication and the relationship between scientists interested in the content or between managers were considered easier than in asynchronous relations. *(I7_RD2_C1)* explained this distinction as follows:

> *The strongest separation is that some of them are organizational managers and some of them are content-related experts. But sometimes the content-related experts will be sent on the road to do what the management leaders should do and vice versa. (I7_RD2_C1)*

Regarding the cognitive proximity, the case study illustrated that the partners had different cognitive knowledge bases, which influenced the communication and interaction between them. There was a tendency that project partners from industry sought to develop new incremental knowledge within their familiar context, while the research partners often found new knowledge in a completely new context that differed from their knowledge base. The interview data revealed that the exchange of knowledge between cognitively distant organizations required special effort and absorptive capacity to recognize interpret and use the new knowledge. On the contrary, similar knowledge rather tended to unite the partners and facilitate coordination between them.

Social proximity

As Polanyi described in the concept of embeddedness, economic relations are consistently embedded in a social surrounding. Looking at the case study project, the partners have established a social relationship during the project work that affected the economic outcome of the tasks. This social bond was perceived very differently. While some partners had difficulties getting closer to some partners, others were able to establish a close relationship with each other. Social proximity was evident in the interviews from the *communication* between them, particularly in the way information was shared. Accordingly, organizations that were socially close to each other communicated and interacted more easily *(I32_DSO_E5).* The interviews showed that the contact between socially close partners was easier to establish and persisted throughout the duration of the project. On the contrary, organizations that were socially distant had difficulties getting along with each other because communication and the tasks development were opaque *(I6_RD2_C1)*. The following statement of a task leader describes how difficult it was to bond and communicate with some project partners.

> *There are project partners who work very conscientiously. You don't have to ask them a lot of question, because the information comes almost by itself. But there are also partners with whom it is difficult to get closer. […] While with other partners everything is very transparent and they already present the information in very detail. The more detailed it is presented, the more I can actually understand it as an outsider. The partners are then open-minded and react to inquiries. But if it is too general described, you don't even have anything to ask for. The more information you have, the better you can understand the details and ask questions. While with other partners, it is in any case very non-transparent. (I6_RD2_C1)*

Some interviewees revealed that many partners invested a lot of effort to make the communication work and of value, both in terms of the data and information communicated as well as the personal value of the relationships developed. The central factor that made communication difficult was the high level of interdependence between the organizations *(I25_RD2_S4; I28_RD_N6)*. For example, research partners required operational data of DSOs and TSOs, while the industry partners were also dependent on the analysis from research *(I6_RD2_C1)*. Consequently, communication in the form of social interaction was a strategic element to collaborate in the project.

In the light of the interview observation, communication was not always difficult between the project partners. Indeed, many partners established a social relationship and communicated on a frequent basis with each other. Some interviewees stated that most partners were open and they could not see any problems from a social perspective *(I14_RD2_S4; I17_RD_E5)*. Not surprisingly, some project partners even built a friendship based on trust and kindness. Overall, trust was found to be greater between socially close partners. This trust relation was explained by *(I11_RD1_S4)* as follows:

> *Technically, we understand, everyone understands. It's the moment you gain confidence with each other, the moment the other one will trust you; then you exchange everything technically. I think the key is trust. If you trust the person, you have a lot of things to share. (I11_RD1_S4)*

One interviewee argued that for the establishment of new formations of social proximity in the project, it was especially important to see, read and engage in physical interaction in the form of body language, gestures and facial expressions. In this sense, body language contributed to a better understanding and created a common ground that was hardly established in online meetings. An interviewee from a Southern European research institute described that communication between socially close organizations created empathy, which in turn led to trust and facilitated information sharing *(I11_RD1_S4)*.

> *[…] I started sharing my pains. […] if on the other side there's one person also willing to share, then he or she starts sharing his or her pains. Then it is getting more open. However, it's a step-by-step approach not the e-mail, nor the phone call is important, but personal interaction is needed. So the physical interaction, because when you speak, the body language says a lot about the people. Then if you immediately see if the people are genuine, then you create empathy. With the empathy comes trust and with the trust you can share (knowledge). (I11_RD1_S4)*

Trust was also particularly strong between partners who had been working together over several different projects. Some interviewees emphasized that they prefer to work with known partners. *(I32_DSO_E5)*, for example, stressed the importance of knowing the partners prior to a project, especially in terms of expecting the outcome and contributions of the other partners. Hence, my empirical investigation showed that pre-existing relationships had a positive effect on the project in the sense that partners could build on them *(I23_RD1_C1)*. Accordingly, the interview data exposed that cross-organizational connections at the social level had already been established prior to the project *(I32_DSO_E5)*.

> *And this is also one of the moment when you are more likely to want to collaborate with companies, institutes and partners that you already know. If you know what to expect from the partners, then everything is much more in control. (I32_DSO_E5)*

Another aspect of social proximity that developed in the interviews was seen in the reliability between partners needed for the establishment of tasks *(I30_RD2_C1)*. The interview data showed that the lack of social proximity between organizations often stemmed from a deficiency in reliability, but also from a scarcity of commitment and agreement among them. The project partners perceived this lack of reliability and long feedback as very negative, which had the consequence of creating a certain social distance. In this sense, one interviewee explained that different levels of reliability existed in the project, influencing the social proximity between them. The matter of reliability was exemplified by *(I30_RD2_C1):*

> *[…] In general, you notice with different project partners, there are also different levels of reliability. Some partners were very, very, very reliable and they always answered very quickly and thoughtfully, while others were perhaps a little less reliable. There were a few differences: as far as the working methods of the various partners or any hierarchies are concerned, I honestly cannot judge that. (I30_RD2_C1)*

Summing up, the interview data revealed that social proximity was not inevitable or organic to a project structure but something that had to be created. While a social bond already existed between some partners that worked with each other before, others had to build up a social relation during the project. Likewise, social proximity was a prerequisite to exchange confidential data between DSOs and TSOs. This suggests that similar ways of working, but also trust and empathy led to a closer social connection. Social proximity, hence, enabled an open attitude and communicative behavior between the partners, which supported data sharing and reduced the risk of opportunistic behavior between them. In this sense, too close social networks have not been identified in the empirical analysis.

Geographical proximity

This EU funded Smart Grid projects involved partners from different European countries. Physical meetings with the project partners were held bi-annually until the outbreak of the COVID-19 pandemic. At these consortium meetings, all project partners met at the premises of one partner. The meetings were perceived very positively for the collaboration, as the partners were able to exchange ideas and communicate intensively with each other over two to three days. One of the interviewees emphasized that the cancelled meetings because of the COVID-19 pandemic were very unfortunate for the collaboration, as communication was much easier in person (*I27_DSO_W2*).

> *I think it was a disaster. For example, due to COVID-19 we could not see each other at all in a physical meaning. I think it was much more difficult to work, because sometimes it is much easier to communicate when you see people, as if you hear some people are not good in English. Thus, we can give some comfort with a suggestion and a personal aspiration, but it is much more difficult when you only have one form to work. (I27_DSO_W2)*

Physical project meetings, therefore, allowed partners from geographically distant organizations to get to know each other better and become socially closer. Face-to-face communication was considered by most of the interviewees as much more straightforward, especially with regard to the fact that English is the second language of those participating *(e.g. I32_DSO_E5).* The interviewees spoke of the usefulness of ad hoc meetings, such as during coffee breaks or lunch together, where partners could socialize and bond between each other *(I32_DSO_E5).* Virtual meetings did not satisfactorily replace face-to-face meetings with regard to the exchange of certain elements of the project. While the timesaving aspect of online communication via online platforms proved efficient for brief 20-minute meetings to discuss something more general on a computer screen, the interviewees stated that face-to-face meetings were seen as more effective to explain something in detail *(I27_DSO_W2).* Again, this revealed the complexity and depth of the expertise that was easier to be shared in a face-to-face meeting. Consequently, personal physical meeting facilitated the exchange of detailed technical knowledge.

> *Yes, I think it was necessary. For this, I think one really big deal was a physical meeting, because when you know some people, it is much easier to communicate than using LinkedIn or these kinds of web meeting tool. (I27_DSO_W2)*

However, the interviews showed that the organizations within one country collaborated more often intensively than organizations that are geographically distant. The interview findings revealed that the DSOs, TSOs and research institutes within the same country had often already worked together on several joint projects and, therefore, already knew each other. However, the project tasks predetermined to some extent which organizations from a country needed to work more closely together, and this was usually based on expertise that was also regionally anchored, for example, due to the fact that demonstrations took place between partners within one country. Likewise, the organizations from one country were often located in a metropolitan region, so face-to-face meetings could take place in this region *(I31_RD2_S4)*. It was significant that most of the organizations in the same region had a high level of geographical proximity. This coordination between the partners within one country was described by (*I31_RD2_S4*) as follows:

> *[…] Then with external partners, let's say from [R&D2_S4] and with the [Southern European] partners, so [DSO_S4] and [TSO_S4]. […] The location, where the tool was going to be demonstrated, was in [Southern European country] and so there was a lot of coordination needed in the beginning of the project, but also in the middle until the end of the project, because the tools are fine, the [demonstrations] work, but then they need to be integrated in a very complex infrastructure that is already in the TSOs and DSOs systems […] So a lot of discussions were held, lots of meeting, particularly with these two partners. (I31_RD2_S4)*

Another interviewee explained that information was much easier to receive from organizations that are geographically located nearby. Organizations located in one region established contact more easily because distances were shorter and, thus, more personal meetings were able to take place. For example, *(I10_RD1_S4)* suggested that information was transferred more easily when a relationship between the organizations already existed and the process of exchanging information was already established. However, this could not be generalized in the interviews, as organizations in one region did not necessarily always communicate more. The geographical impact on information sharing was described by *(I10_RD1_S4)* as follows:

> *[…] No, because it's complicated. We can receive much more easily the information from [TSO_S4], because we are in the same building, and [R&D1_S] is 50 percent owned by [TSO_S4]. It's much easier to get information from the TSO. From the DSO, forget, it's very complicated to get this information and I heard and I read a few days ago that the costs for data information is nowadays very high. It's one of the higher things [the data] that you can find and it's bigger than fuel. So I think it is related with these concerns with the dangers to expose information even between the same countries. (I10_RD1_S4)*

Likewise, the interview data revealed that knowledge output was shaped by the region and, therefore, influenced by resident organizations and existing policies of that region. It is evident from the interviews that certain regions were more receptive for new knowledge than other regions, especially organizations that are located in a broad innovative environment showed a high propensity to exchange knowledge. Nevertheless, *(I27_DSO_W2)* revealed that national differences were evident in the project, as each energy system in the country has different circumstances and its own challenges to solve, which equally influenced the knowledge output of the project.

However, other interview partners explained that geographical proximity only played a role in terms of technical conditions of energy systems, but not in terms of the relation between partners. For example, the interviewees explained that the processes and functions of the TSOs were often opaque to them, citing the fact they were so geographically distant and, thus, had hardly any connection to them *(I11_RD1_S4; I23_RD1_C1).* Hence, different technical systems and conditions in different countries often made collaboration between the partners more cumbersome, but this did not always have a negative impact on the relationship between the partners. Communication was often concerned with developing an understanding of these technical differences. This was also summarized by *(I31_RD2_S4)* as follows:

> *We are in a European context; of course, we have some differences, but this is not only the case of this project. I already worked in several projects and I never saw some kind of constraints, caused by the fact that we are from different countries. The only possible constraints are technical, because in one country you can find different types of input data, different forms to integrate your algorithm in the internal systems of the operators. However, these are more on the technical side, not in terms of relationships with the partners. (I31_RD2_S4)*

To conclude, the interview findings revealed that short distances between the project partners brought the individual organizations closer together and enabled frequent personal communication and the exchange of complex expert knowledge. This was even more important due to the different technical systems and networks in the respective countries. Getting to know each other personally, thus, enabled a stronger communication across national borders.

5.2.2. The arise of knowledge boundaries in Smart Grid projects

Having described the different types of proximity between the project partners in the case study, this section will break down the knowledge boundaries that develop when integrating knowledge. In theoretical chapter 3.1.3, Carlile (2002, 2004) distinguishes knowledge boundaries at the syntactic, semantic and pragmatic level. My empirical analysis follows this distinction in order to make plausible assumptions on the development of knowledge boundaries when integrating knowledge within Smart Grid projects.

Syntactic knowledge boundaries

"The first challenge is to get a common language and common constructs" (I23_RD1_C1). As the quote makes clear, the primary challenge in Smart Grid projects is that the project partners do not always speak the same language or use the same constructs. In this context, shared constructs refer to the conceptions that attempt to bring observations to a common interpretive denominator, while language was referred to the technical terminology or the native language.

To begin with, the *common language* of the project was English. Although all partners were able to converse in English and an overall high level of the language existed in the project, only some partners could speak at native level and were, thus, able to express themselves accurately and formulate knowledge precisely. A different wording was therefore apparent *(I22_RD1_C1)* that resulted from the various mother tongues. Consequently, linguistic differences were obvious, as some partners spoke English regularly in their daily work, while others spoke it rather less. Similarly, partners with the same native language often swapped back into their languages, which facilitated knowledge exchange between them. Since the project involved very complex technical knowledge, the partners had to rely on precise formulations in order to convey this knowledge in a comprehensible way. This was exemplified by *(I22_RD1_C1):*

> *The wording is often a problem, especially in English, which of course also applies to us. None of us are native speakers. This means that we often cannot express ourselves as precisely as we might want to. (I22_RD1_C1)*

In addition to the English language, which only a few people had a perfect command of, *technical terms and data* also played an important role in the project. The challenge from the syntactic point of view was not only the new type of data, but also the quantity of data that the project partners had to deal with. This data, for example, in the field of electricity networks, was seen as very specific and could only be used with certain technical background. In most cases, computer sciences and power systems knowledge was necessary to be able to read and process the data in the project. Since the type of data was also constantly changing, there was still a lack of methods to read and process this data on a syntactic level. The processing and providing of the new data was, therefore, a major challenge in this sense.

> *Nowadays with the energy transition and with the integration of decentralized energy in our system, the business is changing and we need to use other type of data that we are typically not using, but in some cases, we are at the beginning of new processes. These new processes are not well established yet and when you start the European project, you are supposed to have this data available by the next month or next year during the project. Sometimes it is not possible and this is one of the many issues that we have in the project […] (I29_DSO_S4)*

In addition to the increase in data, an upsurge in information was observed in the Smart Grid project, causing difficulties in assimilation. According to *(I6_RD2_C1)*, one reason for the difficulties was seen in the massive flood of information that first had to be absorbed. This information processing became even more difficult due to the fact that a lot of information had to be processed simultaneously because of parallel project tasks. Hence, a way had to be found to coordinate this information process. This was stated by *(I6_RD2_C1)* as follows:

> *Of course, it's also difficult, you can't always know everything. Otherwise, you'd have to know what's going on in the project right now [...]; what they are all doing. But that would also be a massive flood of information that you would have to absorb. I wouldn't know how to best do that now, but there are just a lot of things going on in parallel and there are just a lot of different approaches to coordinating it. I think that this is difficult because it has to be done in a superordinate way and not as the work of a single work package. (I6_RD2_C1)*

The interview data revealed that the technical expression between the partners was an important criterion for the mutual understanding. The different technical wording resulted particularly from the fact that the actors are highly specialized experts from different areas of knowledge. For example, *(I22_RD1_C1)* stated that many technical terms have several levels of abstractions and diverse meanings. This exposed how central the cognitive proximity was to the project, in the sense of influencing the different technical terminology used by the collaborative partners. The different technical backgrounds produced very different vocabularies, which sometimes resulted in the terminological ignorance of partners who did not always question all the terms. For example, *(I2_DSO_W2)* stated:

> *I think the challenge for me is to speak the same language with the others. It is very useful to have a global picture of the needs of the others and how work is influenced. However, it is a challenge, but at the same time, it is also a contribution for my personal skills. (I2_DSO_W2)*

The use of different technical terms could be seen across the entire project. During the evaluation of the interviews, it was noticeable that the project partners were not necessarily aware of the fact that certain technical terms were not mandatoy present in the vocabulary of others. For example, *(I7_RD2_C1)* explained that the technical term "bus", which another project partner was using in the area of CIM and CGMES, was unknown. As a result, the interviewee asked the respective organization for an explanation and further information material. However, the interview data showed that explanations of technical terms were not always available in the material used by the partners *(I7_RD2_C1)*.

> *For example, we asked [TSO_W3] several times if they have any information material about CGMES, so that we could understand even better, what all these classes and attributes mean. For instance, we read that they use the word "bus", but it was not immediately clear to us what exactly [TSO_W3] means by the term "bus". (I7_RD2_C1)*

More examples for syntactic knowledge boundaries due to different technical terms were explained by two other interviewees. While the interviewee *(I22_RD1_C1)* described that the word "use case" was not necessarily known to the project partner, another interviewee

(I7_RD2_C1) stated that the term “association” in the context of Unified Modeling Language (UML) was not clear at all. Therefore, there were various wording problems due to the specification of knowledge. However, once the new terminology was understood, the interviewees were able to formulate questions and obtain the necessary explanations of the terms *(I7_RD2_C1)*.

> *No, that was more for me personally. Afterwards, when I knew much more about UML, I was able to communicate with partners a bit better about their diagrams. For example, I could ask then what “association” means, because I know now what an “association” is. (I7_RD2_C1)*

The interview findings demonstrated that a common wording was indispensable for the collaboration and formed the basis for communication. *(I22_RD1_C1)* emphasized the usefulness of a glossary to develop this mutual wording and achieve a common understanding of the terms. The decisive factor, however, was that all partners agreed on this glossary. The interviewee *(I22_RD1_C1)* criticized the concrete application: Although there was a glossary in the Smart Grid project, it was not always consistently used throughout the project. Particularly, the research partners were concerned about the correct use of terminology in order to avoid misunderstandings from the outset.

> *[…] In the best case, we would be willing to agree on a wording in the project context; not in the sense of: "I am always right about my wording without exception. You just get it wrong.", but as a minimum requirement. You need to have a common glossary and that everyone should be willing to use this glossary. I mean, of course [project name] also has a glossary, I just haven't experienced that it is used consistently. (I22_RD1_C1)*

Further issues on the syntactic level were shown by the fact that the partners had difficulties, for example, with different files for the communication of the web services. Here, it became apparent that despite similar backgrounds, the data basis was often very different, as were the technical terms associated with the differing methods. For example, *(I25_RD2_S4)* stated that many errors were found in the merging of the network data that was provided. The project partners also recognized that the syntax was critical to further developments and adaptations of the project aim to create a common understanding and, ultimately, pursue a shared vision for the Smart Grid.

> *[…] You have a different wording, which is a problem also regarding the different objectives, you can divide the objectives in the sense of; you can have a common vision for the Smart Grid as a total solution. This does not mean, of course, that we have a common vision of how this Smart Grid will work. This can also often lead to conflicts. (I22_RD1__C1)*

In summary, syntactic knowledge boundaries were not only created by the different languages spoken, especially by the fact that English, as the second language of most of the participants, became the lingua franca of collaboration between project partners, but also by unknown data and the varied technical terms used. One partner’s assumption that the technical terms were self-explanatory proved to be incorrect, as it often required extensive definition and explanation. Thus, the different terms jeopardized the basic communication, but the partners offered explanation and clarification and created the potential for communication through this exchange.

Semantic knowledge boundaries

Despite the efforts to share a common syntax in a glossary, the interview results showed that different interpretations nevertheless emerged. From the angle of semantic knowledge boundaries, difficulties were encountered in the processing of new information and data within the Smart Grid project. How the project partners interpreted this information and data from a semantic point of view will be examined below.

Although attempts were made to create a common syntax between the partners, information was still often interpreted differently. The interview data showed that there was a risk that the project partners from different knowledge areas would put the terms in a wrong contexts. This was exemplary illustrated by the word "use case". Although most of the project partners thought they knew what the term meant, it became clear that their understanding varied greatly. At a very general level, the terms pointed to different levels of abstraction and meanings, but this generality proved problematic and it turned out that the term was not clear to all project partners. An interviewee *(I22_RD1_C1)* described that if you ask two different project partners how they used the term, you were likely to get two different answers from them. In this sense, *(I22_RD1_C1)* stated:

> *For example, one term that is often used in [project name] is "use case". The term has many levels of abstraction and has many different meanings. There is of course a clear definition, which is standardized, but not everyone deals with the standards in depth. After all, it is not necessary for everyone. Then, you have the problem that "use cases" is a term that is kept very general. For example, a software developer knows what a use case is and a manager also knows what a use case is, but if you ask both of them what a use case is, you get two different answers. (I22_RD1_C1)*

The different interpretations reflected the various *knowledge backgrounds* and a wide range of competencies that existed between the project partners. As was also evident with syntactic knowledge boundaries, the partner's background played a role in interpreting and contextualizing the data and information. For example, an interviewee *(I22_RD1_C1)* assumed a general lack of background knowledge, such as in the area of standards and information systems, which led to a more difficult interpretation. This lack of background knowledge was also explained by *(I2_DSO_W2)* who described that standardization knowledge was not important in the past and still needs to be built up. In this sense, *(I2_DSO_W2)* stated:

The challenge for me (it was a big challenge) was my background because we don't care about standards or the information system. For us, the importance lies on the power grid and not really on the implementation and how we can integrate our developments with other systems (I2_DSO_W2)

The interviews also revealed that different *technical depths of expertise* existed in the project, leading to semantic knowledge boundaries. Accordingly, different levels of understanding were required to interpret specific knowledge of partners, to answer questions or to carry out activities in the project. Interviewee *(I26_TSO_W3)* described that the partners also had different degrees of technical involvement and, therefore, were able to go into varying depths of technical detail. A difference in the depth of understanding technical knowledge was particularly apparent between DSOs, TSOs, and research institutes. While DSOs and TSOs were often more interested in knowledge for commercial use, research partners often wanted to understand and expand this knowledge fully *(I31_RD2_S4)*. For example, the different depths of understanding required for technical know-how led to difficulties in agreeing on what use cases should be elaborated for the project tasks. Accordingly, partners needed a basic understanding of use cases in order to make this decision. An understanding of the methodology was also needed to find out what modeling approach was best for the proposed use cases *(I26_TSO_W3)*.

Since some of the use cases that related to the processes of the power system are very complex, you must have good knowledge, especially good domain knowledge. Then you will be also able to model them appropriately regarding the Smart Grid Architecture Model and the final states of the schemes for the data exchange and so on. (I1_RD_E5)

Semantic knowledge boundaries were also described as a *missing technical understanding*, for example, in the area of CIM profiles. Accordingly, the interviews revealed that proper knowledge for developing tasks was not always found immediately and that difficulties arose when modeling information exchange with CIM *(I26_TSO_W3).* Overall, the interview data showed that in the area of the CIM profiling, the implementation of innovative solutions was hindered by the sheer amount of knowledge missing in this area *(I1_RD_E5).* The lack of documentation also indicated that the development of CIM profiles for DSO-TSO use cases was something completely new and that many partners could not rely on existing forms of agreed-upon documentation. *(I26_TSO_W3).*

Yes, it is challenging. We have to develop some new stuff, like profiles and implement this in the demonstration side. There are a lot of things that are so far not developed. Also, there is the challenge that we don't have alway good documentation, such as the transfer of open source data, which is not mature. In some tasks, the methodologies are not mature. And this is leading to the challenge on how to implement and how to prove it (I13_RD_E5).

Problems of comprehension were particularly apparent in the *processing of data* and its classification in the correct context of knowledge production. For example, interviewee *(I25_RD2_S4)* described a situation of receiving a lot of data from a DSO for the project task in the field of web services. The file was extremly extensive so that it took a very long time before the interviewee was able to use the data in any capacity at all *(I25_RD2_S4).* In addition to the massive amount of data, this data was often totally original in form. Thus, the project partners often found that it was difficult to use and understand it in its correct meaning due to the information overload *(I25_RD2_S4).* In this case, the interviewees were required to sort out which data was actually needed and which could be ignored or avoided. The partners found it challenging, as it required a broad understanding of the other partners' data and information across the various specialisms and knowledge fields (*I25_RD2_S4).*

> *The main challenge that I found was quite a lot of errors when merging the networks that [DSO_S4] provided me because it was really different type of files and I needed hours and hours and hours to understand how I could manage to do the communications for the web service. (I25_RD2_S4)*

The different backgrounds not only created knowledge boundaries when understanding other partners' knowledge, but also limited the explanation of new data and information to other partners. For example, *(I27_DSO_W2)* explained how the UML standard or load calculations proved to be difficult in the absence of a common knowledge base. Evidence from these interviews suggests that knowledge integration is significantly limited when partners have different knowledge interpretations rooted in different knowledge bases.

> *Of course, it is more difficult to explain when other people do not share the same basis of knowledge. For example, when you need to explain what is a class in the UML standard from the electrotechnical point of view or if you need to explain what is the load calculation. (I27_DSO_W2)*

Another reason for the difficulties stemming from the knowledge boundaries was the different *processing and understanding of data and information*. For example, *(I2_DSO_W2)* explained that the use case methodology, which the interviewee routinely used, was not familiar to many project partners and, consequently, they found the methodology rather difficult to understand. Therefore, it emerged that a common understanding of the methodology was critical to the progress of the project to ensure that the same approach is used *(I27_DSO_W2).* However, problems of comprehension were found to be less significant over time, as the various project partners gained more experience and understanding in the particular knowledge area needed for the tasks assigned. This demanded discussions and exchanges on the respective topic. Interviewee *(I23_RD1_C1)* added that all project partners behave differently when processing and understanding data and information, which made it even more challenging to get everyone on the same page. The experiences already gained were considered significant by *(I31_RD2_S4):*

> *Yes, unless they understand the topic. It might happen. I worked on different projects where there were some specific partners that already worked in that field and in this case, you could discuss about it. (I31_RD2_S4)*

The project partners used different methods and procedures in the project context, for example, to create use cases or to conduct simulations. The problem here was that a methodology had become established within one organization, which had found little application outside of the organization. For example, the knowledge about certain tools was passed on within organizations, making it difficult for project partners from other organizations to comprehend and apply these tools themselves. Especially due to the fact that often only few manuals were available, it was necessary to ask partners from other organizations about tools *(I17_RD_E5).*

> *You have to analyze a lot about the existing CIM profiles in order to be able to really make a change and create something new. Then the challenge was also adopting to a lot of new tools that are also in development. There are not so many manuals or you cannot really google a problem. You really have to research the tool itself. It is kind of a double research task: the tools and the profile and deliverables themselves. (I17_RD_E5)*

The project partners were also demanded to properly place the concepts in the right field of energy research. Therefore, experts had to be found who, first**,** understood the field and domain, and, second, who understood the methods *(I31_RD2_S4)*. The challenge was therefore for the project partners to interpret the information despite the knowledge gaps on the other methodologies. One partner added that it was particularly important to teach the methodologies to other partners so that there would be a common interpretation within the project *(I27_DSO_W2)*.

> *I think the most difficult part was to explain the methodology we want to follow in creating use cases, because we need to have the same approach if we want to share the deliverable and the task. Thus, we had to make sure that all the involved parties understood the methodology. (I27_DSO_W2)*

The findings showed that the handling of new and enlarged information in the form of words and data increasingly encountered conflicts, as they were not always understood and interpreted due to the project partners' different backgrounds. It was identified that even if the same syntax existed, the project partners were not always able to interpret information and data in the same way. A common semantic, consequently, did not always occur.

Pragmatic knowledge boundaries

Having described the syntactic and semantic knowledge boundaries produced by heterogenous data and information and their interpretation, this section is devoted to the pragmatic knowledge boundaries, which delineate the organizational consequences that developed from the transformation of data and information to knowledge. The interview findings revealed that pragmatic boundaries appeared at different levels. First, they became evident on a project superordinate level, in the sense of different energy infrastructures and architectures as well as political and legal regulations in the countries of the partners. Second, pragmatic knowledge boundaries emerged through hierarchies, bureaucracy and other organizational structures. Third, intra-project knowledge boundaries have occurred that related to the different objectives, working habits and approaches, power relations, confidentiality and feasibility of data sharing and finally, boundaries on and interpersonal level and communication.

Different energy infrastructure and architectures in the countries

Starting with the different energy infrastructures and architectures of the countries involved, the interviews revealed that the project partners were not always fully informed regarding the energy transition in the individual countries of the participating project partners. For example, a project partner from the Southern European country described a conversation with an Eastern Europe project partner. The interviewee was not aware of the fact that in the Eastern Europe country, only a small amount of wind energy was used for the integration of renewable energies because wind power is proportionally lower there than in other countries. This showed that the partners were not necessarily conscious of the energy infrastructures in other countries. This was stated by *(I11_RD1_S4)* as follows:

> *I was surprised in the [Southern Europe country] […], because we have a lot of wind. I don't know why, but I thought that every European country has a lot of wind. So when I talked with the [Eastern European country], they said that they don't have wind and I said: "What? We have a lot of solar and [the Southern European country] has also a lot of sun as well". I was completely surprised that they have much more solar than we have in percentage and much less wind than we do (I11_RD1_S4)*

Likewise, the interviews highlighted the existence of different *energy markets* in the countries of the project partners and identified gaps in terms of how new business models were implemented in other markets than their own *(I28_RD_N6)*. This had implications for the development of common information exchange tools. It became apparent that it was necessary to ask about the relevant system and market conditions of partners from other countries in order to be able to link the technical solutions to the different energy systems. One interviewee showed a lack of understanding other energy systems in the sense that the interviewee was eager to learn more about the different systems and the generic market implementation *(I28_RD_N6)*. The different actors in these systems, especially the numbers of DSOs and TSOs, also played an important role here, e.g. while in some country individual DSOs had a monopoly position, in other countries many DSOs existed, leading to different demand in the countries *(I27_DSO_W2)*.

> *In various conversations, I have realized that there is a huge difference. [Some countries] have completely different problems with the number of DSOs and the absolute number of TSOs […] While in [some countries] each DSO thinks he/she is the "king" of the network, even though there are so many small DSOs, in [other countries] there are only a handful of DSOs. Of course, countries with a smaller amount of DSOs do not have the problem with a wide distribution of contact persons. This means that solutions that work for us may not work for them at all, or vice versa. Of course, this is already noticeable in their concepts. This is strongly reflected there, which may also lead to more conflicts in some places and you do not even notice that this is where it comes from. (I22_RD1_C1)*

Furthermore, a lack of awareness regarding specific *technical challenges* in the energy systems was evident in the interviews. The interview results highlighted that the countries do not have the same technical difficulties, as each national grid has different technical settings and conditions, for example, in terms of voltage etc. *(I3_RD_N6)* saw communication between the partners critical in order to discuss technical issues, constraints or standards in the energy architectures. Therefore, it was considered particularly difficult to develop technical solutions for unknown partners energy systems.

> *Sometimes, we analyze or calculate some indexes for the [Eastern European] partners without knowing anything about their system. Then we show the result and say does that make sense or not? They said: "Yes, that it makes complete sense." Then we feel secure about our methodology and vice versa. (I11_RD1_S4)*

The research identified the importance of adaption by the various regional based partners to the conditions of the country's energy infrastructures and architectures *(I3_RD_N6)*. Effects of these different country specifications were also apparent in the joint project work, so that knowledge boundaries occurred when these country specifications were not exchanged in advance. The system architecture in the respective country, therefore, had a major influence on the technical solutions developed in the project. To implement collaborative technical solutions in the project, knowledge about the energy system and architecture in the different countries had to be acquired first, so that no knowledge boundaries would be created in the field.

Political and legal regulations

Pragmatic knowledge boundaries were also seen in political and legal regulations, such as the GDPR - a data protection regulation that was adopted by th EU in May 2016. The regulation aims at protecting the processing of personal data and regulates the movement of data in the EU (European Commission 2022). The interviews revealed that the GDPR had a major impact on project work and led to restrictions, particularly concerning data sharing, which *"made the process somewhat harder" (I4_DSO_S4)*. Since the project took place under the umbrella of the GDPR, which is designed to protect European data transfer, the interviewees described an overall high sensitivity in dealing with data in the project. The interviewees described that data was not always allowed to be exchanged or needed to be verified before sharing, especially with the industry partners. This was stated by *(I5_DSO_S4)* as follows:

> *Researchers have the advantage that they can talk with all the partners in an easier way. [...] The DSOs and the TSOs are a little bit more closed due to the grid and GDPR issues, which have been implemented recently. As R&D perceives, the function [of DSO and TSO] is to be totally open, in the sense of developing our grid with several companies. On the TSO and DSO side, it is a little bit the opposite. Having those companies coming to us and try to create value inside the TSOs and the DSOs [that does not work] (I5_DSO_S4)*

Many interviewees emphasized that the difficulties do not necessarily stem from the technical understanding, but rather from legal and policy issues and how to implement these technical solutions in the face of these constraints. For example, two project partners from Central and Eastern Europe were able to understand the technical solutions developed by the Southern European partner but they stated that the national and international regulations often stood in the way of that knowledge transferability, thereby making it more complex. Clearly, political and regulatory requirements also had an influence on the speed of implementation, especially, when many data protection guidelines had to be complied with at national and international level. The interviewee *(I5_DSO_S4)* remarked that this led to knowledge limitations, as the transfer of knowledge was restricted.

> *If, for example, a University teaches highly differently, you would have differences in technical aspects. But that's not much the case. We see that what we do in [Southern European country] is perfectly understandable in [Eastern and Central European country]. If we put it in practice or not that is another question and that depends on regulatory issues, on the advances in terms of technology in the country. In that aspect, [Central and Western European countries] are the head of the pace. [...] But I would say that the technical skill itself, I don't see any big differences. Maybe I would say [Eastern European country] could be a little bit behind, but not much. (I5_DSO_S4)*

In conclusion, the interview data showed that the general pace of implementing innovations and new solutions within the projects depends in particular on political and regulatory decisions in the respective countries. Regulatory aspects from national politics and international laws steered the partners and reduced or increased the dynamics of innovation. Policy directives, therefore, also determined the exchange of knowledge and the implementation of knowledge in the different countries *(I5_DSO_S4)*.

Hierarchies, bureaucracy and other organizational boundaries

Apart from superordinate difficulties through the different energy systems, as well as political and legal regulations, pragmatic knowledge boundaries also developed because of organizational boundaries. As this research has already identified, different hierarchical internal structures and predefined action competencies strongly affected organizational proximities of the partners. In this sense, boundaries within the organizations became noticeable as most of the project partners had to coordinate their tasks with their chiefs and ask for permission, for example, to share data and information with external project partners *(I27_DSO_W2)*. Hence, internal validation processes led to difficulties in knowledge sharing and communication at all. In the case of DSOs in particular, various topics had to be clarified across several hierarchical stages.

> *It is a bit more difficult to communicate with [DSO_S4] because of the internal structure at [DSO_S4]. [DSO_S4] has a vertical structure with too many boss. Therefore, it is very difficult to get the data. (I21_RD2_S4)*

Consequently, internal processes led to delays, e.g. when answering inquiries from other project partners or exchanging data. Some of the interviewees, such as *(I2_DSO_W2)* noted that the size of organization has an impact on knowledge exchange in terms of bureaucratic structures and many levels of hierarchy. Next to the DSO partners, also TSO partners were subject to strong administrative control within a fixed hierarchical framework. Again, decision-making processes were shown as an example of this formal structure, leading to pragmatic knowledge boundaries. Consequently, TSOs had to obtain various approvals and signatures, e.g. to perform tests and simulations as part of the project *(I32_DSO_E5).*

> *It is difficult because big organizations or TSOs have many levels of decision-making. When you start to get approval for some tests, then you need let's say five, six, seven signatures saying you have to preserve each of them. And if you have, for example, five partners, then it proves that you don't have enough time to get to the end of this story. (I32_DSO_E5)*

Although research partners did not experience their work as structured by organizational hierarchies, nor did they face the same organizational hurdles as DSOs and TSOs, they too expressed concern regarding the difficulty of obtaining multiple signatures and approvals to complete their tasks. The need to obtain ongoing approval for every disputed or questionable disclosure of information not only limited knowledge sharing, but also hindered substantive work on project tasks, leading in task delays. *(I14_RD2_S4)* described that these various background processes and approval procedures were not even perceived by all the project partners. As a result, not all of them were sympathetic to delays in the project work. In this sense, *(I14_RD2_S4)* stated:

> *[…] of course, they always have to worry about data issues, security issues and so on. You need to go to the departments to get the proper approvals and establish the networks that are safe. It is a big data basis to handle, just to get some field data and to run one tool. There are background processes that are very huge. Normally as researchers, we don't imagine these problems: We just get some data from a database with all techniques and in a specific format and then you just use the tools and it works perfectly. The biggest worry is not the tool running, but it is when you go to the real world and see the list of real worries to run the tool. We have several processes to overcome. (I14_RD2_S4)*

As the relationship between the hierarchically organized partners showed, more effort had to be put into knowledge sharing, especially because of the very bureaucratic structures. For example, *(I32_DSO_E5)* generally described that the higher the organizational hurdles were set, the longer the approval processes took. Particularly with regard to knowledge sharing, it became clear that some organizations interviewed have established specific organizational rules about what knowledge can or cannot be shared *(I2_DSO_W2).* Similarly, the case study project showed that the organizations had different internal resources that were dedicated to the project. For example, tsome project partners found it easier to carry out the tasks if certain tools were provided or if the organization already had a wide range of material. One project partner explained that project tasks were easier to accomplish for many DSOs because the data equipment and tools were already in place in the organization. For TSOs, who do not normally trade and use network data from DSOs, this equipment was not always available. Therefore, funds had to be provided to equip laboratories with materials. However, ordering new materials often involved a high administrative burden *(I27_DSO_W2).*

Project objectives

Taking a closer look at the pragmatic knowledge boundaries developed in the project, an important point was the different and conflicting interests and goals of project partners, which had consequences for the application of heterogeneous knowledge in the project. The interviews showed that the organizations were often influenced by the overarching corporate strategies of the respective organizations and could not always work on the project detached from them. It became apparent that the overarching goal of energy transition appeared to be the same for all organizations from the outside, but the *goals for implementing Smart Grid solutions* were very different. One of these goals was the energy mix for the future Smart Grid, which was considered very differently. While some partners focused on wind or solar energy, the interviews revealed that other organizations were also researching in fossil fuels.

> *You need a common vision, which is very difficult because not everybody has the same vision. The objectives can also contradict each other. That can be a problem. You have a different wording, which is a problem, and regardless of the different objectives, you can divide the objectives in the sense of, "You can have a common vision for the Smart Grid as a total solution. This does not mean, of course, that we have a common vision of how this Smart Grid will work." This can also often lead to conflicts. (I22_RD1_C1)*

The different project goals and strategies for the overall Smart Grid solution also became evident with regard to the platform design. Partners openly questioned the developments regarding the project's goals and implementation, for example, with regard to the operation of flexibility markets or the coordination of society issues *(I5_DSO_S4).* Another research partner explained the inconsistency of aims by saying that each organization *pursued its own objectives* in the project. Due to the aforementioned openness of task fulfillment to the project plan, organizations often brought their own motivations and aims to the project work. However, this was not always negatively evaluated by everyone, since each organization had different problems to solve and this unintended diversification of research aims enabled the project participants to develop the individual solution. Hence, some project partners were more aligned with the spirit of project than other *(I12_TSO_S4)*.

> *[…] Over time, however, you notice a little bit, or rather, you learn this problem, that every organization participating in this project has its own objectives. That's perfectly fine because every organization has its own problem and its own solution, similar to what we had before. However, a solution that works for one company does not necessarily work the case for the other system. (I22_RD1_C1)*

The partners had different visions for the Smart Grid but also prioritized and worked on their own organizational goals within the project. Partners were often cross-subsidized by the EU projects. Accordingly, their funds were used to advance research within their own organization. For example, *(I23_RD1_C1)* explained that often a lot is promised by the project partners, but the implementation of these commitments cannot always be kept. The interview data indicated that the difficulties in implementation are related to the fact that a lot of communication and organization is needed.

> *Usually, when you apply for a project, people want to get funds and they promise lots of things that are then in reality very difficult to achieve. Not because they were so hard, but because they require some communication and they require lots of organization. You have to break some started rules if you want to achieve something. So, the paper can hold many things but in reality, you are sometimes locked to some rules that cannot be bride (I32_DSO_E5).*

One cause for the different project objectives was identified in the interests of the three types of organizations. The different objectives followed by the industrial partners and research partners were particularly stark. While some industry partners brought their own topics into the project and developed them further for wider corporate gain, research partners often had more interest in getting publications and developing a reputation so that they can successfully apply the new knowledge for the next project *(I23_RD1_C1)*. On the one hand, this showed that the industry partner actually intended to use the ICT developments from the project for future use, why it was important to develop them in their spirit. On the other hand, research partners used the developments more as new experiences for future research.

> *However, if you look at more academic actors, such as [R&D_N6], they want to publish some papers. For example, they want to write a board to publish a paper. It is not, for example, a priority for a DSO, such as for [DSO_W2]. For us, the priority was that the work was also useful in the case of the [DSO_W2]. (I27_DSO_W2)*

Disagreements between the three types of organizations were also evident in terms of standardization and interoperability between the actors, which was the ultimate goal for the data exchange platform. Although the involved organizations were dependent on a mutual exchange of data and information in the project, the interview findings showed that a standardized exchange of data did not exist in the project. While TSOs had the overarching aim of using CIM or CGMES as a standard for information exchange, DSOs often had their own proprietary tools for information exchange and, thus, did not always see the need to pursue these goals together (I10_RD1_S4). DSOs often justified their methods by saying that the processes of data and information exchange were well established and no reasons were seen to change the way they processed and shared data. Therefore, data evaluation could not always be done as proposed in the project goals. Difficulties in achieving and using the data led consequently to time pressures.

> *As I mentioned yesterday, the DSO from [Southern European country] sends their data via Excel, because there is no standardized way of message exchange. Ok, but they think that we are putting CIM in one Excel. And this is not because of cultural facts, but it is because our system users in the company. One person in the company can't change everything, because when we talked with the other guys, people say that, "The system is working, why should it change?" (I2_DSO_W2)*

> *One of the tasks of [project name] is really to extend the profiles for CIM and CGMES. This is tough because it takes months and years for everyone to agree, to develop and then to implement this new standard. So sometimes for us, it is boring, because it is just a detail and it took two years to add this new feature. (I12_TSO_S4)*

As noted in this research, the interviews showed that the partners did not immediately agree on how data should be exchanged in the future and, therefore, were not always willing to share knowledge. The interviewees argued that the operators in particular exchanged data in the same way for many years, and are, therefore, sluggish in implementation and do not always show a willingness to change the way they work in line with the new standards *(I31_RD2_S4).*

> *It is described on that standard and the problem is first, that in the past this did not happened and even nowadays, many of the operators still not use this standard. And what happened is that if you have, for example, the demonstration of one year and a half, at least you need half of the year to allow you to adapt your tool to the way how the operators provide information. Nowadays we need to adapt, but I can say to you that this is the perfect world. The perfect world would be, if we go to one place or another, you simply plug and play your tool and everything work. I understand of course that the operators have internal systems that were born 40 years ago (I31_RD2_S4)*

The overall project aim of achieving interoperable information exchange did not meet any approval between the partners and, therefore, represented a critical aspect in project objectives. Other partners focused on representing the views of the organization at every stage of the project. One TSO partner described a case where they disagreed on statements in a deliverable because they did not align with the other organization's vision. This case involved the development of a use case for the active management report, which led to discussions in the project as the partners tried to explain their concerns about the statement in the use case. However, the conflict could not be solved as another organization wanted to keep this statement in the deliverable. In the end, a disclaimer was finally placed that not all organizations agreed with the statement. However, internally, it was not possible to continue working with the use case in the deliverable *(I26_TSO_W3)*.

> *If the project proposes a new vision or makes a new preposition, it has to be aligned with [TSO_W3] positions. This was a very big concern and it brought some problems, because there was a new preposition from one partner of the project, but [TSO_W3] was not in favor with this preposition. So we argued and we had fights. This is the issue that we had in the projects. Whatever you propose, it has to follow the core goal from the government. If you make a new preposition, it cannot be put in place. I mean this was the concern. (I8_TSO_W3)*

Likewise, it became apparent that the goals of the project were not always clear due to staff changes and openness of the tasks in the proposal. One research partner described that some organizations did not always know the reasons for participating in the project because sometimes the organizational members, who were involved in the proposal phase, were no longer participating in the project (I23_RD1_C1). This was also seen by the very vague descriptions in the project plan. While this gave the partners enough leeway to accomplish tasks, it was also criticized for making it difficult to understand the overall project aims. Not surprisingly, this fact led to different interpretations of project partners, who ultimately used different approaches to solve the tasks. On the one hand, this was perceived as positive with regard to the scope for design; on the other hand, it was negative because of few concrete instructions. However, the interviewees found that especially in research projects, results can always turn out differently and goals as well as tasks are able to change in the course of the project. This was explained by *(I6_RD2_C1)* as follows:

> *[...] So, that's one thing when the project plan simply leaves too much open. Of course, this can have advantages, but it can also lead to project partners releasing themselves from the responsibility. (I6_RD2_C1)*

Particularly in the pursuit of the company’s own goals, there was a threat of knowledge boundaries, as a shared vision for the project goals receded into the background. Subsequently, little coordination between the partners often prevailed as a result, increasing the danger that partners withdrawing from their responsibility. The interviews showed that due to the lack of coordination, project partners did not always know what to do with the information and how to integrate it into the larger project goals *(I14_RD2_S4)*. A meaningful storyline was all the more important to usefully apply and integrate knowledge.

> *In particular, in the proposal or in the grand agreement, it is not always very clear which partners take on which tasks, in terms of exact definitions. Even if it is not precise defined which is standard, then it is especially important to talk about it at the beginning of the project. (I26_TSO_W3)*

The predefined project goals and the implemented version of these, therefore, proved to be a double-edged sword. This openness of the project goals indeed was deliberate for possibly changing the direction of the project and enabled organizations to adapt the ways of dealing with the project tasks according to their learnings. However, for the integration of knowledge by partners, this required a greater need for coordination between them. The exchange of knowledge and joint discussions about the direction of the project was particularly necessary here (I16_RD_E5). The interview findings showed that it was important for the project partners to hear other person's experiences and points of view. Talking to people with different perspectives was, therefore, an interesting part of the project as other project partners presented new aspects and approaches that the interviewees were not aware of (I2_DSO_W2*)*. In this manner, *(I9_TSO_N7)* explained that it was first necessary to find out what political interest the organizations were pursuing and what positions they held in the project. Thus, the organizations had to take into account the different points of view. This was especially important during the implementation of systems, as misunderstandings about the different goals of the project partners could have influenced the further success of the project.

Working practices and habits

Another central theme identified in this research was the different working habits and approaches used in the organizations and applied in the project. These working practices and habits had a great influence on how work was conducted in the project in general and, thus, how knowledge was integrated. On the one hand, this refers to the methodological approaches in the sense of which and how knowledge was used in the project, on the other hand to the procedures and habits in terms of how work was generally organized between the organizations. Starting with, the case study showed that the organizations had different methodological approaches and solution strategies to be tackled for the project tasks, which led to boundaries. Consequently, the organizations had different attempts to allocate their resources to the project and comprised different ideas for solving the tasks in the project (I21_RD2_S4).

> *With [DSO_S4] we have meetings in the dispatch area with IT guys, who are very different partner and they have different ideas of solving problems. I think this is the main difference between the partners. (I21_RD2_S4)*

The challenge of using, but also understanding different methodological approaches to the tasks were particularly needed for creating joint solutions that had to be satisfactory for all partners, which, however, was not self-evident. Consequently, the understanding of the different practices was seen as a boundary. For example, *(I4_DSO_S4)* described that it took a very long time to comprehend new approaches and find a common working practice that everyone was satisfied with. In this sense, *(I16_RD_E5)* stated:

> *[…] Exchanging ideas, exchanging experiences and also trying to understand their way of thinking […] is very important because sometimes when you assume that you are correct in your thinking, you can try to implement something or specify something and then at the end, it might turn out that the DSOs have a completely different view of the same situation. Therefore, it is really important to discuss matters and to actually implement things that are useful for them. And that's what we try to aim for (I16_RD_E5).*

The difficulty of aligning different working practices and habits was also evident in the way of how organizations dealt with mistakes and failure. In this way, some interviews partners found it especially important to try out and make mistakes in order to develop further, while others saw mistakes as a general failure, which had a decisive influence on the project. Therefore, the weighting of errors was perceived differently, which also influenced the collaboration. Hence, the handling of failures was handled differently in the project *(I9_TSO_N7).* According to *(I26_TSO_W3)*, besides the error culture, transparency in the working habits also played an important role, which was needed to recognize how knowledge could be used. Given these explanations, transparency led to higher project synergies and complementarities, as organizations were better able to assess the working methods *(I26_TSO_W3)*.

> *I think a really important thing is to have some transparency from the beginning of the project between the partners, in terms of their skills, what they can do and what they cannot do. That way, we can work with complementarities and synergies and I think that is really important in order to avoid that one partner thinks that another partner will deliver something and then it is not possible (I26_TSO_W3)*

The working practices and habits when conducting the work in the project varied significantly among the three types of organizations, as DSOs and TSOs operated quite differently from the research institutes. This again revealed difficulties between the research and industry partners. While the research partners were particularly likely to put forward a more theoretical approach to the tasks, the DSOs and TSOs had a more practical one. For example, *(I28_RD_N6)* stated:

> *Well, there is an obvious difference between industry partners and research partners. So, we [R&D_N6], or as I mentioned earlier, [name from R&D2_S4], their establishment [in the project] was from the research side, whereas from [DSO_W2] or even from [TSO_W3] you could see an industry approach to the project. So that's one major difference. (I28_RD_N6)*

These two different approaches were characterized by the interviewees as the researchers being more open-minded for new knowledge areas, while the industry approach was particularly concerned with economic growth, increasing sales and were often more focused on the usefulness of innovation, rather than the innovation per se. Similarly, the interviews revealed that it was often easier for research institutes to try out different approaches and methods, to swap into different fields of knowledge and change the path again, if a certain way has not led to any significant results. The interview data showed that in research institutes more room was available for the further development of ideas and the exploration of different approaches, while the partners from industry were often not as flexible, mainly due to a lack of time. For example, *(I28_RD_N6)* explained:

> *Usually in research, we are using a lot of simulation and we are doing more theoretical research, while in the industry they are doing more practical oriented research. So that's a difference, I would say. Our advantage is time, because we are a bit more open sky, while in the industry the research is very incremental. You have a solution, for example, a tool, which you are trying to develop further. For us, it is easier to say, "Okay we are scrapping this tool, we are changing direction and we are developing the new one from a different perspective." (I28_RD_N6)*

Different approaches to work were also evident in the fact that project partners had a different need for discussions and a different way of arranging meetings. Organizations, therefore, brought different rituals of communication to the project, which had a major impact on the way of working together. While some partners wanted to meet regularly, others found it sufficient to meet monthly. However, the different work schedules and pace of task execution or development created challenges in the project work and had a critical impact, as knowledge could not always be integrated according to all the partners' needs. This was explained by *(I3_RD_N6)* as follows:

> *As I said, it's good to collaborate and to meet with the partners. But this is very different between the project partners, some like to meet very frequently, even if you do not have anything. For me this is also fine. But at the end, you need to meet at least ones in a month in order to share what they have and as I said we have this problems actually between some of the partners that some people don't like to share what they have. (I3_RD_N6)*

Country-specific working habits were also evident between the organizations. The interview findings revealed that the organizations from the Southern European countries especially had a different daily routine in contrast to the Northern, Western or Central European organizations, as the organizational members took siestas and worked more in the evening hours. One interviewee, *(I3_RD_N6)*, described this approach of working as an exchange of knowledge from time to time. In particular, different perceptions of joint meetings to share knowledge have led to knowledge not being there in time or to misunderstandings arising beforehand.

> *I think it is misunderstanding regarding the culture, because of the language and habits. For example, the meetings: You know we suppose to schedule the meetings, is it in the morning, afternoon or evening. These kind of barriers could happen due to the culture and the habits, because I think, the habits are a source of the culture (I3_RD_N6).*

Taken together, the interviews showed that organizations had different ways of working and habits. Overall, it appeared that DSOs and TSOs adopted rather similar approaches in contrast to the research institutes. This illustrated that knowledge boundaries were more likely to occur between industry and research partners. It was, therefore, questionable to what extent the project partners with different ways of working and habits were able to integrate knowledge or to what extent they had to adapt their different approaches. However, it was generally seen as rather challenging to change the organizational working practices and habits *(I12_RSO_S4).*

Power relations between the project partners

Adjacent to organizational differences in terms of hierarchies that led to knowledge boundaries, the interviewees also highlighted power relations as a difficult factor in the collaboration. In this light, power relations played a significant role in the project work and have been mostly reflected in the form of *responsibilities and control* within the project. The interviewees explained that certain partners took on more responsibility than others and emerged as leaders, who paved the way, exerted pressure, or had a vested interest in the project's success. The interviewee *(I32_DSO_E5)* used the metaphor of building a home, whereby strong partners had to lay the foundation and the cantilever stones, and the other partners were working on top of this foundation. This was stated by *(I32_DSO_E5)* as follows:

> *Maybe the only difference I somehow felt was that you have certain partners who have bigger award or bigger influence on the project or on how everything will proceed. However, you know that I already have some grey hair now, which means that I find this is somehow natural. You have some strong partners that have to lead, that need to make good foundation and corner stones and then you have partners who have to build this house. Basically, I think it is not possible that all partners are completely equal – on paper, yes, but in reality you have some who take bigger responsibility and bigger challenges and are driving forces to make our project happen and also to bring the project to completion. Basically, I think that applying for projects with the partners is one part of the story. This is important and it is not easy, but it is easier than to execute and complete the project. (I32_DSO_E5)*

Based on these considerations, the interviews evinced that an *equality of power* would not be possible in Smart Grid projects because the partners were too heterogeneous. Accordingly, it would be natural for some partners to have more or less power in such a collaboration. In a strategic fashion, certain interferences have been played out, impacting the exchange of knowledge in the common work. This image was also underlined by a DSO interviewee, who observed that some project partners tried to influence decision makers in order to push through their position and to impose its views and approaches on other project partners.

> *It is important to have influence, to have a position and to have influence about their activities. Sometimes when we are participating [in such projects], we need to be aware about this, because sometimes some players are trying to influence the decision makers showing that what they are doing are the best thing in the world. But, anyway, I think that happens in European projects, not only at the company level, but also even at the individual level (I29_DSO_S4)*

The organizational functions of DSO, TSOs and research institutes also played a role in this case. The three roles of the energy system were often used as a justification for power relations. The interviews emphasized, *"there are views that depend on […] the side of business you work* *or even the side of the business you used to work" (I4_DSO_S4)*. Arguably, the interview data revealed different positions between the three approaches of DSOs, TSOs and research institutes in the project. The role of the DSO partners, which was not clear at the beginning of the project, particularly within the future Smart Grid, was represented by the DSO partners with great passion and commitment. For example, *(I4_DSO_S4)* stated:

> *It was a big surprise for us to see that the earlier business use case proposals did not take the role of the DSOs much into account. And of course, with discussions, we managed to reach a balance to business use cases that respects the DSO role, but also the TSO role [...]. I have already talked to other people in [Central European countries], that come from DSOs, or from companies that work for DSOs that have a different opinion on some subjects. And I think the main difference that we had was to see a somewhat deconstructive idea [of roles] that people had in this project. (I4_DSO_S4)*

The role of DSOs in the future energy system was very striking in the interviews and, consequently, led to discussions in the project work. The interviewee *(I4_DSO_S4)* summarized that some partners strongly agreed with the viewpoint of the TSOs, while others were more aligned with the perspectives of the DSOs. According to the interviewee, too little attention has been paid to the role of DSOs in some use cases and, thus, they have not been sufficiently integrated. During the course of the project, some discussions did not lead to any agreement because not all use cases complied with the TSOs regulations. The view of the future role of the DSO depended very much on the countries from which the organizations came, thereby influencing the alignment with the TSOs or DSOs point of view.

> *I think it was very clear in the early discussions of the project: TSOs have a view, which sometimes not include much the DSO role. I think it was apparent. It varies from country to country. What I saw from our [Central European] partners, not from me specifically, it was that even in academia they were very much aligned with the TSOs view. Other partners like the [Western European country] were more balanced, I mean our partners in [DSO_W3]. (I4_DSO_S4)*

In accordance to that, the interview data showed that DSOs sometimes even feared that their role would change in a certain direction, conflicting with their interests and competencies. Thus, some of the DSO partners wanted to emphasize the importance of their role in the system, ensuring that it would not be neglected in the project work. The conflict of roles was particularly evident in the investigation of the TSO approaches, such as the platform design or information exchange with CIM and CGMES. However, there were also other interviewees who did not place any emphasis on highlighting the individual roles in the system. For example, *(I11_RD1_S4)* described that it was more important to find common ground and establish a good cooperation in the project. According to the interviewee, this was achieved by sharing needs and knowledge between DSOs and TSOs, which ultimately worked out very well, as various common knowledge topics could be identified. *(I11_RD1_S4)* explained this as follows:

> *I have to say that the first meetings were tough because one typical reaction at the beginning was, "Welcome, we are willing to participate, but remember only one simple rule: We are the DSO and we tend to continue the DSO." This was the first five seconds of the meeting and then I said, "Ok, I didn't say anything in that sense." We just want to find common things that, for example, are the [common] pain. So, if you share your pains, some of your pains are my pains and I think if we find common pains, we find common ways of solutions. And that's the exercise that we have done. We have identified five or six topics. Then we focused on four and we managed to incorporate three [topics]. In these exercises, we have already three in the pipeline and four new calls. If the topics are in this area, we will address them. This is the first step, but we want to continue to cooperate and it's really nice. (I11_RD1_S4)*

The interview data identified that the execution of power in the project was equally evident in terms of tasks deadlines that were relevant to all organizations. According to *(I22_RD1_C1)*, the assertiveness for the joint working on tasks and the adherence to deadlines was not always present in the project. The difficulty developed that partners did not officially had the authority to force the partners. This was also evident in a workshop where certain topics were discussed that required persuasion to convince all project partners to submit data or other relevant materials to the project – even though some partners did not have official authority to issue directives. However, partners in leadership positions and responsibilities also sometimes found it difficult to exercise their power when partners could not be coerced into delivering certain results *(I6_RD2_C1).*

> *I have learned for myself (because I simply have the role of the architect and the system engineer in the area systems networking) that sometimes I have to push people around a bit and force them to sit together in a workshop. Even if the partners sometimes do not want, it is often the case that people realize that they need to discuss things together. That is also the experience in other projects. Sometimes, it's like giving an impulse. I don't have any influence on it; we don't have the authority to give instructions or anything else. Even if you have the knowledge and know that it's a problem, you cannot force them (I22_RD1_C1)*

Summing up, it became apparent that different power relations developed within the project, which not only influenced the execution of functions of the project partners but also decided which and to what extent knowledge was shared. It was considered particularly important which items were finally included in the deliverables, as they represented the position of the entire project. At another level, enforcing tasks without actual authority was challenging, as it was more difficult for some partners to implement and demand results.

Confidentiality and feasibility of data sharing

As has been mentioned repeatedly, data sharing has been one of the most important issues in the project, not only due to hierarchical and bureaucratic structures *(I21_RD2_S4)*, but also due to confidentiality and feasibility matters. Hence, the interview data showed that project partners were equally confronted by restrictions that inhibited data sharing despite the recognition that all organizations benefit from it. According to *(I22_RD1_C1)*, the network data of the different

DSOs were needed to describe information exchange on the platform, mainly for the creation of payloads in CIM and for the final testing of communication exchange processes. Although data was imperative for the project work, there were reservations about sharing network data to partners, mainly in the beginning of the project. Accordingly, agreements had to be made first on the sharing and usage of the data within the project. Two main reasons existed for this reluctance: On the one hand, these data were often confidential, which were particularly worthy of protection and were not intended for the general public use. On the other hand, the data was often extensive to the point that all information relevant to the project had to be prepared and filtered in order to obtain computable data. Therefore, it was particularly challenging for the project partners to receive network data from other partners. In some cases, it was even impossible to get the network data at all *(I6_RD2_C1)*. Furthermore, interviewee *(I30_RD2_C1)* added:

> *Technically, one of the biggest challenges was to obtain enough network data, which was not the problem but to prepare computable network data from it. Thus, it was a big effort to get the network data with the corresponding time series and to prepare them so that we could use them with our simulation tool. That was quite an effort. That's what I remember most about the effort. (I30_RD2_C1)*

According to the information from the interviews, the respective organizations had to prepare and process the new data before it could be shared with other partners. The interviews showed that there were the partners that waited for the data, on the one hand, and the partners that hosted the data and who were regularly contacted regarding the status of the data. Overall, the data topic was perceived to be rather difficult for both parties, which tended to hinder a regular exchange of knowledge. Nevertheless, the need for constant communication concerning the data sharing was still very high. Some interviewee explained that they needed a long time to get feedback from partners and even offered help in resolving data issues. Particularly in the case of time-relevant tasks, *(I30_RD2_C1)* explained that deadlines were set for the forwarding of data so that further knowledge could be generated with it. In this sense, *(I22_RD1_C1)* stated:

> *For this communication, I need concrete communication processes, e.g. in the order in which they communicate. Also, for each message that is communicated, I need the payload, e.g. what content is communicated, what data structure it should have, what meaning it should have, such as semantics and syntactics – and all this in detail. This is, for example, necessary knowledge to carry out tests. Without this knowledge, I cannot prepare a test. That is something I should have tested in the project, but which was out of reach. Such profiles arrived very late, at least for me, even after several requests. This would have been knowledge, for example, which would have been needed in any case. However, I cannot say whether the partners were not willing to share this knowledge or whether the it [the request] did not reach the right people. (I22_RD1_C1)*

Dwelling on the feasibility of data sharing, another point was that organizations needed to build the skills for new data treatment. According to *(I29_DSO_S4)*, experts for specific type of data were required in order to explain the data to partners and build the ability in the project to extract and organize the data, to apply some type of statistics as well as to analyze the data and its quality. The interviews showed that dealing with the amount as well as the type of data was completely new, in that new tools were needed to process big data, but also that data itself was very complex. Likewise, problems existed with databases, data converters, data communication, data collection as well as with the gathering of data measurements, which needed to be addressed in the project. To this end, *(I14_RD2_S4)* suggested to develop a list of processes to improve the exchange of information in order to be able to determine the performance of short-circuits. The interviewee also described that due to the limited amount of data, a proof of concept had to be created first in order to deploy the solution *(I14_RD2_S4)*. Although there were many tools for data processing that ran in the project context, *(I14_RD2_S4)* explained that the problems started with real-world data.

As indicated earlier, the interviews revealed that there were still *confidentiality issues* in the organizations, which resulted in partners being uncertain about exchanging data. The industry partners demanded especially detailed confidential specifications from other organizations in order to protect knowledge and data, as these may one day become a product *(I6_RD2_C1)*. Likewise, some involved organizations did not yet have a data distribution policy, why the project partners often had to talk to their legal departments about security issues and proper authorization, as well as setting up a secure network. Therefore, the partners had to prepare the results in such a way that they could be made available to the public. Subsequently, a huge amount of confidential data had to be processed just to get some field data and run the project tools *(I14_RD2_S4)*.

> *Yes, network operators actually make the network data available for simulation, but they just don't want details to be published. Accordingly, we can only pass on our knowledge about the network data in the form of results. However, that's what matters in the end. In our organization, there are areas, which are slimmed down. Knowledge that can later become a product or what we want to sell cannot be provided for project partners. (I6_RD2_C1)*
>
> *In some case, it can take a lot of time. For example, we do not have the right to provide some parts of the network. Today, this knowledge that we can share has been published as open data. In the next project, it will be easier to use it for [DSO_W2]. (I27_DSO_W2)*

The interviews showed that data sharing was taking on an increasingly important role in organizations as more partners recognized the importance of it. For example, *(I10_RD1_S4)* stated that the project partners came to realize that providing information and data was not a bad thing and that both partners would benefit. However, it was argued by *(I11_RD1_S4)* that in Smart Grid projects, not all data had to be shared, but it was necessary to know and share the right data. For example, *(I3_RD_N6)* explained:

> *From my point of view, if you do not share your knowledge, you are losing more than you are winning. […] When you share the knowledge with others, they are also sharing the knowledge with you. So, you gain extra knowledge. (I3_RD_N6)*

The interviews revealed that confidential issues could be addressed when DSOs and TSOs started to trust each other. Accordingly, when individual partners began to share knowledge, so did other partners. For example, *(I8_TSO_W3)* explained that when a DSO partner passed information, also the TSO partners started to share information e.g. about platforms.

Interpersonal boundaries and communication

> *I think some of the challenges are how to come up with a way that it will be working; that is, adapting to new challenges because as you are getting new productions and the network changes, also the challenge will change. So how do we build good relationships? (I9_TSO_N7)*

This quote illustrates the new challenges posed by the new structures and networks that are currently changing the relationships between organizations and their representatives. New relationships emerged and old ones changed, prompting the question as to how good relationships can be designed against this backdrop. The interviews revealed that this phase of creating new relationship constellations between each other has also brought with it interpersonal boundaries, which were, first, evident in missing communication with each other. One such example of poor communication was stated by *(I6_RD2_C1)*, who saw the reason for omitted communications in a lack of coordination function. The interviewee criticized that it was not always obvious how the status of the tasks was, whether problems developed or if the tasks were running adequately. Therefore, the lack of communication led to the fact that knowledge was not always sufficiently shared, even when necessary for certain tasks. This was explained by *(I6_RD2_C1)* as follows:

> *There are also partners with whom it is difficult to get closer to them. The information from these partners about the status is formulated very general, so that you cannot really hear what is actually happening at the moment. It is very, very difficult to have an overview of what is actually going on and whether they are adhering to the plan or not. (I6_RD2_C1)*

Such a situation was not an isolated case in the interviews and often led to misunderstandings and conflicts in the project work. Other interviewees pictured similar scenarios in which the project partners encountered the same problems at different points in the project's work. Due to the lack of communication, they did not exchange information about a problem until quite late in the project. Consequently, each partner tackled these problems on their own and they were not able to exchange their different approaches to solving them. Communication on an interpersonal level, hence, did not always succeed in the project, as some partners were not aware of the other partner's activities and challenges *(I6_RD2_C1)*. In this sense, *(I10_RD1_S4)* stated:

[...] in some work package or some other task, we had people that had the same problems that we are having and we probably missed some communication between the tasks and between the people that are leading the tasks in order to understand that. [A conversation was] for example, "Oh you already tackle this problem. What you find could probably help us. And vice versa, this is also a problem that you could look at and try to improve in future projects." (I10_RD1_S4)

While communication was missed at some areas of the project, other interviewees indicated that communication did occur but was *not intense enough (I1_RD_E5)*. Especially in the case of learning new methods or project specific content, *(I1_RD_E5)* said that it was considered as very important to communicate intensively. However, this did not happen in some parts of the project, although thorough communication was crucial for preventing interpersonal knowledge boundaries *(I1_RD_E5)*.

It is interesting to note that even with a high level of communication, not all partners were equally able to *understand and empathize with each other*. Accordingly, knowledge boundaries developed in the sense of a missing chemistry between some partners. Here, too, *(I22_RD1_C1)* showed that it was not always known what was happening in the background, whether something was actually being developed or whether there was "just much talk and no action."

I would not know where to draw the borders. I find this point very difficult to evaluate, but there is a difference between (I hope this does not come out wrong) those who talk a lot but deliver little and those who do not talk at all, but deliver their tasks [...] But when you look at it from the side, you just notice the difference: Some people deliver relatively little themselves and nag a lot, so at least I get to hear that from them. That doesn't mean, of course, that nothing happened in the background. And with others, I often did not hear much, but then I suddenly read a deliverable and thought: "A lot has happened there - more than I was thinking." (I22_RD1_C1)

It became apparent that a common understanding between the project partners was not always present. However, the lack of understanding for each other was also blamed on the complexity of the tasks, as well as the scope of the project and the involvement of various partners. Overall, the opacity of the project itself has led to an uneven picture of communication strategies and their social relations. One interviewee criticized that the partners would often stay in their own field of knowledge and would rarely leave their comfort zone to integrate new knowledge. In this vein, it was also criticized that not every author when trying to solve a problem, understands why a problem existed *(I9_TSO_N7)*.

Sometime when there is mutual interest, people start to find common ground of understanding. But it is still difficult. I believe people are more focused in this project [such as] on data models, communication infrastructure, protocols and so, thereby they tend to be in their comfort zone. There is one partner in this consortium that really can mix best of it. I think it is [R&D2_C1]. They have expertise on both sides (I14_RD2_S4)

As was also noted with the difficulty of data exchange due to the feasibility and confidentiality matters, high need for communication was required for the testing of data within the project. For this purpose, different DSO partners had to be contacted in order to achieve the data for the testing. This proved difficult due to the lack of feedback required for the final data communication test, which resulted in little understanding for each other and a delay in implementing tests *(I22_RD1_C1).*

5.2.3. Knowledge boundaries as a result of heterogeneity

The interview findings on proximities and knowledge boundaries have provided valuable insights into the complexity and challenges of Smart Grid projects. It became apparent that Smart Grid projects in particular place specific demands on collaboration and are, thus, by no means a matter of course. Therefore, the interview data is used to answer H1, namely, *"The heterogeneity of project partners is a knowledge boundary that prevents the integration of knowledge in Smart Grid projects."*

To pave the way for the connection between heterogeneity in form of proximities and knowledge boundaries, anomalies and particularities have to be stressed that developed in the descriptive analysis and that are useful for linking both theories. Through these new linkages, new theoretical insights will be gained. At a first glance, the interview results showed that all forms of proximities developed in the case study, which indicates that the Smart Grid project partners are heterogeneous with respect to the five dimensions. An important distinction that crossed all dimensions of proximity and impacted knowledge boundaries concerns the three roles of DSO, TSO and research partner, with the research role strongly distinguished from the industry partners DSO and TSO. Based on the knowledge boundaries that occurred on syntactic, semantic and pragmatic levels, the following section analyzes which influence proximities had on their appearance.

The empirical investigation revealed that syntactic knowledge boundaries emerged primarily due to geographical and cognitive differences in the proximity relation between organizations. To start with the influence of *geographical proximity on syntactic knowledge boundaries*: Geographic distances affected languages because most partners did not share the same mother tongue. The project partners, therefore, had to switch to English, with the result that the interviewees from different countries were not always able to express themselves freely and often changed to their native language when talking to their colleagues. However, since most partners have been working in an international context of the energy domain for many years, an overall high level of English was identified. The geographical proximity was, therefore, decisive in determining which language was spoken in the project context. *Cognitive influences on syntactic knowledge boundaries* were seen in the application of different technical terms in the project, which were not always known by the project partner. A precise exchange of information between the sender and receiver was consequently not always possible. Knowledge boundaries, thus, prevailed at the lowest syntactic level of simple information processing. As Lawrence and Lorsch (1967) suggest, a shared and stable syntax would be needed to bridge differences and increase the quality of information exchange. Following this approach, the interviews revealed that the partners tried to agree on common denominators of information exchange by developing a common base of technical terms. This involved the creation of a common glossary in order to work with the partners on the same syntactical line. In addition to the classical wording, knowledge boundaries also developed in terms of data that were neither uniform nor interoperable readable. Taken together, the interviews showed that difficulties at the syntactic level arising from geographical and cognitive proximities were comparatively minor in the project as a whole.

To visualize the influence of proximity on the different knowledge boundaries, I developed three Ishikawa diagrams each for the different types of knowledge boundaries. On the Ishikawa diagram, it can be seen that the higher the influence on the knowledge boundaries, the closer the proximity dimension is to the broad arrow leading to the knowledge boundaries. Figure 7 visualizes the proximity relations influencing syntactic knowledge boundaries in the case study project.

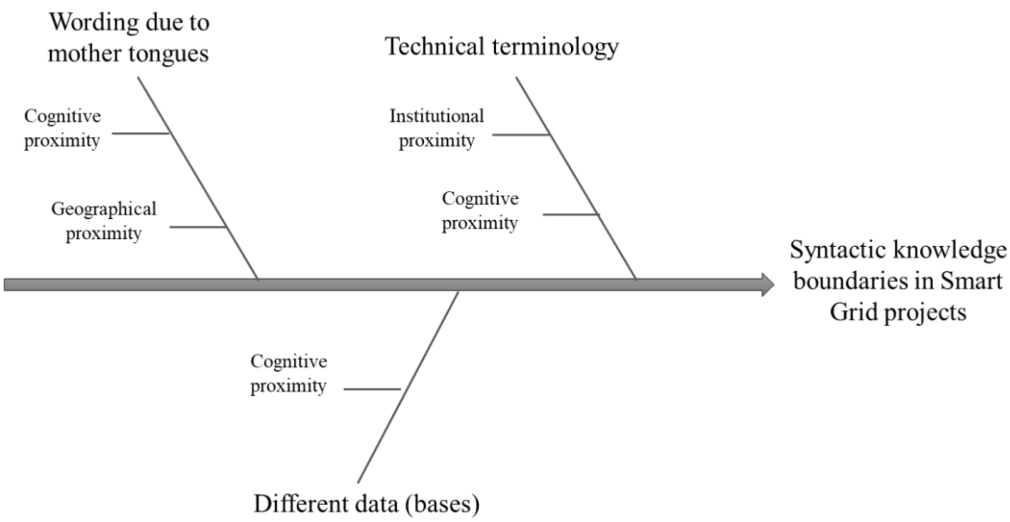

Figure 7 Influence of proximities on syntactic knowledge boundaries

Carlile (2002) already noted a shift in difficulties from syntactic information processing to the semantic comprehension. This change was also observed in the interview data. Thus, the *cognitive proximity dimension* had incremental effects on the *semantic knowledge boundaries.*

Cognitively, it was discovered that the use of a wide range of technical terms and the presence of different expertise and knowledge bases led to knowledge boundaries on the semantic level. Hence, the partners were not only demanded to process the new information, but they also had to understand the information to the extent that it could be reused for their project tasks in the next step. The interviews showed that a high technical and conceptual understanding was required for the project tasks, even though not all partners had the same depth of technical expertise in the various Smart Grid topics. This was also evident in the processing and use of data in the project, which required next to the cognitive knowledge also organizational resources. A heavy reliance on partner knowledge as well as the flood of information and data to be processed made it increasingly difficult to interpret the data in a way that could be used to achieve the overall project aims.

As already indicated by Fleck (1979), it became clear in the interviews that the different interpretations and opinions evolved primarily from the different functional environments. In terms of proximities, cognitive distant organizations showed more affinity for knowledge boundaries here. Nonaka and Takeuchi (1995) suggest considering both contextual factors and the externalization of information. The interviews equally showed that tacit knowledge must first be articulated before it can be shared with other partners. Consequently, only explicit information could become new knowledge for the partner by being reinterpreted and understood. The different specialization has made the externalization and consideration of contextual factors even more necessary in order to prevent a lack of understanding of different specialized information, including methodological and procedural information. In summary, the interview results showed that the cognitive level played a crucial role at both the syntactic and semantic level, especially at the beginning of the project. Accordingly, the focus during the course of the project was on building cognitive proximity to create a common basis for collaboration. Figure 8 illustrates the influences of the proximity relations on semantic knowledge boundaries in the Ishikawa diagram I designed.

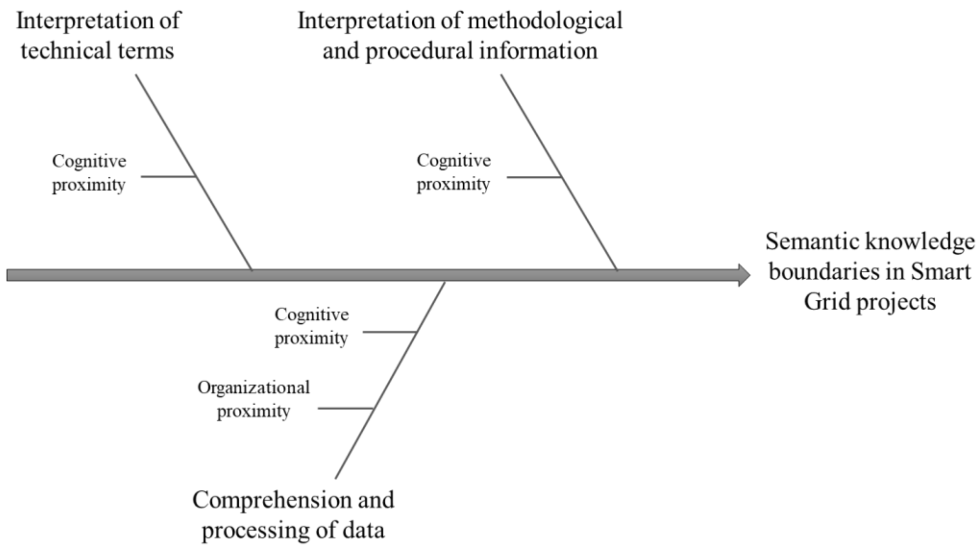

Figure 8 Influence of proximities on semantic knowledge boundaries

Although syntactic and semantic knowledge boundaries were prevalent in the case study, they proved to be less significant than those observed at the pragmatic level. Since pragmatic knowledge boundaries refer to the comprehension of the consequences that stem from knowledge (James 1907; Peirce 1898), the interviews disclosed that knowledge in Smart Grid project always served a purpose determined by the project partners. Hence, the knowledge was always purpose-bound and served to influence or maintain power between competing organizations. Along the same line, diverse contextual factors have led to pragmatic knowledge boundaries. Both of these are addressed below.

The pragmatic knowledge boundaries refer to not only the understanding and interpretation of information and data, but also to the changes in the partners' development processes caused by knowledge of the external partners. Theorists, such as Carlile (2002), have argued for the fundamental usefulness of transforming pragmatic knowledge. The interview data is replete with examples of partners speaking of the engagement with new systems of thinking and theorizing, all of which reflect the need to adapt knowledge across partners' functions. However, given the high degree of specialization in the Smart Grid project, it was observed that the different knowledge of partners was often passed on without further translation and explanation. The partners' statements that the project involved a wide range of knowledge and that some partners seemed overwhelmed by the cognitive breadth of the specializations confirm this challenge of knowledge integration. Cognitive proximity was not only found to be missing in terms of the different energy architecture and infrastructure, but also regarding organizational boundaries, working practices or power relations. The cognitive level between the partners, therefore, had a subliminal role for multiple knowledge boundaries, as it was indirectly necessary for a basic understanding between the heterogeneous organizations. Although Bourdieu and Wacquant (1992) recommend adapting knowledge to different functional partners to avoid negative effects on knowledge integration, it was found that partners were often reluctant to adapt their knowledge because it required a lot of effort. Therefore, organizational consequences developed from the different application of knowledge, which hindered the co-creation of new knowledge.

In addition to cognitive proximities, it was also noticeable that *organizational structures* had the strongest influence on pragmatic knowledge boundaries. The more hierarchical an organization was structured, the more difficult knowledge sharing became. This was due to lengthy decision-making processes, bureaucracy and general inflexibility of the accompanying work practices, which led to a high effort in sharing knowledge. The organizational structure also implicitly affected which project objectives were pursued by the partners. The overarching corporate strategy was found to influence the achievement and fulfillment of the project goals more strongly than other organizations, like those with more start-up like structure, resulting in unequal power relations. The same applies to strategies and working practices. In particular, similarly structured organizations with analogous approaches and work cultures proved to be advantageous for knowledge sharing across organizational boundaries. Finally, the organizational proximities influenced the handling of data in terms of feasibility and confidential issues, as organizations were caught between competition and cooperation.

The origin of pragmatic knowledge boundaries are often seen in the communication itself (Bourdieu 1977). Communication was manifested in the case study not only as the origin of knowledge boundaries but also as a knowledge boundary itself, occurring especially between *socially distant partners*. Hence, insufficient social proximity was the main cause of poor communication and interpersonal boundaries in the project and had an impact on the project goals, confidentiality and feasibility of data sharing. For example, it became apparent that when partners were socially unequal, it was difficult to achieve an agreement and thus trust, which other, more socially close partners described as conducive to knowledge integration. Accordingly, there was often a lack of understanding and trust between socially distant partners, which ultimately made communication on all levels problematic.

Missing institutional proximities led to knowledge boundaries in terms of policy and regulatory aspects, particularly regarding the different regulations for Smart Grids innovations and the institutional context in which different knowledge could be shared. Institutional proximity also influenced the implementation of regulations and objectives in the project, reflecting the different working practices and their influences on setting collective goals. In a similar way, informal institutional proximity also led to limitations in terms of working practices and habits. Finally, *geographical proximity* had the least overall influence on pragmatic knowledge boundaries, despite the impact of, for example, different energy infrastructures and architectures across countries. Figure 9 shows an own visualization of the influence of proximities on pragmatic knowledge boundaries.

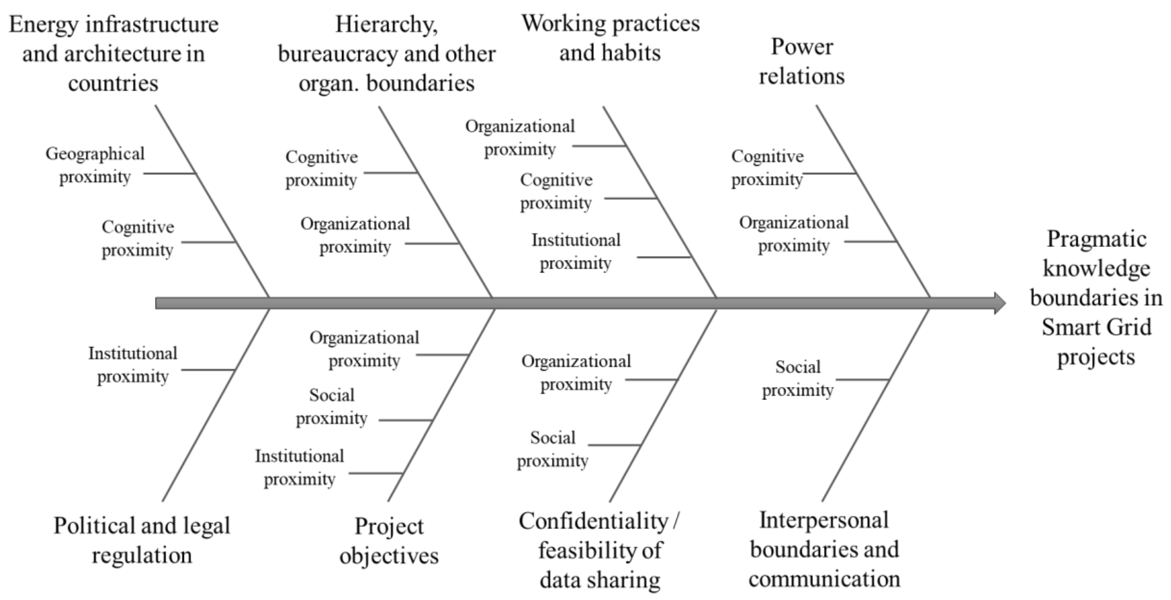

Figure 9 Influence of proximities on pragmatic knowledge boundaries

The empirical analysis showed that the cognitive proximity particularly influenced the syntactic and semantic level at the beginning of the project. This was especially necessary to create a common knowledge base of theoretical and practical knowledge between the organizations. While this was the basis for collaboration, syntactic and semantic boundaries were not perceived as a major challenge. The pragmatic knowledge boundaries that were more difficult to resolve emerged in regard to the dimensions of organizational or institutional proximity that played a stronger role in collaboration. Even with fewer syntactic or semantic boundaries, the interviews revealed that actors still had different purposes for knowledge acquisition and that this impacted decision-making in the innovation processes and business operations with respect to the overall project goals. In the case study, it became clear that pragmatic knowledge boundaries played the most important role of knowledge boundaries within project collaboration. In particular, the organizational size was shown to be influential for the overall collaboration. While some industry partners had more hierarchical structures, other organizations, such as research institutes tended to have smaller organizational structures. This had an impact not only on decision-making processes but also on the overall communication in the project, as relationships between flatter, less hierarchical organizations were considered by the interviewees as more flexible.

In conclusion, the interviews showed that the origin of knowledge boundaries often derived from the different proximities of the partners. Project partners who share many commonalities, such as in the cognitive knowledge fields, who work within in a common organizational and institutional frame, who are geographically close and who have already developed social ties from previous projects are often less influenced by knowledge boundaries. The fact that the interviewees are highly specialized and distributed complicates collaboration and often leads to a higher need and effort in sharing knowledge at different levels. Despite the fact that knowledge boundaries developed, it became apparent in the course of the project that knowledge could nevertheless be successfully integrated. Therefore, knowledge boundaries did not completely prevent knowledge integration, although an impact at various levels could be empirically traced. This suggests that the partners developed strategies to cope with the knowledge boundaries resulting from the heterogeneous nature of organizations. As possible processes for integrating knowledge, the following chapter examines interorganizational learning and knowledge bridging.

5.3. Interorganizational learning vs. knowledge bridging

The empirical analysis of H1 has demonstrated that the project partners in the case study were heterogeneous at different proximity dimensions, producing various boundaries in the knowledge integration process. The empirical investigation showed that the interviewees were able to integrate knowledge despite the surfacing of boundaries in the process. In outlining this phenomenon, the question of how knowledge integration occurs in spite of limitations is further discussed at this point. Chapter 6.3. unravels both processes of interorganizational learning and knowledge bridging, starting with the former.

5.3.1. Interorganizational learning in the case study

In general, the interview findings elucidated the interorganizational learning within the project and enabled to break down its underlying process. At a first glance, the interviewees made clear that they considered interorganizational learning as very important for the project, but also for developing on a personal level. The interviewees described that they particularly appreciated gaining insights into new knowledge from the project partners and expanding their own knowledge. For example, two interviewees *(I3_RD_N6; I28_RD_N6)* stated that they learned about various aspects in the areas of big data, data mining, cloud technologies or services for the platform use that were not previously in the partner's knowledge base. *(I28_RD_N6)* described this as follows:

> *I would say it is important because as I said, there was knowledge for me to share, but there were a lot of aspects and details that I didn't really know beforehand, for example, the service catalogue and these kind of things. There were things that I heard of, but I never worked with before. (I28_RD_N6)*

The acquisition of new knowledge within a short period was particularly highlighted by *(I18_DSO_E5),* who argued that without learning, no progress in the field could have been possible. The interviewee saw interorganizational learning as an indispensable prerequisite for developing something new *(I25_RD2_S4).* Learning was, therefore, given a significant role in innovation, recognizing the problems of the other partners and identifying their future function in the Smart Grid *(I4_DSO_S4).*

> *Since I am a younger person, the importance is very high. You really have to be open to new things. As I said, I haven't used most of these tools and things ever before. So, I really learned a lot in a short time and I think not only young people, but also the colleague with more experience probably learned a lot. It is a new field, we want to make a change and we want to improve something that already exists, and that always includes learning. I think learning has quite a big role in this project. (I17_RD_E5)*

Interorganizational learning, therefore, broadened the partners' perspective to new areas of knowledge and to understanding processes and roles in the system *(I13_RD_E5)*. For example, *(I30_RD2_C1)* stated that many project partners saw the newly acquired knowledge as valuable for future projects. Learning was essential to find out which topics will become important in the short to long term and how businesses can position themselves in the future with new concepts and ideas *(I29_DSO_S4).* The following learning topics and associated types of knowledge stood out in the interviews.

Learning topics and knowledge type

The interviews revealed that learning took place in different project areas, whereby four main content-related topics yielded the greatest learning effect for the interview partners. These learning areas were primarily related to the use case and SGAM methodology, including UML modeling, information exchange with the standards CIM and CGMES, platform tools as well as knowledge about simulations and demonstrations activities.

Use cases and the SGAM methodology

Above all other learning areas, the use case and SGAM methodology stood out because it affected all partners equally. Acknowledging the importance in the project to design the requirements for the data exchange platform, the use cases and SGAM methodology was learned by almost all project partners involved in the first two work packages. These use cases aimed to ensure that all important actions or steps that needed to be performed for a given interaction on the data exchange platform were written down. Specifically, the organizational partners were demanded to apply the method by filling out a specific word template. *(I27_DSO_W2)* described that these templates served as a useful guide to check on all relevant data and to guarantee that all-important information are included. *(I27_DSO_W2)* elaborated this as follows:

> *One of the test of the template is to monitor some data. For example, when you just create some use cases, using a blank sheet, you do not think you need to specify with some final granularities, such as which kind of data must be exchanged etc. You don't explain which document must apply. I think the use case template is useful to guide and to check that we think of all relevant information. (I27_DSO_W2)*

In order to learn how to fill out the word template, interviewee *(I6_RD2_C1)* explained that workshops were offered by two expert organizations to ensure that all partners acquire the same knowledge for using the methodology on their own. According to the interviewee, the use cases offered the same structure to which all partners had to adhere equally. The interesting point that emerged in the interviews was that the templates had to be developed collaboratively by placing them on the project's communication platform and thereby making them freely accessible. This allowed each partner to work on his or her own use case *(I6_RD2_C1)*.

> *But I think there are generally some learning effects. For example, I have the impression that we had some learning effects with this description of the use cases in WP1. Within this task, [DSO_W2] also offered workshops. So you got a uniform structure in order to display these use cases in a standardized form. I found it impressive that all partners really managed to develop their use cases within this template, which looked uniform. (I6_RD2_C1)*

The need to come together to learn the methodology intensively was stressed by *(I2_DSO_W2)*, who explained that the partners often required three to five intensive meetings only to understand the methodology. Often, partners from the same region used to sit together to comprehend the methodology at a more complex level. For example, *(I2_DSO_W2)* described that it was necessary to apply the learnings to other colleagues in the organization. The following quote confirms that the knowledge had to be passed on to other organizational members, who were not able to attend the interorganizational workshops within the project.

Usually, several people from one organization worked on a use case in exchange with about three to four external partners.

> *Yes, this was mainly when we started with task 1.3 (the system use cases). At this time, I have a more or less three, four, five meetings only to understand the methodology, but the interesting thing is that afterwards, I should explain the methodology to the other partners. However myself, I needed a lot of time to understand it. (I2_DSO_W2)*

A distinctive aspect of learning use cases and SGAM was that the methodology was expanded and improved not only by the experience of the experts in the workshop, but also by reading other documents and literature. For example, *(I17_RD_E5)* explained that the IEC 62559-2 standard was recommended to the interviewee to gain a deeper understanding. This showed that some partners wished to deepen the methodology, as the workshops did not always offer them the sufficient complexity they felt was required for a project of this nature. As *(I3_RD_N6)* stated, some project partners also had an intrinsic motivation to engage even more intensively with the methodology.

> *Everyone has its own knowledge regarding what I gain. […] Equally I can get knowledge internally and from the partners, e.g. from the meetings, from previous research. For example, [R&D1_C1] send me a book about SGAM, because I was looking for gaining more knowledge in the SGAM. Especially, how it is used. […] So I cannot say that I am gaining knowledge more from one (partner), than from the others. (I3_RD_N6)*

Although some project partners wanted to build a deeper understanding of the methodology, the core aim of the learning between the organizations was to build at least a basic understanding of the use case and SGAM methodology. For this purpose, *(I2_DSO_W3)* described that the methodology was explained to the partners to the extent that they could independently apply it in the project. Building additional knowledge beyond this was consequently not necessary for the project tasks. In this sense, it was sufficient for the partners to understand how the methodology works and where to insert the different entries in the template. *(I27_DSO_W2)* explained this need to comprehend the methodology as follows:

> *I think the most difficult part was to explain the methodology we want to follow in creating use cases because we need to have the same approach if we want to share the deliverable and the task. Thus, we had to make sure that all the involved parties understood the methodology. (I27_DSO_W2)*

Overall, the interorganizational learning of the use case and SGAM methodology in the workshops and in the application phase of the templates required intensive communication between the partners - not only because the methodology was new but also because the partners had to build a common knowledge base to fill out the templates together. Hence, shared knowledge had to be developed and understood by all partners within and across organizations.

UML modeling tools

Since a common approach was needed throughout the project to meet the objectives, it was even more important that all the parties involved were able to master and apply the methodologies that were agreed upon the project proposal *(I27_DSO_W2)*. With the increased emphasis on the use case methodology, the UML modeling language was essential for developing use case diagrams that captured dependencies and relationships of systems and organizational actors. For this purpose, *(I8_TSO_W3)* stated that the UML modeling software tool Enterprise Architect (EA) and the add-ins [tool_1][2] and [tool_2] from the project partners had to be learned between the organizations in the project. However, the interview data showed that EA and its add-ins were previously unknown to most project partners, triggering many requests for details about the tool, such as how to insert graphics *(e.g. I7_RD2_C1; I6_RD2_C1)*. Hence, interviewees had to build new knowledge in this area, as many partners had no previous experiences with the tool. According to *(I10_RD1_S4)*, the explaining of the UML modeling was also made with solid previous work. The learning of UML modeling tools was explained by *(I6_RD2_C1)* as follows:

> *We also worked with these tools, like Enterprise Architect. There, it was possible to ask a partner about such little things as "Oh here, I saw you exported a graphic from Enterprise Architect that looks like this, how did you do it?" I think it's nice and relaxing that you can work together in this uniform way. You can definitely learn from each other. (I6_RD2_C1)*

Although some partners already learned about UML at the beginning of the project, not all project partners were familiar with this standardized tool-supported modeling language. In some cases, UML was not even necessary for the tasks in the work packages. However, the knowledge was still acquired by *(I7_RD2_C1)* to understand what the project partners were doing in other work packages. It was, therefore, about building an understanding for the tasks that were processed even at different project teams *(I7_RD2_C1)*. Nevertheless, the learning process proved challenging for some interviewees in this field, particularly if their organization routinely used a different analytical and modeling frame. For example, *(I27_DSO_W2)* stated:

> *I think the methodology was difficult for some people. We already use known concepts and, for example, some people also know how to model using UML, but some have to learn it from scratch and others only want to use a tool approved by their institute or by their company and this can also be a kind of difficulties. (I27_DSO_W2)*

[tool_1] as an extension of EA for modeling Smart Grid architectures played an important role in interorganizational learning in order to support Smart Grid data exchanges. The interviewees indicated that they learned primarily from [DSO_W2], who incorporates licenses and specific

[2] The tools have been anonymized to preserve the anonymity of the organizations that develop or use the tool.

knowledge about the software tool. As an expert on the tool, the organization shared its knowledge of the methodology with other partners who could apply it to the project tasks. At this point, an intensive exchange took place between the partners who already had experiences with the tool and the partners for whom the tool was new. *(I8_TSO_W3)* explained this as follows:

> *We learned from them. An example was [tool_1]. They dominate these tools and they gave us key explanation of how to integrate [tool_1] in the use cases. So we indeed learn from the partners. (I8_TSO_W3)*

> *[…] I am also involved with other teams, for example, at the beginning of the project, there was a big knowledge exchange between [DSO_W2] and us and that was very beneficial. […] I was taught how to use this special software tool [tool_1] […] and that was very good. In this respect, this was deeper knowledge for broadening horizon. (I16_RD_E5)*

This image underlines that learning and acquiring high-level competencies for [tool_1] was considered important for the case study project and beyond. In this sense, the project partners anticipated a use of the tool outside the project context, as the interviewees stated that they continued to apply and deploy the tool in subsequent European projects *(I10_RD1_S4)*. Another add-in for EA that was learned between the partners in the project was the [tool_2]. The interview data indicated that [tool_2] was explored among the project partners to manage, for example, CIM Profiles, CIM-based architects or IEC CIM.

> *No, we actually did learn from each other, for example, at [DSO_W2]. The learning there was about the usage of tools, like [tool_1] and also [tool_2]. We not only read instructions, but we also asked [DSO_W2] how it works and we had a telephone conference with them to learn how to do the profiling. (I7_RD2_C1)*

The learning of [tool_1] and [tool_2] took place in the first months of the project. The interview findings showed that the tools formed the basis for all further project tasks, which is why a common understanding had to be developed. Learning the methodologies of the tools was consequently needed to design all use cases within [tool_1]. Thus, [tool_1] and [tool_2] in the area of UML modeling for Smart Grids were a key part for defining the requirements of the platform to be developed. The interviews showed that the project partners have intensively exchanged knowledge, especially about the different tools needed for the design of the platform *(I16_RD_E5)*. Learning the basics of the tools was, therefore, seen as imperative to project success.

Methodology on information exchange via CIM and CGMES

A learning effect was also conspicuous between the organizations when learning how to exchange information with the standards CIM and CGMES. Knowledge in this area was initially lacking as technical communication and data exchange between DSOs and TSOs did not exist to this extent before *(I30_RD2_S4)*. Therefore, interviewees indicated that they need to become familiar with the standards and how to apply the methodology in order to create communication interfaces between them on the data exchange platform. CIM as an open standard for exchanging management information and for representing common sets of objects was cross-utilized among the stakeholders. Thus, building knowledge in the area was perceived particularly critical, as ICT is taking on an increasingly meaningful role in the organization in the long-term *(I29_DSO_S4)*.

> *That is knowledge that can be useful for the next years, not only in new European projects, but also in the daily cooperation with TSOs. For instance, we developed the web services to exchange some data with the TSO. Our intention is to keep using this infrastructure tool to exchange data in the daily tasks, not only in the scope of European projects, so I think this is a good outcome from the project. (I29_DSO_S4)*

The learning was generally guided by the understanding how the standards can be used and how they can be applied in the project. Since information exchange was one of the core topics of the project, it was necessary for the organizations to gain a generic understanding of how to apply the standard CIM and CGMES. The project was, subsequently, a starting point for building a knowledge base in the area of information exchange, for example, in the area of forecasts or real-time data *(I4_DSO_W2)*. A closer look at the interviews revealed that this knowledge mainly concerned the question of how an ICT infrastructure could be established and what type of data should be exchanged between the DSO and TSO, particularly on the common data platform *(I29_DSO_S4)*.

In general, the interview data showed that the learning of the CIM and CGMES model consisted of different parts. In order to specify the information exchange with CIM and CGMES, the business objects defined in the use cases had to be considered first. The interviewees stated that the information that should be exchanged between DSOs and TSOs in the use cases was analyzed according to the CIM standard *(e.g. I8_TSO_W3; I30_RD2_C1)*. Similarly, the gap between required and existing CIM and CGMES classes and attributes was detected in order to expand them in the sense of creating new classes in CGMES *(I6_RD2_C1)*. The interviewees described that the aim was to improve CIM and CGMES so that they can be used to coordinate the TSOs and DSOs in the project. Finally, the CIM experts used the analysis to determine which classes and attributes were needed but did not yet exist in the standard and, therefore, had to be added.

For the application of CIM as a communication method on the data exchange platform, CIM profiles had to be created by the project partners. Hence, the interviewees explained that the learning mainly consisted of the development of CIM profiles, which are an agreed-upon subset that derived from a canonical model (e.g. CIM) and should arrive at a contextual model (Uslar et al. 2012). The development profiles had to be learned between the partners in order to realize interoperability in the mutual exchange of information. This CIM profile creation was stated by *(I17_RD_E5)* as follows:

> *I am working on the profiles, i.e. creating the profiles. I work with different tools, so I can also make a comparison on how good the tools are and maybe test some interoperability between them. (I17_RD_E5)*

The interviewees described that the CIM profiles contained classes and associations that were important for later scenario or task building in the project. For example, *(I6_RD2_C1)* described that experiences were exchanged among the project partners to find out where CIM profiles and standards have already been used by the organizations and which purposes they served there. With this in mind, knowledge of the standards was queried to better integrate them in the project context. The partners involved in the tasks also had to learn and use specific tools for the CIM profiling, such as CimConteXtor. This tool moved the profiles into a package structure in an Enterprise Architect (EA) file. In this step, CIM and CGMES experts gave feedback to the partners who acquired the methodology in the project *(I7_RD2_C1).* Specifically, one organization was an expert in the CIM and CGMES methodology and guided the process of integrating these standards in the project *(I17_RD_E5).* Here, direct feedback from the involved partners was obtained from the organization's team of experts *(I7_RD2_C1).* Based on the previous assumptions, learning of CIM and CGMES was not uniformly present and the depths of learning among the project partners drifted apart. While some partners were less familiar with the standards, others already applied them in previous Smart Grid projects. In this sense, *(I29_DSO_S4)* explained that the organizations did not feel prepared to implement CIM in the organization. According to *(I10_RD1_S4),* some project partners even declined to learn about the standards because information was already being exchanged in other, more conventional ways. It was noticeable that many discussions took place, the problems of which were already described in the knowledge boundaries. The difficulty of learning CIM was made clear by *(I29_DSO_S4):*

> *[…] One of the topics that we addressed in [project name] was the data exchange and the format of data exchange and one of the discussions that we had during the [Southern European] demonstrator was the usage of CIM model, because we saw that other partners are using the CIM model. However, we detected, for example, that we are not prepared to use the CIM model in our case. Therefore, we decided to use the XML files for data exchange. For instance, this was one of the discussions, I detected, for instance, that [name R&D2_S4 partner] has some experience using the CIM model due to the participation in other European projects, in which he needed to use the CIM model. An example that we learn in the [Southern European] demonstrator is the CIM model. […] We need to think how we can use the CIM model for the data exchange. (I29_DSO_S4)*

Learning how to apply and profile CIM was also evident in the analysis of deliverables and in several discussions. In this course, inconsistencies and different points of views became apparent between the organizational partners. This fault detection required a deeper engagement with the CIM material and a deeper understanding of the methodological procedure for the CIM profiling *(I17_RD_E5)*. This communication for learning CIM and CGMES was described by *(I7_RD2_C1)* as follows:

> *I think we had a phone call or a telco or maybe just email traffic. Anyway, we were always communicating back and forth with them in order to learn how to do the profiling (I7_RD2_C1)*

According to the interviewees, CIM profiling was not only a new topic, but also required extensive communication between the project partners and, thus, a deeper learning in the field *(I18_DSO_E5)*. However, not all project partners needed to know every detail of CIM profiling but referred to the particular experts who knew the rules according to which, the profiles had to be developed. The new insights gained from the CIM profiling were also utilized for subsequent research projects and, thus, wider adaptability was integrated when new profiles had to be developed *(I26_TSO_W3)*.

Taken together, the interview data showed that while not everyone needed to technically model CIM standards, there were many discussions with system operators about their use in the project. Hence, conversations were held on how to incorporate the standards into the project tasks, especially for use of the latter platform. However, many project partners were previously unaware of CIM and CGMES and their importance as a cornerstone for future energy systems *(I10_RD1_S4; I30_RD2_C1)*. Even a simple understanding was incredibly difficult to achieve due to the technical complexity of the standards and their application. Without the help of experts, it was hardly possible to acquire a general knowledge on one's own. Reflecting this, the interviewees described that understanding the standards and the methods for its application required deep learning *(I18_DSO_E5)*.

Platform tools

Another strand of interorganizational learning was identified in the area of data exchange platforms. All previous tasks were incorporated into the creation of a communication platform for DSOs and TSOs and other market participants. For this purpose, similar and already existing platforms were analyzed for the specific project aim and reviewed for their potential to expand. This learning area mainly involved knowledge about three platforms, such as [platform_1][3],

[3] The platforms have been anonymized to preserve the anonymity of the organizations that develop or use the platform.

[platform_2] or the [platform_3]. Learnings in this area mainly comprised their scope and aims, their structure and their possible use for the project tasks *(e.g. I6_RD2_C1)*. The interviews disclosed that individual organizations were more concerned with learning than others and, therefore, showed themselves to be experts in this field *(e.g. I8_TSO_W3; I28_RD_N6).* The learning was, thus, driven by the partners drawing on specific experts. The use of the platform was intensively discussed by experts and non-experts to determine whether their scope for DSO-TSO information exchange could be extended. This was stated by *(I32_DSO_E5)*:

> *I think that it was information that was lingering that there is a platform that could potentially be used for this [information exchange between DSO and TSO], but nobody really had experience. Then it was tested and it was proved that it is okay and we can use it. (I32_DSO_E5)*

With the project aiming to develop a platform for data and information exchange between DSOs and TSOs, it was essential for the project partners to learn knowledge about the platform usage. For example, *(I1_RD_E5)* stated that [platform_2] was studied for the conceivable use in the project, in particular how to configure and operate this platform. As with other learning topics, knowledge was provided by particular partners who supervised the platforms and could share the necessary knowledge. The platform experts pooled the necessary information, tailored it to the respective project partners and provided support, so that all organizations could build a common basis for platform knowledge *(e.g. I8_TSO_W3).*

> *It's fundamental, because every partner will show their knowledge, not only the [Western European partner 2], but also the [Central European] partner and also we from [TSO_W3]. When we share the information about the [platform_2] or the [...] tools like the [platform_1], it is not only important, but it is fundamental. (I8_TSO_W3)*

Again, in this case, one expert shared platform knowledge with the other non-experts, who had to get familiar with the platform usage. In particular, one organization was involved in very specific internal discussions, offering advice on how to develop and set up the platform. All in all, the interviews showed that the partners benefited from the new experiences gained by the platform experts that did not exist before. In this sense, *(I32_DSO_E5)* stated:

> *I think there was information that there is a platform that could potentially be used for this [project purpose], but nobody really had experiences with it. Then it was tested and it was proved that it is okay and we can use it. (I32_DSO_E5)*

As the project progressed, [platform_2] crystallized as a possible extension for DSO-TSO communication. This was a significant factor that led the partners to learn more intensively in this area. The platform demonstrated the potential for a rigorous and secure basis for information exchange between DSO and TSO and was tested notably in the demonstrations conducted within the Western and Eastern European countries *(I6_RD2_C1).* In these demonstrations, interorganizational learning was an integral part of being able to use and enhance the platform tool. If there were any issues, the responsible partners were contacted and they exchanged mutual feedback on the platform. This process of interorganizational learning was stated by *(I6_RD2_C1)* as follows:

> *I think that we also learned about the use of [platform_2], which is also deployed in the [Eastern European] as well as in the [Western European] demonstrations. I think there was a lot of exchange between the two partners. For example, [TSO_W3] asked what problems we had with the implementation of [platform_2]. They were also simply interested in getting some feedback from us, for example, to improve their manuals or simply to enhance the tool. That's what we wanted to support. Therefore, we have set up a special time slot to discuss and give feedback. I think there was also a learning effect between us in the development of [platform_2]. (I6_RD2_C1*)

For the application and implementation of the [platform_2], one interviewee explained that specific measures had to be taken, such as defining the conditions for the installation and carrying out a set-up. To that end, diverse knowledge had to be brought together *(I18_DSO_E5)* in order to learn how to best perform the set-up. Besides [platform_2], some project partners were also asked to learn knowledge about [platform_3], which was new to them *(I28_RD_N6)*. The [platform_3] was used in the project as a hybrid enterprise data and cloud platform from an external software provider, which aimed at delivering data for any occasion, regardless of the field in which the data was used.

> *For example, in our local meetings, [name project partner R&D_N6] was presenting his proposals and I was told that this does not come across well or that you have to implement this and that in the cloud platform. But those were very specific discussions. It was very directed because we already had the system use cases developed. (I28_RD_N6)*

Other learnings effects ensued in the area of web services, which were used in the project as platform-independent software components and were needed for the implementation of distributed applications. In the case study, the web services generally defined the functionalities that should be implemented by a subsystem. Most interviewees revealed that the topic was new to them and that they needed to improve their knowledge across the organizations in that field in order to understand how web services usually work *(I25_RD2_S4).* For instance, a project partner explained the necessity of becoming familiar with Representational State Transfer (REST), a paradigm for software architecture of distributed systems and, in particular, for web services. Although it was not used before, it was still considered as important for the interviewees to understand how the services between the communication worked.

> *I'm not an expert in communications, but we are developing a web service to exchange information. At this moment, I am studying a little bit about that, but also about web service and how the message is built, how I can send this information and what are the main subject and the main things that I should comprise to fully understand the information. (I10_RD1_S4)*

These web services were perceived by *(I25_RD2_S4)* as a higher level of knowledge. In this learning process, the interviewee received data from a DSO that was transferred into the program to get an optimal answer for the DSO organization *(I25_RD2_S4).* All in all, the platform knowledge played an important role in the learning between organizations.

Demonstration and simulation tools

Interorganizational learning was also discernible in the area of simulation and demonstration practices and tools. For example, TSOs simulated exemplary DSOs networks that were needed to draw conclusions for their own networks. For each action on the network, certain profiles had to be elaborated, revealing the need for knowledge of simulation tools that some of the partners acquired during the project. As part of this learning process, two research institutes from different countries worked closely together to learn and use a specific operational simulator. This tool was applied during the project to test and simulate Smart Grid environments with specific applications.

> *I think that learning processes are necessary. We also did a coupled simulation with [R&D_E5], for example, and part of it was that I explained to [R&D_E5] how it works, how they are able to connect to us and how they can now bring in their own code. That would be the first step, so to speak. (I7_RD2_C1)*

A closer look at the knowledge learned within the simulation tasks exposed that the content was mainly about data metering and the development of scripts that were needed to run the simulation. These scripts, programmed in Python, were required to calculate the short circuit in an automated way, including the typology and the scenarios. Correspondingly, the scripts were shared between the organizations, which applied them within their different systems *(I11_RD1_S4).* Simulation engineers and system developers had to engage more intensively in the development of these scripts, but also non-experts had to learn using such tools. This was stated by *(I13_RD_E5)* as follows:

> *I believe that it is necessary to learn, get a wider-angle view and understand the processes. As for a developer, it is necessary to go in depth. But they have to understand how it is functioning, maybe at a higher level, but they must know. (I13_RD_E5)*

Interestingly, *(I29_DSO_S4)* noted that the project partners discovered that their tool could also be applied in other countries, thereby solving similar problems regarding the automation of distributed resources at the DSOs and TSOs. This was used as a proof of concept to the interviewee *(I29_DSO_S4).* Prior to sharing the results of the scripts with external partners, internal meetings with both organizations took place beforehand. In this way, the quality of the scripts was checked and approved for the later dissemination *(I11_RD1_S4)*. It became evident that synergy effects have been successfully exploited in this area.

> *For instance, they use the same software that we use for the short circuit operation and we are programming a script in Python to do that in an automatic way. We can share the script with them and then they start using the script and they apply to their system. It is no problem. (I11_RD1_S4)*

The concrete learning for simulation tasks was reflected in the circumstance that the project partner obtained a few scenarios and networks, which were tested to see whether they make sense and to decide if the methodology was robust enough *(I11_RD1_S4).* Again, most interviewees indicated that the knowledge did not need to be understood in depth, but had to be acquired at a sufficient level to be used in the common project work. While a specific programming knowledge and, therefore, a significantly more complex understanding of the project tasks was necessary for the developers of the simulations, a basic understanding was sufficient for other organizations. This was stated by *(I13_RD_E5)* as follows:

> *We are learning through the exchange of experiences between each other. And for the simulations, the new knowledge we are getting is not fundamental, it is more knowledge about new tools. So we are making these meetings for the demonstrations, for instance with [R&D2_C1] about data metering because of some urgent scripts. (I13_RD_E5)*

Aware of the complexity of such simulation tasks, another project partner stated that the project partners commonly brainstormed in order to find new ideas to setup the simulation in the project. For example, *(I6_RD2_C1)* described that experiences and ideas were exchanged between the Eastern and Central European organizations on how the set-up can succeed and how to manage the exchange of information via the message bus. While the Eastern European partners conducted the simulation in intensive collaboration with the Central European partners, the Southern European partners had a strong connection to the Western (W2) European partners. In this vein, a lively exchange was observable between them in form of sharing data and results. This was stated by *(I21_RD2_S4)* as follows:

> *Well, we communicated with [DSO_W2] while configuring the algorithm - I would say, almost three days at least in the end because we have a [Southern European] colleague there, which was [name]. We communicated straight forward to develop the algorithm. Everything went fine and we developed the idea and the algorithms quite fast. We exchanged data, we exchanged results, we also thought of the results after we exchanged the results. [DSO_W2] gave us insight in their tools. We have discussed whether the results were similar and they validated our tools. It was a very good communication between [DSO_W2] and [R&D2_S4]. We were also writing papers together and actually submitted one in a journal (I21_RD2_S4)*

Likewise, a new tool for simulations was learned between organizations to compute the optimal power flow of the DSOs. Both, the Western European and the Southern European partners needed to share knowledge about the observability area so that the demonstration tools could optimally calculate and optimize reactive power flow. However, the Western European country had a different policy, which is why the organization had to adapt the algorithms to their specific circumstances *(I21_RD2_S4).*

> *Yes, we need to determine, for example, what kind of data was exchanged between the DSO and the TSO in the observability area. We want to run specific calculation and for this we used a [Southern European] tool. So, I needed to learn how this tool was working because in the [Western European 2] demonstration we send some data to the [Southern European country]. There, they did some*

> *calculation and returned the result to determine if the network will be okay or not. Thus, I needed to understand the electrotechnical implementations and I also needed to learn some differences between the [Southern European] and the [Western European] network because we need to adjust the configuration. (I27_DSO_W2)*

In conclusion, most simulation knowledge was discussed internally with the experts from the organizations by coordinating tasks and holding regular meetings. Afterwards, the ideas were passed on to other non-experts, which had to be involved for learning the tools for their purposes. The interview data revealed that regular internal expert meetings ensured that everything was developed correctly before it was implemented more broadly in the project *(e.g. I11_RD1_S4)*. A learning-by-doing approach emerged, since there was no predefined strategy or solution for the simulations, but instead the partners had to foster blueprints on their own. Making mistakes was seen as integral to theorizing, testing and learning. Good results for the simulation tasks, in the sense of appropriate and faultless scripts, had to be continuously reviewed and adapted within the organization in order to finally achieve the project goals *(I11_RD1_S4)*.

> *First, we used an algorithm to run some specific functions internally and the outcome was that it was not properly doing what we wanted it to do and it was not as fast and reliable as we wanted it to be. In the middle of the project, we needed to change the algorithm and develop another algorithm in order to have things as we imagined. […] This is an example, because it exists on other stages of the project as well. But these kind of things are very much associated with what is research, because you fail and you try again and you fail and you try again. It's the most challenging thing. (I31_RD2_S4)*

The descriptive summary of the interview data provided initial information about what was actually learned between the organization and at what points in the project more intensive knowledge exchange took place. The next step will be to examine how learning occurred between organizations.

Learning Method

The first part showed that an intensive exchange was necessary, especially for different methodologies, such as use cases and SGAM, UML modeling, CIM and CGMES standards, and for different platform and demonstration tools. To acquire knowledge in the above-mentioned areas, the interviewees also used different learning methods based on self-study, the learning from deliverables and publications, and on learning in personal interaction.

Learning for themselves

First, the project partners explained that they learned a lot for themselves. To do so, they absorbed new knowledge, such as from books or via the Internet. For example, *(I17_RD_E5)* stated that project partners were frequently asked for advice and book tips to find appropriate literature for the specific knowledge area. The self-acquired knowledge came from standard literature, for instance, in the area of use case and SGAM and in the field of CIM and CGMES standards *(I17_RD_E5)*. The interview data showed that the open standards CIM and CGMES were looked at in more detail on the Internet, but also in a book provided by a project partner. Since the interviewees needed literature for the CIM profile development and for testing data models, it was important to understand the IEC 61968/61970 standard on a more complex level *(I22_RD1_C1)*. This was also stated by *(I17_RD_E5)* as follows:

> *Yes, I used CIM, for example, as my topic for my bachelor thesis. That's where I went very deep and, for example, not personal, but [name] was a big help. I really read his book from page 1, from the first word to the last word. It really helped me a lot because it was also written in a very student friendly mode. I could really understand the words right clear and it helped me a lot with learning CIM and entering this world of CGMES - that helped, for example (I17_RD_E5)*

The phenomenon of self-learning was, thus, evident in the use case and SGAM methodology. Different interviewees explained that specific literature from project partners was consumed for self-study of the methodology *(e.g. I3_RD_N6)*. As the methodology was perceived as generally complex, the interviewees often wished to engage more intensively with the subject matter and to read literature beyond the project purpose. In this sense, *(I3_RD_N6)* stated:

> *From the meetings and previous research, [name] sent me the book about SGAM because I was looking for gaining more knowledge in the area of SGAM, especially how it is used. By sending this book to me, I gained knowledge. But I cannot say that I am gaining more knowledge from one partner or the other. (I3_RD_N6)*

Acquiring knowledge through self-study was justified as being faster and more effective for them. The exchange with colleagues, in the form of discussion so forth, was seen by some project partners as more time-consuming *(I17_RD_E5)*. Besides, the partners were able to determine the depth of knowledge required for themselves and learn the knowledge to the degree that was necessary for them personally in the project. This was summarized by *(I17_RD_E5)* as follows:

> *Well, first of all, I was able to work also like alone to be more able to work on your own and to not always have to ask everything, because that is really time consuming. It is much easier for me to go through some books and learn a little bit additionally and then to be able to work a little bit more on my own, then always having to have somebody sit next to me. Anyway, I am interested in the field. I do not see it much as an obligation, but also as an interest. (I17_RD_E5)*

Learning from deliverables and from the creation of publications

The interviews revealed that the project partners learned new knowledge by creating and sharing deliverables and publications *(I26_TSO_W3; I7_RD2_C1)*. This reflects that knowledge was not always acquired and shared personally, but that it was easier for some project partners to learn and acquire knowledge in a documented way *(I23_RD1_C1)*. However, interorganizational learning took place not only in writing the deliverables, but also in reading and correcting them *(I14_RD2_S4)*.

> *Interaction - by working on the issue, by reading deliverables, by revising deliverables and by meetings. For instance, I give you an example: We were discussing a subject and they did not know much about it. Of course, I could have talked to them directly, but I don't have the confidence to start a conversation when I don't know the subject. It's easier to walk through some writing and see if it's helpful or not. By seeing what other people are doing, you are learning. (I14_RD2_S4)*

The externalization of knowledge, in terms of writing it down and casting it into artefacts was, therefore, an important source for the interorganizational learning. This was also reflected in the fact that the interviewees appreciated collaborative writing on the deliverables. Through multiple stages, the deliverables were collaboratively prepared, reviewed and finally disseminated, reflecting the effort that was put into the development of the deliverables. Similarly, it was considered important to publish the research findings, with the aim of making a wider contribution to research *(I26_TSO_W3)*. This learning in a documented way was stated by *(I23_RD1_C1)* as follows:

> *You always share knowledge by externalizing it, by writing it down, by pouring it into artefacts, which are then reviewed internally by the peer review and of course approved by the EU Commission. This means that there is a certain quality assurance with a multi-stage procedure. As researchers, we work together and make a good foundation with our partners, where new knowledge is prepared and documented and then disseminated. Of course, it is easier to share knowledge with some partners and less easy with others. (I23_RD1_C1)*

The documentation produced as part of the project had another advantage, in that it was readily available for immediate use by the project partners in the project. For example, *(I16_RD_E5)* stated that the deliverables were also used for identifying what needs to be done in future work packages. This was observed, for example, when developing CIM profiles that were built on previous deliverables. Hence, the interview data showed how important the initial documentation was as a foundation for all further work in the project *(I22_RD1_C1)*. The knowledge shared in the deliverables and publications was approved by the managers and organizational leaders *(I7_RD2_C1)*.

> *Yes, I do and I get most of this data from the already existing documentation. As you know, the documents and deliveries that have been done at the beginning of the project, have kind of summarized or have specified what needs to be done in the future work packages. That is what I am dealing and presenting now. (I16_RD_E5)*

The interviews also showed that the details of knowledge had mostly been provided within the deliverables. The complexity of knowledge within the deliverable was also expressed by one of the reviewers, who did not understand everything in detail due to the technical specifications *(I14_RD2_S4)*. However, the interviewee explained that the reviewer was nevertheless able to understand it sufficiently to make sense of the deliverable. Overall, these results showed that a learning process was necessary to understand the wide range of knowledge in the deliverables, such as communications, analysis, protocols, standards and so forth *(I14_RD2_S4)*.

> *[...] But the details are in the deliverables of course. It is very complicated stuff and sometimes people achieve results and it seems very easy, but once you read the report or the deliverable, it is a completely different thing. The subjects are very, very technical. (I14_RD2_S4)*

Learning between different organizations

The interviews revealed that some project partners approached individuals from other organizations in order to receive specific know-how from them *(I1_RD_E5)*. The project partners were contacted in a variety of ways - online or on site, depending on the geographic proximity of the respective expert. Acquiring knowledge from other organizational partners was seen as beneficial, especially because it avoided the need to learn new knowledge from scratch and enabled a quicker overview of specific topics. The interviews showed that the project partners often had suitable examples in their expert area, which simplified the learning of new knowledge for other partners. This was also explained by *(I14_RD2_S4)* as follows:

> *No, once you have this objective and you start from scratch, it's very difficult if you have someone that has already some experience and can give you some hints, you can go much faster. That's what happened with [DSO_W2]. This is a learning curve, which is quite difficult to begin. We didn't have this problem, because they provide us examples with tutorials and we had several meetings. It was easy for us to get on board. Easier than, for instance, if I had to attend a course or to read a book by myself. When you interact and they show you the shortcuts, it's much better than to learn by yourself (I14_RD2_S4)*

By requesting knowledge from other organizations, extensive and detailed communication took place in the area of standardization and regulation as well as cloud-based approaches. One interviewee explained that it was necessary to get more knowledge on technical issues, such as voltage regulations or balancing mechanisms *(I3_RD_N6)*. It was also argued by *(I7_RD2_C1)* that knowledge conveyed by individual experts was easier to understand, for example, in the case of information material on CIM and CGMES. Differences to self-directed learning were seen in the opportunity to gain insights from the experiences of other experts in the project. *(I2_DSO_W2)* argued that accessing knowledge through other organizations is a great time saver compared to reading books. In this sense, *(I2_DSO_W2)* described:

> *[...] By asking and reading. Normally, asking is much faster than reading, because reading needs to find right and good references. If you talk to people and say, "It is like this or you can read this one, because we have the explanation here," this is much faster and easier. In the [Southern European country], we say that engineering needs to know two different laws. First, it is the law that manages the relation between the voltages [...]. The second law is the law of lesser effort. You should enjoy your life and do the same with as little effort as possible. (I2_DSO_W2)*

The interviews also revealed that the knowledge for use cases and SGAM was mainly gained from two research organizations involved in the project, while knowledge for the demonstrations and simulations was mainly received from industry partners. For example, one of the research partners contacted industry experts to gain knowledge about new algorithms or ideas for enhancing the system to make it appropriate for operations. Questions from industry to research partners were also asked, for example, in the area of use case and SGAM or on other standardization topics. A general offer of help from the different experts was observed to involve non-experts *(I17_RD_E5)*.

> *[…] We need to have contact with an expert, because [R&D2_S4] is working in the academia world. I would say that they have a lot of experts developing algorithms because it's their business. And we like to have this close contact with them to understand what they are doing in terms of new algorithms, new developments and how we can bring them to our systems to understand if they are suitable for our operations (I29_DSO_S4)*

In the same way, a project partner with electrotechnical engineering background wished to gain more understanding in the area of computation, web services and the communication of different services. Here, specific experts were contacted for this purpose *(I25_RD2_S4)*. Exceptions were identified regarding the consultation of experts outside the project, such as the developers of a particular platform used and analyzed as a part of the project *(I1_RD_E5)*.

Lively interaction between experts from organizations working in the same field of knowledge was particularly encouraged within the same local area, such as on-site meetings between geographically close organizations. The main advantage of these face-to-face meetings was the simultaneity and ease of exchanges. This was stated by *(I29_DSO_S4)* as follows:

> *For instance, in some cases in the Southern European demonstrator, we have physical meetings to correct some problems with the grid data. [R&D2_S4] detected some problems. We had some calls and some web conferences to try to solve these problems, but it was not possible. We decided that it was easier to fix it and solve the grid data in one day, when we are physically in the same room. This was very nice because we fixed the problem in two days in February and March and we easily resolved the problems together in the same space. (I29_DSO_S4)*

Given the complexity of knowledge, many interviewees emphasized that they were better able to interpret the information through the gestures and facial expressions in a physical meeting that would otherwise get lost online (*I11_RD1_S4*). By talking with each other and sussing out how the other partners worked, some project partners were able to build up stronger social ties, which were necessary for them to engage in interorganizational learning *(I30_RD2_C1)*. The interview data showed that some topics were clarified more quickly and effectively in a joint meeting than, for example, in short phone conferences that took place over the period of weeks. Thus, it would be a matter of weighing up when a simple telephone call would be suffice and when a longer on-site meeting would be appropriate for the exchange of information and for whom *(I27_DSO_W2)*. This was summarized by *(I29_DSO_S4)* as follows:

> *In some cases, it is easier because sometimes with a simple call, we can solve a simple problem or we can check a detail or something like that. Sometimes, we can fix a call just to see the progress of*

the task, but sometimes, we are discussing very specific topics and then the people, on the other hand, are not seeing what you are saying. You identify in several years that probably it is easier to fix it in a day and to have a physical meeting to discuss and to solve the problems. (I29_DSO_S4)

Learning requirements – Trust and confidentiality

The interview data indicated that learning new methods and tools collaboratively indeed required experts to acquire the knowledge more quickly and easily, but that this was still learnable in terms of the overall effort and complexity. This is due to the fact that most of the methods and tools shared between the project partners were less confidential, since a large part of this knowledge was publicly available or could be purchased for a fee *(e.g. I2_DSO_W2: I30_RD2_C1).* For example, *(I2_DSO_W2)* stated that the [tool1] was open source and therefore freely accessible to all partners.

Organizations possessing expertise in these areas were usually quite open to sharing their methods and tools in the project. This was especially applicable with regard to the research institutes, for whom publishing, writing papers or documents as well as sharing knowledge at conferences are common practice. Some research partners even argued that they did not have any knowledge that could not be shared *(I1_RD_E5).*

Well, I'm actually relatively open, if you ask me. After all, we don't have any company secrets. This is relatively public knowledge and we are always grateful if someone is interested in this knowledge. I think I share it quite openly and I am communicative, but more passively when someone asked. I don't really push myself to share knowledge. (I22_RD1_C1)

This propensity to share knowledge was very different from that of industry partners, for whom the market value of the research is fundamental, as they rely on the dissemination and acquisition of knowledge *(I27_DSO_W2)*. Even though the research institutes also protected their ideas and were not always able or willing to publish all results of their investigations with other partners, they had an overall high interest in sharing knowledge and were, therefore, much more open in comparison to industry partners *(I14_RD2_S4)*. In this sense, interorganizational learning was easier when research partners were involved in the tasks. In this sense, *(I16_RD_E5)* described:

No, for my part and the institute's part, we share our knowledge with everybody from the project; regardless we have no proprietary issues or any kind of other issues where we would not be allowed to distribute our knowledge. For my part, there are no conditions. But I know that people in DSOs and TSOs have these constraints since they are more strictly supervised. And they are not allowed to give away their data. That is also one big difference between us (research) institutes and institutions and DSOs and TSOs, who are not allowed to distribute their knowledge. (I16_RD_E5)

It is worth highlighting that interviewees from research institutes were even grateful to have possibilities to share their method and tool knowledge with project partners that were interested in it. The research partners, therefore, attempted to convey knowledge in the field of research in the most simplest and understandable way possible.To this end, the knowledge was provided in particularly small units. The aim was to provide a broad understanding of methodologies and tools within the framework of the project *(I17_RD_E5).*

> *Actually, we have a team of people who work together very strongly and I really do try to always share my knowledge as wide as possible and to write down every step of the work done. If someone else also wants to join me or help me, that is possible. (I17_RD_E5)*

With regard to learning platform tools, confidential issues were also less likely to be asked and mutual support for learning was more prevalent. Some interviewees explained that usually one of the partners started sharing information, whereupon the others also revealed their information, for example, in the learning of [platform_1] and [platform_2] *(I8_TSO_W3)* According to the interviewees, the learning required not only e-mail or telephone contact, but also physical interaction, such as face-to-face interaction and body language *(I11_RD1_S4).* Similar content was expressed in the learning of CIM and CGMES standards, since documents were mostly freely available. Consequently, no restrictions were observable, why a partner should not have access to them. Rather, the core of the standard aimed at its application to a broad mass of partners.

> *Of course, you always have to consider confidentiality issues. However, that was not really a problem because this is rather standard. (I30_RD2_C1)*

Overall, most method and tool knowledge was shared openly with all partners as long as no one was given access to confidential material, such as programming codes *(I7_RD2_C1)*. Hence, the learning was more about the application and understanding of the methodologies and tools for the project context, leading to few concerns regarding the sharing. The interviewee *(I30_RD2_C1)* described that specific software modules and codes could only be shared internally within one organization and not with other project partners. The confidentiality of software codes was often justified by the fact that it could be later sold as a product *(I6_RD2_C1)*. However, the interview data showed that a distinction was made here between open source tools, whose use was welcomed in the project – and some restricted software codes, which could not be distributed under any circumstances *(I2_DSO_W2)*.

> *We have a certain code that we can exchange in the project with the partners by means of emails and messages. However, it is always written in those emails and messages that this code should only be exchanged in the project and only with certain partners. I always formulate the clause that if you still want to exchange it with other partners, please let us knows in advance. (I7_RD2_C1)*

> *For example, we cannot share with anyone the source code of the algorithm because this is an intellectual property. If I would share, I would lose what I have done because anyone can use it. (I31_RD2_C1)*

During the Smart Grid project, the interviews revealed that a basic level of trust was important to collaboration in general. According to some partners, this basic trust was already given by the fact that contracts were signed, which guaranteed the confidential handling of results and so forth. *(I28_RD_N6)*. From this perspective, agreements were concluded between the project partners that specific data and knowledge within the project remained confidential. The interviewee *(I30_RD2_C1)* argued that, while the contracts were, indeed, a basis for trust, the exchange of knowledge in such Smart Grid projects also required an interpersonal level of trust. This was further elaborated by *(I30_RD2_C1)* as follows:

> *Trust is an important point. I have the feeling that in projects like this, you always assume a basic level of trust until you are proven wrong. Maybe that is just my personal impression. Of course, you have all the official agreements that exist between the partners. But still, there is also a certain amount of interpersonal trust necessary, which plays an important role. (I30_RD2_C1)*

Some of the interviewees emphasized that sharing knowledge was generally better than withholding it. In this context, the interviewee *(I25_RD2_S4)* stated that thanks to the contributions and inputs of other organizations, new ideas were developed that did not exist before. Overall, there was a great desire among the partners to share information as much as possible in order to learn from each other and gain extra knowledge *(I3_RD_N6).* Learning methods and tools were, therefore, seen as a crucial point for establishing a fundamental basis for the project work.

Learning requirements - Power and competition

As outlined earlier in the chapter on knowledge boundaries, imbalances existed in terms of power differences between the organizations collaborating in the project. The interviewees described that there was a natural balance of power between partners in Smart Grid projects that stem from their functional differences. However, when learning method and tool knowledge between the partners, there was no competition over the ownership of the knowledge at all. For example, *(I29_DSO_S4)* found that the usual power imbalances from the different functions in the energy system were eclipsed and communication at eye-to-eye level developed. Since the methods and tools were relatively openly accessible, there was no thinking in terms of how to execute power or squeeze more out of the project at other partner’s expenses. Accordingly, the interviewees explained that they were *“completely open”* when learning common methods and tools *(I1_RD_E5; I14_RD2_S4).* Although power was exercised in the sense that core ideas or proprietary knowledge were not shared, conceptual grounding and learning were seen as necessary for project work *(I14_RD2_S4)*.

> *Yes, because we are a private research institution, but one of our rules is to disseminate knowledge and bring this knowledge to companies [...]. We are completely open. Lately, they are trying to protect some ideas, but we are in this ongoing process for two years, we disseminate using scientific papers and reports to publish. Of course, we have contracts with the industry and we do not publish*

> *the results, because they make us sign NDAs, but for pure research, we can share everything. We do not do pure research […]. Sometimes, we do this to advertise our sources. (I14_RD2_S4)*

As shown earlier in the need for confidentiality and trust in collaborations, the methodologies and tools should be learned so that the partners were able to participate effectively. Hence, most partners did not see any need for competition behavior. With the exception of intellectual property, no observable competition was highlighted for the learning within the project, as the release of information for interorganizational learning did not put the organizations at a competitive disadvantage.

> *In some other projects, we have developed some solutions that are our intellectual property and this was also managed accordingly with other partners. There are some projects that have some work that can't be uncovered, but in case of [project name] we can be completely open. (I1_RD_E5)*

> *We are actually sharing all the knowledge through deliverables, writing papers and attending the conferences. Actually, to the scope of this project, we do not have any knowledge, which could not be shared among all partners. (I1_RD_E5)*

Summing up, sharing methodologies and tools that had to be learned between partners did not involve any risk on behalf of the partners. On the contrary, sharing the knowledge and learning from other partners was considered as a quality factor, as the knowledge was verified and confirmed by other partners *(I23_RD1_C1).* Since the partners themselves had the power over what knowledge they shared for the joint learning, there were no challenges in that sense. Consequently, competition and power played no big role in the learning of the methods and tools.

Common Knowledge Base

The breakdown of these interview findings confirmed that interorganizational learning was an overarching structure that characterized the relations between the partners. With this in mind, it is necessary to ascertain how the knowledge learned has led to a shared knowledge base between the project partners.

In general, the interview data showed that most project partners often did not know exactly how to ascertain a specific method or how to use it in the project. To ensure that all partners have a basic understanding of the methods, tools, platforms and standards, experts were needed to explain them and get all partners on the same page. It was clear from the interview data that the know-how for this purpose could not simply be poured into codes or artifacts, but required communication and personal exchange *(e.g. I11_RD1_S4).* Although some parts of the expertise could not be separated from the personal knowledge background, it became apparent that only the parts of the method and tool knowledge that could be learned were easily transferable. As a result, not all method and tool knowledge was easy to learn, forcing partners to rely on the experiences of individuals.

> *And the methodology has many details of course. So if we need to learn first the concept, then the methodology and then to apply the methodology to get the use case. I can understand that this will be difficult for some people. (I27_DSO_W2)*

Knowledge of common methods and tools had to be built across all organizations, and this required a wide range of skills and knowledge, instructed under the guidance of experts. Likewise, a high amount of knowledge was also learned between the partners especially through deliverables and documents. However, most partners learned the methodological knowledge only to the extent that they understood it and were able to apply it in the project. The common knowledge base thus related less to general engineering things (*I28_RD_N6*), but mainly to methods and tools that have not necessarily been used before, but could be important for the future energy system *(I29_DSO_S4)*. This basic learning needed from all partner for a common knowledge base was described by (I17_RD_E5) as follows:

> *But there is also this basic learning, for example, where I just have to figure out some tools, what I am going to click somewhere, which I would say is more basic knowledge […] (I17_RD_E5)*

My research data revealed that the knowledge base was developed in collaboration with experts. Each partner brought a particular methodology or a tool to the project, which served as a basis for meeting the project objectives. Understanding different points of view and applying different methods and tools was key for its establishment *(I2_DSO_W2)*. Likewise, the interviews revealed that the knowledge base acquired mostly came from practice or was imparted by more experienced partners *(I30_RD2_C1).*

> *I think the most difficult part was to explain the methodology we want to follow in creating use cases because we need to have the same approach if we want to share the deliverable and the task. Thus, we had to make sure that all the involved parties understood the methodology. And there were also technical difficulties because we choose to liberate a tool, which each party had to use. (I27_DSO_W2).*

However, not all partners had to learn at the same level of complexity. The knowledge acquisition could remain relatively general, so that the partners could even learn it in the short project duration. The consistency of method and tool knowledge for the common knowledge base was, thus, justified with a small amount of working time, resulting in a more superficial insight into the knowledge of the partners. For example, *(I30_RD2_C1)* explained:

> *Well, for me personally, because of my tasks and the fact that I was not working in that project for so long and that deep, it was a little bit more superficial than in-depth. As I only had a small amount of working time, I couldn't go that deep into the knowledge. (I30_RD2_C1)*

To summarize, the interview results showed that tools and methodologies were key elements that needed to be learned interorganizationally during the project in order to meet the requirements for the development of new ICT tools and platforms. By not only consulting individual experts, but also producing results and papers, the common knowledge base was expanded to include method and tool knowledge needed to perform common tasks. Interorganizational learning was generally enabled to the extent that each partner was able to learn it. Building on this, the following chapter considers the process of knowledge bridging.

5.3.2. Knowledge bridging - a complexity-reducing alternative?

Arguably, the Smart Grid project was characterized by the specific expertise that each partner brought to the collaboration. As was made clear in the chapter above, interorganizational learning was an indispensable part of the collaboration that ultimately built the foundation of the common knowledge base. However, the interviews revealed that integrating new expertise is very costly and requires significant amounts of personal and time expenditure *(I12_TSO_S4).* This can be seen as contrary to today’s rapidly changing and fast-paced project environment, in which relationships are often in a state of flux. This chapter thus examines to what extent knowledge and specialized expertise were integrated between partners and how knowledge bridging functioned as an alternative for interorganizational learning.

Knowledge type

The project partners already indicated that there were different types of knowledge exchange: the relatively straightforward exchange of the method and tool knowledge necessary for the functional participation of all partners and the more complex, resource intensive exchange that was only dealt within one team of experts and was not shared between all partners. The interview data showed that this essentially bridged expertise was fundamental, especially in the area of electrotechnical engineering, computer sciences, standardization and architecture modeling *(I27_DSO_W2).*

Field of expertise in electrotechnical engineering in energy systems

One example of the complex exchange can be found in the demonstration and simulation activities within the project. This meant that expertise in the field of electrotechnical engineering was required, especially among the system operators DSOs and TSOs, such as how the power system and other processes in the energy sector work. This was considered as knowledge at a more complex, advanced level *(I27_DSO_W2).* In this sense, *(I27_DSO_W2)* stated:

> *For the methodology on computer sciences and concepts, it was at the basic level, but on the electrotechnical engineering part, it was at a much more advanced level. (I27_DSO_W2)*

The interview data showed that it was rather the industry partners, who did not immediately bring their expertise in the area of power systems fully into the project. Even though scripts and tools were shared for the common usage and application, actual tool implementations as well as network configuration or operation was not shared between the project partner. Hence, the actual tool implementation and network configuration was rather excluded from the common project tasks. The more complex the insights into internal details of network operations and configurations were, the more likely it was that this knowledge remained with the professionals in the field and was tightly controlled as to who had access to it from the different organizations *(I2_DSO_W2)*. As a result, the more complex the expertise in electrotechnical engineering became, the less it was possible to make it freely available. For example, the interviews showed that the system operators had simultaneously knowledge of the core operation. This knowledge was shared between partners without other organizations delving deeper into it *(I2_DSO_W2)*.

> *I can give you an example. That exchange platform is something that we developed internally in [DSO_W2] and we do not share it with others. In fact, we can share the use, but we do not share the development. We have the tools […] that are open source and we are happy to share that tool with the others. […] Our grids that we use for the network configuration is something that we are instrumentalizing. We can share the main idea of our grid and the same applies to the information of the grid. We can test the grid in [DSO_W2] and define the rules, but afterwards the implementation is more or less impossible to share because it is something that tires us developers when the project is scaled by other companies and in fact the product is not from [DSO_W2]. Because it is from other companies, it is not easy sometimes to manage this knowledge. You develop, you put your effort in it, but in the end, you sell the product and our grid. It is not yours and that is a little bit strange. (I2_DSO_W2)*

Most of the experts in the field of electrotechnical engineering had in-depth knowledge in the area of network calculation and network modeling. The interview data showed that it was not only confidential knowledge, but that it was also technically more complex. For example, *(I30_RD2_C1)* described that one organization added network knowledge while others added time series simulations. Both expertise were later used to implement the control system. However, instead of real technical data in the area of network calculations or modeling, partners often exchanged ideas and more simplified models to reduce the complexity. In this sense, *(I30_RD2_C1)* explained:

> *Yes, I had that impression, because we have a lot of expertise in network calculations and network modeling. As I could see when I was involved in the tasks, there were certainly some things beyond that, for example, where we could exchange ideas with the project partners about the topic. That's what I noticed. (I30_RD2_C1)*

The interviews showed that experts were needed in the project to share the functional features that were inaccessible to other project partners. However, detailed knowledge on fundamental electrotechnical engineering knowledge was not routinely exchanged amongst all partners

(I6_RD2_C1), but the aggregated results were often provided to the project partners without going into the depth of the knowledge. This was explained by *(I6_RD2_C1)* as follows:

> *Accordingly, we can only pass on our knowledge about the network data in the form of results. However, that's what matters in the end. […] For example, we're currently running a test with [name], where he can send his network calculations to us via the message bus, i.e. via any set point. But he doesn't see the code of the message bus or how the […] tool works. He can only use it but does not see the code. We provide the function rather than the knowledge. However, of course, you can also acquire the code. (I6_RD2_C1)*

The interview data showed that these experts in the field of electrotechnical engineering were essentially required for the dispose of knowledge in terms of network operation and exchange processes. Quite often non-experts referred to the knowledge of experts. For instance, *(I7_RD2_C1)* explained that technical experts were addressed for specific data exchange expertise. As a result, not all partners were able to map the depth required for the project with the electrotechnical engineering knowledge. The decisive factor was, therefore, not that each partner was an expert in electrotechnical engineering, but that the expertise was bridged between each other. For example, *(I11_RD1_S4)* stated:

> *I don't want to know everything about you, I just want to know the sufficient information about how the grid operates correctly and vice-versa. Every time I design the process of exchange, I try to do in a balanced way. Of course, I work many years in transmission, so I tend to know more about transmission than distribution. (I11_RD1_S4)*

The electrotechnical engineering knowledge associated with the power system was also critical to the development of the *use cases*. The interviews revealed that various energy-related knowledge was needed to complete the word template for the use case. Only in exceptional cases did interviewees indicate that it was necessary to deepen the electrotechnical part in order to understand how the power system functions *(I17_RD_E5*), but for most partners this deeper insights was not possible within the project duration. The use cases were, thus, seen as an opportunity to bridge different knowledge from the energy domain. Interviewee *(I5_DSO_S4)* described that TSOs provided technical data and commitment plans for the reactive power and control use case to the DSOs. This was considered particularly important given that the energy sector is structured very diversely in each of the partners' countries. The partners were, consequently, able to gain knowledge about the field in other countries *(I5_DSO_S4).*

> *As I mentioned it for understanding the point of views. We have some examples that we say in [Western Europe country 2] it is somewhat like this and in [Northern Europe country 6] it is somewhat like this. We say okay, it is not the same thing, but we understand why and develop shared knowledge. (I2_DSO_W2)*

During the development of the use cases, each partner received the necessary knowledge from the various organizations. This enabled the organizations to identify unforeseen problems and find potential solutions *(I32_DSO_E5).* The interview findings showed that there was a high degree of dependency, as the organizations could not map and offer all the expertise needed for the development of a use case. It was also striking that the use cases were mainly created at the beginning of the project, which meant that the in-depth expertise contained in the use case was needed for the further development of the demonstrations and simulations, especially for the definition of the requirements for the platform. This was explained by *(I23_RD1_C1)* as follows:

> *People find that the whole methodology gives them easy access to knowledge once they have understood it and that they no longer have to work hard to acquire a lot of things themselves, but can simply consume the knowledge. It's just a saving of effort. It's like having a common language, which you then have and with which you suddenly understand other things. (I23_RD1_C1)*

Field of expertise in computer sciences in energy systems

Exchanging fundamental knowledge in the area of computer science also did not routinely take place in the project. More in-depth technical knowledge, such as in terms of software tended not to be exchanged with several partners, but established at the experts and later passed on in the form of results in the project. This computer sciences knowledge tended to be tied to the individual experts and their preparedness to collaborate. Consequently, this level of expertise was not easily transferable nor accessible elsewhere; only the basics could have been found on the internet. This type of knowledge was observed, for example, in the development of the cloud platform in the project, which required specific computer sciences knowledge that could only be provided by an expert. In this sense, *(I28_RD_N6)* explained:

> *I was providing advice when it comes to creating the platform, but we had [name] who was implementing it. For example, in our local meetings, [name] was presenting his proposals and I was telling [name] that this doesn't come across well or in the cloud platform you have to implement this and that. But those were very specific discussions. It was very directed because we already had the system use cases developed. We just had to make sure that the platform can do that. For example, I didn't need to know too much, even though I know a little bit. I didn't have to know too much about everything. (I28_RD_N6)*

In addition to expertise in software development required to develop the cloud platform, computer scientists were also needed to set up CIM converter *(I6_RD2_C1)*. The interviews showed that this knowledge is enormously specialized in the field of computer science and that not even individuals studied in this subject necessarily have this knowledge. The expertise was often gained through years of work in a specific area and, thus, practical experiences were decisive for the acquisition. Consequently, the knowledge could not simply be acquired, but was often developed through trial and error. This once again showed the specificity of learning computer sciences in the power domain. For example, *(I6_RD2_C1)* described:

> *[...] Some of them are more in the field of programming, such as computer scientists, who are testing the CIM converter with the network data and find out that the converter is not quite right yet (I6_RD2_C1)*

The depth of knowledge was also evident in other interviews. For example, *(I26_TSO_W3)* stated that some parts of the computer sciences knowledge especially in the energy domain could not be found on the Internet but was developed within the cooperation of experts. The knowledge was, thus, built up in daily exchanges with other experts within the organization or in collaboration with external experts. This was explained by *(I26_TSO_W3)* as follows:

> *I think it is very specific expert knowledge. It is knowledge that comes out of collaboration between different parties. So it is not like, "Okay, I find something on the Internet," it is more complex knowledge that can only be gained as an output of a project with different partners. For me, this is a value obviously. (I26_TSO_W3)*

The level of expertise and the time required to reach that level of expertise meant that some partners' knowledge did not have to remain rudimentary. For example, most forms of collaboration required that some partner only need to understand the central concept of [platform_2] rather than the specifics of its programming (*I28_RD_N6*). Similar experiences were made in the area of modeling with UML. The central point was to get to know the idea of the respective partners and to gain a mutual understanding of the application of UML in the project, but not to develop a deeper technical understanding. Hence, the partners needed to become familiar with the key forms of this modeling in order to achieve mutual understanding, rather than elevating all partners to the level of experts.

Field of expertise in standardization and architecture modeling in energy systems

The interview data revealed that experts in the field of standardization and architecture modeling were equally necessary to fulfill the tasks in the project. The specific topic of standardization and architecture modeling ran through the entire project and was seen as crucial to the creation of interoperable ICT tools, the use case development and Smart Grid architecture. This specific expert role was described by *(I22_RD1_C1)*, for example:

> *I would say that my tasks tend to be in the field of Smart Grid architecture modeling and the use case methodology. I would say that I have the role of architecture development, modeling and assessment in the project. (I22_RD1_C1)*

The knowledge in standardization and architecture modeling was equally unique, so that it could only be mapped by experts who contributed their particular knowledge. What became apparent was that experts were needed, particularly in the use case methodology, to instruct the project partners. The necessity and dependence of expert knowledge was made clear by *(I7_RD2_C1)* as follows:

> *We definitely need the expertise of other project partners in the field of standardization. So you at [R&D1_C1] are well versed in the standardization topic, but also [TSO_W3]. If we need help in the area of standards and generally for answering the question of which standards are necessary, then these are good contacts. (I7_RD2_C1)*

Similarly, experts were needed for standardized information exchange. The application and implementation of CIM and CGMES in the project required not only a deep understanding of the standards in information exchange, but also years of experience to implement them meaningfully in the project context and beyond in the individual organizations. For example, *(I30_RD2_C1)* described that more experienced partners were asked to provide the expertise in CIM and CGMES standards. The depth of knowledge was also evident by (I8_TSO_W3), who has built up expertise through various expert groups:

> *My specific expertise is the standardization. I worked back with the standardization groups and standardization meetings at [TSO_W3] and also with data exchange. So, I have a participation with communication standards subgroup through [TSO_W3]. I am the contact person at [TSO_W3] for this group. So, this is my specialization. (I8_TSO_W3)*

The different field expertise clearly showed that knowledge was available in terms of different roles, each of which was expected to make a specific contribution to the project. Notably, the field expertise was shown to be highly adapted to the energy domain. To conclude, the interview data revealed that the complex development of innovations in Smart Grid projects was dependent on very specialized expertise that was difficult to acquire on one's own.

Characterizing bridging of expertise

To comprehend the concept of knowledge bridging, it is critical to characterize it from a process perspective. The data offered here showed that while knowledge integration was necessary at many points in the project in order to build a common knowledge base, the integration of field expertise tended to occur at the *knowledge interfaces (I22_RD1_C1)*. Hence, the exchange of knowledge occurred only in the sense that one field of expertise touched another expert field. Hence, the integration of knowledge only went as far as understanding the knowledge connections between them. For example, the following statement revealed that the field expertise needed to be framed in the deliverables in such a way that a common understanding of the interfaces could be developed. However, once knowledge became more complex, there was no interorganizational learning evident anymore *(I22_RD1_C1)*.

> *In [project name] rather less [learning took place]. I would have liked that, especially with the communication protocols and everything that goes with it for the tests, because I had no other points of contact in that sense. However, I must admit that I read all the deliverables from the other work packages anyway. This gave me an overall perspective and I was always able to gain insights in the sense of, "Ah, they see things quite differently than I do." I cannot say now whether I would call it learning in that sense. At least I was prepared to familiarize myself with the perspectives and tasks that the others had. If I had my points of contact with them, I at least understand that we don't mean the same thing and can adapt, so to speak. (I22_RD1_C1)*

Finding common interfaces was not self-evident, as a large *gap between the disciplines and the various expertise* became apparent. For this reason, the project partners had to clarify at the beginning of the project which expertise was available in which organization and how it could be integrated into the project. Thus, not only were technical interfaces necessary at the system level, but also in the area of knowledge fields *(I32_DSO_E5).*

> *Yes, I think as usual the big difference is when people come from different domains and there is a gap between what is needed and what can be achieved and what was imagined or expected from the beginning (I32_DSO_E5).*

Thus, knowledge bridging became a means by which interfaces could be discovered, because what was exchanged depended on a rough idea of what was likely to be needed and on the application and use of the resulting expertise *(I4_DSO_S4)*. Understanding a project partner's perspective on the common tasks guided largely what needed to be exchanged rather than the acquisition of an encyclopedic understanding of all the expertise. Creating a familiarity with each other's expertise and becoming aware of what the other project partners were dealing with, proved more compelling for the project partners. In this vein, one interviewee reported that a familiarity with CIM and CGMES topic needed to be established, but a deeper insight was not always possible at all in the project *(I30_RD2_C1)*. The depth of knowledge required was also determined by the tasks and the partner's role in the project. While some project or work package leaders involved themselves more comprehensively in the project and looked deeper into the tasks other partners were undertaking in order to gain an overview and provide guidance, other project partners were only involved on a brief short-term basis. For example, *(I30_RD2_C1)* stated:

> *I think it really depends on the task and the project. If you are only working on a project for a short time, for example, to help out at short notice, and you don't have to get so deeply involved in a specific topic, for example, when creating reports and supporting corrections, then I do not think that you have to get so deeply involved as if you are the expert for the entire project, for example, for network conversion or something. That is something else. I think it always depends on the project and on your own task and the integration into the project. (I30_RD2_C1)*

Several interviewees described how exposure to expertise was more akin to *higher level learning* and only sometimes went beyond the basic knowledge required. If higher-level learning was required, it tended to be in the areas of synergies and correlations *(I31_RD2_S4)*. This higher-level learning meant an understanding of the main idea of the different expertise in the project. Consequently, most partners remained experts in their pre-existing fields. Similarly, those partners who had acquired new kinds of expertise could not say whether they would use this in future projects. For example, *(I31_RD2_S4)* stated:

> *I learned from other topics that are not from my field. I cannot tell you if this is going to be useful for me in the future or not because since it is not from my current field, it is difficult to say if it is going to be very useful or not. But it is always good to learn and to understand other fields of knowledge. At least, it is good to have a higher level learning because although I am not from that field, everything is correlated. Even though I don't come from the optimization field, everything is*

> *about power systems and about our expertise. Everything that you can learn from the project is good to do experiences. (I31_RD2_S4)*

The *acquisition of new expertise* was generally characterized as rather superficial. Some partners even explained that they considered some of the learning irrelevant in terms of not only the complexity and quantity of information, but also by the fact that knowledge was not necessarily relevant to their own tasks *(e.g. I2_DSO_W2; I5_DSO_S4).* In this regard, the project partners made clear that much of the content was heard for the first time and was quickly forgotten. Not surprisingly, one interviewee expressed this in the sense that knowledge going in and out - only entering the mind briefly without deepening it further. In this way, *(I10_RD1_S4)* stated:

> *Probably in the meetings, but it's not very specific. It's just okay that you are talking about some protocol or presenting some stuff that I never heard of. If you are hearing it for the first time, it's already very good and you can learn something. However, in a very focused way and with going in-depth for a certain thing, I think that didn't happen until now. (I10_RD1_S4)*

Similarly, the interviews revealed that the partners often did not acquire more knowledge than was deemed necessary for the elaboration of the tasks. Hence, with the completion of the task, the chapter and the associated expertise included was often pragmatically guided and no further action was initiated to continue educating themselves in this particular area if it was not deemed directly relevant. By efficiently achieving the goals of the project tasks in this way, the partners' targets were met and a deeper knowledge building was mostly perceived undesirable.

> *I would say yes [that it is more a basic understanding]. We were more focused to complete, or to fulfil or to reach the goal to have some data exchange and once this was achieved and it was achieved in a reliable way. For us the story was closed. (I32_DSO_E5)*

In summary, the interviewees indicated that expertise was added to project tasks only when expedient to ensure proper understanding of interfaces and basics for the application in the project, as well as no more effort was expended than necessary *(I11_RD1_S4).* Therefore, it was more about gaining a rough understanding of the activities of other project partners in order to get an overview of the project and to develop a common basis for communication. One research interviewee defined this as a simple exchange of knowledge *(I11_RD1_S4):*

> *We have not yet reached the level of deep learning, but we have already conquered some level of exchange and I think this will be intensified in the next month. Definitely, because we are going to exchange network, models, scenarios and with this a lot of questions come [...]. (I11_RD1_S4)*

The interview results pointed out those experts were largely used to integrate and contribute their domain knowledge without demanding other partners to learn it in-depth. The concrete role of expert knowledge and the method of bridging it in the project will be addressed in the following chapter.

Method of Knowledge Bridging

The second sub-question of this dissertation aims to find out how exactly the partners in the project integrated distributed and specialized knowledge. Therefore, it is essential to find out more about the method and underlying process of knowledge bridging. While methodologies and tools were learned interorganizationally, more specialized expertise was exchanged only superficially or not at all between the partners *(I17_RD_E5)*.

Expansion of the own expertise

As already identified, learning for themselves played a major role within the project, especially when the partners wanted to develop a greater understanding into the methodologies or domain knowledge *(I23_RD1_C1)*. Independent learning was used in the case study project primarily when expertise in a particular area was already available and could be expanded through further documents and books, making it worthwhile to take a deeper look. Therefore, project partners engaged in more complex forms of learning only when the partner saw a personal benefit to that knowledge acquisition *(I17_RD_E5)*.

The Smart Grid project indicated that the project partners often *remained their own experts* and sought knowledge in their respective field of expertise. For instance, *(I31_RD2_S4)* summed up that self-learning was necessary to delve deeper into the algorithms that should be used for the project tasks – but which was, however, seen as additional knowledge that goes beyond their role in the project. What is significant here is that expertise needed for the project was available in the organizations, but has not mandatorily been exchanged between the partners for elaborating the project tasks. However, the acquisition of expertise was no guarantee that this knowledge was also shared between other partners. Similarly, not all organization always had experts in a particular field. In this case, too, the knowledge was acquired autodidactically from the Internet. For example, *(I10_RD1_S4)* stated:

> *Yes, because at [R&D1_S4], we don't have so much people that are expert on these kind of things. So I'm just learning from the Internet. (I10_RD1_S4)*

The interviews also evinced that project tasks were worked on without knowing the exact details of the other project partners' knowledge area. Accordingly, an interviewee provided the example of not knowing specifications of the energy system of the Eastern European country, but still had to make calculations for it. Hence, it was not always necessary to delve deeper into the power systems networks, as not all details were relevant for the work assignment. In the end, the tasks were verified by the Eastern European project partners, who were actually experts in their systems and networks *(I11_RD1_S4)*.

Sometimes, we analyze or we calculate some indexes for the [Eastern European] partners without knowing anything about their system. Then, we show them the results and say: "Does that make sense, or not?" And they said, "Yes, it makes completely sense." Then, we feel secure about our methodology and vice versa. (I11_RD1_S4)

Although there was an exchange of knowledge among the organizations, the interviews showed that in most cases this sharing was not linked to the learning of other domain-specific expertise. The search for knowledge, therefore, occurred primarily in the partner's own knowledge base, where they furthermore saw a purpose beyond the project tasks.

Internal expert teams

The Smart Grid project was also characterized by strong groups of experts working together within one organization. Learning, consequently, did not only take place across organizations but new synergies were also created within their own organizations *(I17_RD_E5)*. For this purpose, more experienced individuals within the organization were consulted in particular. The interviews revealed that some of project partners had tutors or mentors within the organization by whom they were guided *(I17_RD_E5)*. Here, the contact was described particularly close, as regular and intensive exchange took place between the project participants from one organization.

I also worked with an IT guy from [R&D2_S4] that is [name] who also worked on [project name]. He understood better how to manage this type of information and he had a lot of more experience in Computation than me. I was like his pupil and he was my tutor in some parts of this project. (I25_RD2_S4)

The interview data revealed that many *experts worked in the background of their organization* and had, therefore, less direct exchange with other organizations. *(I5_DSO_S4)* even explained that additional knowledge from outside the organization was rarely necessary as all relevant knowledge for their tasks already existed within their organization. In this sense, *(I5_DSO_S4)* explained:

Regarding this project, no [additional knowledge was needed from partners]. We have all knowledge that we need for elaborating the tasks. (I5_DSO_S4)

For example, most organizations elaborated the use cases within their own organizations and later uploaded the template filled with expert knowledge to the project's communication platform. The use cases were, accordingly, prepared within the organizations, and afterwards shared with other organizations that were involved in that use case. In this way, developments were created after pooling the knowledge from experts that had previously been elaborated within the organizations. The learning between experts from one organization was described in the area of programming, use cases as well as in the area of CIM conversion with network data

I think in the demonstration everyone is working beyond side. We don't have a lot of exchange. Before in work package 1 activities, I think it was like that, because we have a set of use cases that

> *each use case was developed by a different entity, but we arrived having a common library, a common information model. This is great that everyone contributes different types of tasks. (I2_DSO_W2)*

The interviews also identified internal expert teams, such as computer scientists, who were asked to provide more knowledge in the area of CIM and CGMES standardization *(I6_RD2_C1)*. Likewise, topics such as programming languages, cyber security or demand response in power systems were discussed and learned in internal expert teams. As a result, participation in Smart Grid projects often involved more intensive work in smaller teams of experts in order to learn about best practices and more complex issues *(I14_RD2_S4).* For example, this was explained by *(I16_RD_E5)* as follows:

> *Yes, but I learned internally. I have a colleague who is skilled in Python and I learned from him. Apart from that, I did most of the learning myself, in coordination with my superior and in coordination with the project coordinator from our side […]. (I16_RD_E5)*

The increased internal exchange of expertise was attributed to the greater familiarity of this type of knowledge compared to that of external partners, facilitating the exchange of information among each other. According to an interviewee, it was more difficult with external partners to communicate without a common knowledge base, especially given the fact that this knowledge was different between industry and research *(I31_RD2_S4).*

> *[We communicate] more internally, yes. More discussions are held internally. Internally is easy because we have the same expertise – not everyone of course, but the partners that were working on this project. We have the same expertise. It is easy to discuss this. When you discuss with external partners, it is not easy. It is not easy for several reasons because sometimes they are not from that field. I gave you the example of network operators. They are from the field of operation, but they are not from research. When I am going to talk with them about what algorithms are used, I want the thing to work as I want. There would not be much conversation about this because it is very specific. (I31_RD2_S4)*

Not surprisingly, the interviewees disclosed that in the case of difficulties mostly the organization's own colleagues were contacted. One of the interviewees exemplified that they wanted to take a different approach, which had been introduced by an external partner, but due to cybersecurity problems, a solution had to be sought from within their own organization, at least in the first instance. Although the approach of finding a solution in-house seemed more viable, it came at the price of limiting innovation. In this case, an independent approach was finally adopted to overcome the difficulties *(I21_RD2_S4).*

Taken together, the required expertise was mostly examined individually as a part of the project tasks, and the outcomes of these tasks were then merged in the deliverables or publications *(I7_RD2_C1)*. The interviews revealed that the individual experts added their particular knowledge for the joint elaboration. For example, interviewee *(I30_RD2_C1)* described that one organization added network data while another partner added the time series. By linking the two areas of expertise, the control system was developed as part of the project. This was stated by *(I30_RD2_C1)* as follows:

> *For example, one partner provided the network; the other then provided the time series. We then implemented a control system, on which we worked very closely together. (I30_RD2_C1)*

The process of merging the various field expertise also became visible in the creation of use cases. The use cases were gradually developed and linked to real-world problems with the help of the different expert knowledge *(I32_DSO_E5)*. In this manner, a clear separation of the use case parts was apparent in the project, meaning that the tasks were allocated to the respective experts with specific knowledge. Overarching collaboration was not evident in most cases during the initial elaboration of the tasks and only took place in the second step of the joint consolidation of the individual results *(I2_DSO_W2)*.

> *We have, for example, the use case that is on the one part about real time simulation and the other part is about operational planning, which is [R&D2_S4] part. And of course, we have to share more, because we will compare the two things and we need to share. But these limits are really difficult to define in the sense of what we share or not, but not because it is personally, but of the company. (I2_DSO_W2)*

Finding knowledge interfaces at project meetings

The interviews findings showed that knowledge interfaces between the different experts were often identified at the biannual project meetings, which were organized locally at one of the partner's facilities. Since most of the meetings took place before the Corona pandemic, only the last joint meeting could not take place on site. In general, there was the perception that the communication at the project meetings was perceived quite easy, promoting the general identification of interfaces and the getting to know each other *(I27_DSO_W2)*.

> *Yes, I think it was necessary. For this, I think one really big deal was a physical meeting because when you know some people, it is much easier to communicate than using LinkedIn or these kinds of web meeting tool. (I27_DSO_W2)*

Internal workshops also served to ensure that knowledge interfaces between experts could be found. Personal exchanges in particular made it easier to highlight commonalities and differences that were necessary for subsequent collaboration. These project meetings or workshops often did not involve learning details from each other, but rather determining which partner brought a particular expertise to the project.

> *[…] But we have made the experience that if you point out a small problem to project partners and at least try to bring people together in a workshop in a small group, then you often get back, "Oh yes, they are right." At least with those partners where we point out the interfaces and tell them where we see the problems and then try to bring the people together. Then many partners realize that there is still a need for discussion and very often, they meet bilaterally. [..] (I22_RD1_C1)*

Working in parallel

Delving deeper into the process of knowledge bridging, it was also characterized by the fact that a lot of work was *carried out in parallel* between different partners, roles and organizations. The knowledge therefore did not inevitably build on each other. Accordingly, *(I6_RD2_C1)* gave the example of parallel approaches in mapping the observability area in CIM. While the interviewees' organization was developing new classes for mapping the Observability Area in CIM, other Eastern European partners were using a different methodology without new classes. At the same time, CIM experts were using a third concept *(I6_RD2_C1).* This equates that the tasks were approached differently and pursued in parallel, depending on the organization's expertise.

> *A larger topic was, for example, how the Observability Area can be mapped in CIM. There were different concepts that were proposed. [R&D2_C1] suggested, for example, to introduce a new class, i.e. a container class, where elements can be collected. In the discussion with the CIM experts, however, it was discovered that they had a different idea for mapping this. I think it is important to see that we are already discussing and exchanging ideas, and that the proposals will be accepted. The thing is that you have to realize from time to time that things are going on in parallel that you didn't really know anything about. Of course, that's another challenge. It's also difficult, you can't always know everything. [...] But that would also be a massive flood of information that you would have to absorb. I wouldn't know how to best do that now, but there are just a lot of things going on in parallel and there are just a lot of different approaches to coordinating it. I think that this is difficult because it has to be done in a superordinate way and not as the work of a single work package. (I6_RD2_C1)*

This aspect makes clear that knowledge was not necessarily integrated in collaboration rather that individual experts attempted to bring their methodology into the project. However, this statement also showed that some of the experts had opposing opinions for the integration of CIM in the project. The interviewee described that not all communication proved to be fruitful with the experts as *"we can learn a great deal from each other, but there are also things that are addressed and discussed, that run a little into the void" (I6_RD2_C1).* It was noted here that a superordinate partner was missing to coordinate and decide on how to proceed with the different approaches *(I6_RD2_C1).*

> *One of the CIM experts gave feedback that this could be represented differently and another expert said that this would be a good idea and that it could be discussed. If the experts then disagree among themselves, I find it again difficult, because then simply the superordinate, coordinating expert is missing, who determines what happens with this proposal. You can just write it into the report now, but you do not know whether it will be discussed further or whether it will bear fruit. (I6_RD2_C1)*

In the end, a method had to be agreed upon, which is why some of the partners' ideas had to be discarded by the experts. These experts largely decided which idea should be pursued in the project. These decisions were largely based upon finding the best common denominator or points of consensus amongst the varying perspectives *(I27_DSO_W2; I6_RD2_C1).* The difficulty for the project partners was to keep the overall picture of the project in mind. One interviewee explained that the only way to get an idea accepted was to consistently push it through and draw attention to it *(I6_RD2_C1)*. Nevertheless, many ideas had to be rejected, because not all ideas could be implemented within the project duration. In general, the interviews shed light on the observation that in the project areas where experts were needed, fewer ideas were worked on together. As a result, ideas from non-experts were sometimes discarded and not reintroduced into the project *(I6_RD2_C1).*

> *At the end of the day, we can only bring what we have now considered to the CIM experts, but if they say that they already have completely different ideas, then it can also be that what we are working on is discarded or does not bear fruit. If you still have arguments why our idea is better, you might be able to push it through somehow or draw attention to it. But it can also be that it is quickly dismissed by the CIM experts, because they think we have already thought about it and we don't even accept your suggestion now. We are already on a completely different path. (I6_RD2_C1)*

Working in parallel, without really learning from each other, was also evident from other statements made in the interviews, especially through the amount of work packages. Thus, it became apparent that not everything could be learned but expertise, when required, came via experts or deliverables. Nevertheless, not all partners were always able to read all deliverables and to keep up with everything that was being done in other work packages. The complexity and comprehensiveness of tasks from the project structure often resulted in the bridging of expertise *(I22_RD1_C1).*

> *Yes, that is the point. This is a common problem in such projects. However, I'm very cautious in such statements, because I had very little direct communication with the project partners. It can always happen that things that were not part of my work package just completely bypassed me. Of course, I cannot exclude that. (I22_RD1_C1)*

Reasons for applying knowledge bridging

My empirical investigation showed that specialized expertise from different organizations was needed for elaborating common tasks in the Smart Grid project. The interview findings identified that experts could mostly stay in their respective fields, as they did not have to deeply understand the expertise of another to successfully integrate this knowledge. This picture underlines that the learning of expertise was not obligatory and the mechanisms of knowledge integration were more centered on the identification of interfaces. Other reasons were also given in the interviews as to why knowledge bridging was done on a pragmatic basis. To start with, the general constraint of time was one of the main arguments for not learning expertise from other organizational actors. For example, *(I30_RD2_C1)* stated:

> *Well, for me personally, because of my tasks and the fact that I was not for so long and deep in that project, as I only had a small amount of working time, it was a little bit more superficial than in depth. I only had a small amount of working time, I couldn't go that deep. (I30_RD2_C1)*

Time limitations were mostly argued with the fact that projects were not only temporary, but the partners were also often involved in several Smart Grid projects at the same time.

Consequently, the project partners could not take enough time to go deeper in the more specific knowledge field and were, thus, not able to acquire new expertise. As a result, some tasks tended to be worked on more superficially *(I30_RD2_C1)*.

> *I think it depends. Sometimes, I would not say on a basic level, but an intermediate level. They try to push hart to give us all information that they have. But of course, sometimes we don't have time to get so deep. It made me learn in inevitable level, but it is not because the partner teaches in a basic level. They really go deep, they really keep themselves the time to explain us. Sometime the time is not possible to go in a deep level. (I8_TSO_W3)*

The same applied to the deepening of the exchange of information with CIM and CGMES. Accordingly, the project partners did not always have to familiarize themselves with this new type of knowledge and learn it in greater depth *(I30_RD2_C1).* Other interviewees described how the time restraints of the project itself set a limit, as some explorative work, for example, in the area of time series simulation, could not be pursued further within the project. It thus remained for most of them on a rather superficial level. In sum, the interviews revealed that expertise was often associated with a high level of effort and, therefore, could not simply be learned quickly in the project context. *(I30_RD2_C1)* explained this as follows:

> *CIM was not necessary at the beginning, but came later into the project in form of analyzing CIM files whether something in the CIM files could be missing. I had to learn that again, but I didn't have the time to familiarize myself with it. That was learning by doing and of course by asking more experienced people, e.g. [names of partners RD2_C1] directly. Also, the knowledge of how to carry out simulations, such as time series simulations and generally a little bit about electrotechnical networks was needed. However, I didn't have to acquire that specifically, because it was already part of my work. (I30_RD2_C1)*

The expertise most partners included were often in a particularly sought-after field, which is why they were highly demanded in the Smart Grid domain. This fact also led to the situation that they did not always have time to learn other expertise. Given their critical resources and know-how in developing the future Smart Grid, it became increasingly unlikely that they would delve deeper into outside areas of their expertise *(I26_TSO_W3)*.

> *I think for the knowledge about profiling and things like that, the main issue was about time, because people who have this knowledge are critical resources. However, in this case there are no confidentiality issue or things like that. So that is also something which is interesting for this kind of project that in some project, for example, when in terms of cyber security, the partners are very cautious to share some knowledge. Here, when it is about standardization and interoperability, it is not the case at all, because most of the information is public and we know that the more we have partners that are in involved in this topic. (I26_TSO_W3)*

In addition to the time barrier, the interviews reflected that the expertise, such as in the field of new standards for information exchange were not further learned and applied throughout the project due to insufficient resources in terms of financial and organizational aspects. However, these resources were often dependent on higher organizational and institutional levels and not changeable in the project context. Plus, the relatively open nature of the project plan, which meant, for example, that partners decided when to include the new standards, introduced a high degree of flexibility and made the partners responsible for whether and what knowledge they sought to acquire at more complex levels *(I6_RD2_C1)*.

> *When it comes to implementing the demonstrations, it can also happen that a partner doesn't quite go along with them because there are bottlenecks, financially or because the partners aren't so keen and don't do their work as conscientiously; then it just leads to others being involved as well. Of course, no data can be exchanged if one of them does not change and implement their system. That's the big problem. (I6_RD2_C1)*

The fact that learning was not pursued further and rather a bridging of expertise took place was also seen by using different approaches and concepts between the organizations. Even though more specific knowledge was not necessarily learned, it was clear that experts were still needed for the collaboration so that the required methods and tools could be correctly applied in the project. In this sense, expertise was also needed to build tools on top of that *(I12_TSO_S4)*. Since learning activities were generally costly, organizations often had less motivation to expand their resources so that their team would acquire competencies that were available anyway through collaboration. This mentioned cost factor led to the fact that the organizations were not in favor of implementing new standards in the project *(I10_RD1_S4)*. This exposed a clash of interest because the industry partners had to carefully consider what they really wanted to implement in the context of wider financial gains expected by the corporation, whereas trying out different methods for research was not directly tied to any financial hurdles. For example, *(I10_RD1_S4)* stated:

> *It's not easy at all, because this is a project and it's let's say an R&D project, but it is much more [DSO_S4] oriented and also [TSO_S4]. Since we are from the [R&D1_S4], we are focused on R&D, but [DSO_S4] focus on businesses. When we are saying, "Oh, but it's just a project, let's try to implement CIM," the answer from [DSO_S4] can be, "...But this really costs money and this will cost time. So probably we'll just follow with what we what we get." This is the main message from them. It's not easy. (I10_RD1_S4)*

To sum up, the interviews revealed that the reason for knowledge bridging was not necessarily due to confidentiality issues, but was mainly due to the lack of time and financial resources of the project partners, which hampered a complex engagement with certain specialized knowledge. In practice, the partners did not have to familiarize themselves too much with the subject matter of another specialist area, but could draw on their experience when it was needed in the sense of the project *(I6_RD2_C1)*.

Knowledge bridging requirements - trust and confidentiality

Having characterized the way expertise was exchanged between the project partners, it is still necessary to take a closer look at the requirements of knowledge bridging, beginning with trust and confidentiality. As identified in the above chapter, it can be said that project partners generally did not delve deeper into each other's expertise, which required a high level of trust between the partners. From the interviews, it became clear that the project partners had to rely on the expertise of others, as it was not possible for them to engage in more in-depth research. For this reason, building trust was especially critical for the organizations in order to bridge expertise. In this sense, *(I31_RD2_S4)* highlighted that the project meetings were particularly important to build a common basis of trust between each other, to connect even after the official meetings and to exchange more information on some topics that were necessary for the project work. The interviewee *(I32_DSO_E5)* said that sitting together and having coffee breaks created a common bond between the partners and even enabled long-lasting connections. For example, *(I32_DSO_E5)* described:

> *I think that communication in [project name] was very good. I think it was pre-COVID-19 time and I know that at least [name] was willing to take part in the meetings. I also think that these personal meetings, when you see people, when you sit together and you have coffee breaks, when you have let's say dinners or lunches; if you have this ability or wish, you are able to make contact that last for many years and you can harvest with the exchange of information. You somehow connect with people, you bond with them and then you have telephone numbers, you can call in the case you need some information. (I32_DSO_E5)*

> *Maybe it takes a bit of time at the beginning, but once you have talked to each other a few times and noticed a bit how the others work, I think you can build that up even in such a distributed system. (I30_RD2_C1)*

The interview data revealed that the providing of expert knowledge for the project was not a matter of course from the outset. Interviewee *(I10_RD1_S4)* claimed that some project partners were initially skeptical about providing confidential data and information, since this meant trusting on the one hand and giving up power on the other. This was particularly the case with sharing network data, where persuasion was needed as this type of data had not been shared before. In this sense, *(I27_DSO_W2)* explained:

> *I think trust was built during the project. For example, if we know we can trust somebody, we can at some time give some network. If we know that we are going to add authorization, we have to spend the next few months gaining some time, which is not really good, but it is useful to be authorized. (I27_DSO_W2)*

Accordingly, some of the partners, especially from industry had to be persuaded that it would be necessary to share this type of information for accomplishing the project tasks *(I10_RD1_S4)*. Overall, these information exchanges were characterized, at least initially, with skepticism and a reluctance. In this case, *(I11_RD1_S4)* stated that the partners who needed the data approached the partners with the relevant information and explained that both parties would benefit from sharing. However, the aim of building trust was not to learn this knowledge together, but merely to incorporate the knowledge into the project context. For example, *(I11_RD1_S4)* explained:

[…] They said that we don't want to give you everything. And I said that we don't need everything. Then, when I developed the first version, I said, "Look, I think we have found some simple rules to exchange information from this to you and we think that you also deserve to know much more about that - tell us how. We have some ideas, but we want to hear your view." Once you start with this point, not directional but bidirectional, then you get the trust and then you will see. (I11_RD1_S4)

During the course of the project, the project partners gradually gained more trust between each other. According to the interview data, trust was seen as a key enabler for the collaborative development of results. When trust was present between the partners, much more knowledge could have been shared *(I11_RD1_S4)*. The interview data showed that even between TSOs and DSOs, trust was gradually built up, which enabled a common basis for the exchange of expertise between the partners involved. In this sense, *(I11_RD1_S4)* stated:

In my task, I had to conquer the trust of both the TSO and the DSO in a time, in which they do not exchange so much information. This project was amazing, because once we gain the trust, then they start to share and they start to understand that there is much more to share, much more information to exchange. We have to face some corporate legacy and trust environment. (I11_RD1_S4)

Once a common trust base was established between the partners, confidential information and data, such as network data, were shared with the project partners, but under clear legal framework of exchange and thus authorizations for the respective parties *(I27_DSO_W2)*. It became clear that trust building was necessary for this step-by-step process within the project, which was accomplished gradually. As the sharing of field expertise increased, other project partners also started to provide their knowledge for the common work *(I11_RD1_S4)*. Even stakeholders who were previously skeptical began to make expert contributions. Obviously, the partners got to know each other better in the course of the project and were, consequently, able to constitute trust.

I start sharing my pains. In addition, if on the other side, there's one person also willing to share, then he or she starts sharing his or her pains. Then it is getting more open. However, it's a step-by-step approach - not the e-mail, nor the phone call is important, but personal interaction is needed. (I11_RD1_S4)

Other expertise could not be shared at all, although mutual trust had been established between them. For example, software codes were in most cases not allowed to be shared. The same applied to codes for the message bus in network calculations or for certain codes of simulation tools, which could not be shared per se *(I6_RD2_C1)*. Accordingly, the project partners only had access to the tool applications, but could not gain insight into the development of the software code. The interviews revealed that system operators were very cautious with their critical information about the network infrastructure. Consequently, the process of sharing expertise for collaboration has not yet been anchored and implemented in every organization. *(I21_RD2_S4)* said that persuasion and a high amount of trust are generally needed to use more expertise in future Smart Grid projects. Likewise, confidential issues due to the GDPR played a role here when sharing data between the partners *(I11_RD1_S4)*.

> *I think the main challenge was exchanging the data, because there are very strict rules regarding the data exchange. They don't want to exchange data. Their mentality is from 30 years ago. They are improving, but they are really not convinced from exchanging data so easily. They don't have this process already implemented. If you want to exchange data you need to sign some agreement of how to use the data and so on. You have to follow this policy in terms of confidentiality, even if it is just for research. In the internal process, they have to ensure that no data goes to public, which is why they evaluate strict or very roughly, if this can create some problems in the future to the company. This is why we face so many problems. (I21_RD2_S4)*

Knowledge bridging requirements - power and competition

Fundamentally, Smart Grid projects have shown that they rely on collaboration. Given the interdependences of the knowledge exchanges, there was a general consensus that collaboration was necessary and no single party was in a stronger position to exploit this process *(I32_DSO_E5)*. However, it was clear from the interview data that power and competition were present at another, more hidden level. The way that expertise was used during the project work was considered by *(I32_DSO_E5)* as rather critical for the functioning of the collaborations and was therefore influenced by power and competitive relationships. Competitive thinking was found, for example, in domain-specific knowledge that had to be added to the project. This was explained by *(I23_RD1_C1)* as follows:

> *Precisely because sometimes […] we are in a kind of competitive situation. Thus, it is not possible to let an unlimited amount of knowledge flow away, because in the area of research strategies, open points, future projects, you are in a competitive situation again after the project. (I23_RD1_C1)*

Since much of this expertise was core resources of the organizations, there was the concern that the expertise and key competencies would be passed on to others. Some interviewees also had the impression that some project partners were still unwilling to share their knowledge for fear of losing power and control over the outputs. Others interviewees highlighted the gain from sharing expertise was greater than the risk of losing knowledge *(I10_RD1_S4)*. Overall, the interviews revealed that a middle course of sharing expertise was necessary to reach the milestones of the project and to enable interorganizational learning between them. For example, *(I10_RD1_S4)* stated:

> *It's dangerous and it gives power to the other side. I think nowadays the people are very concerned about it - about the exchange of information; but this project is about exchanging information. So, we need to find a middle term to reach the milestones of the project and I think that the people need to open their eyes and understand that it's not so bad to give this kind of information, because you will find and you will reach solutions; and you will improve the work, the operational work in such a big way that we should not look for the best things at this moment and try to view the future in a different way. This is our feeling (I10_RD1_S4)*

A general dichotomy emerged among the partners between *sharing and releasing critical* domain-specific knowledge from experts and those withholding it. For example, *(I10_RD1_S4)* described that a general openness and willingness to share data and information with all partners contributed to the success of the project. Overall, there was a change in the understanding of the need to release expertise and to eclipse power relations to some extent - not in the sense of fully understanding the expertise, but rather applying it. According to *(I11_RD1_S4)*, positions of power should not play a role here:

> *It is the classical saying that information is power. Behind this dogma, people tend to defend themselves by not allowing access to information, but information tends to be free. So the nature of information is that it wants to be free, but if you lock it, it is difficult. My difficulty is to prepare the environment in a way that you show to the persons that I want more information from you, but the information I am getting is a win-win situation. I don't want to know everything about you, I just want to know the sufficient information, e.g. if the grid operates correctly and vice-versa. Every time I design the process of exchange, I try to do in a balanced way. (I11_RD1_S4)*

The interviews showed that the case study project was *unevenly structured* in the sense that some partners had more power in directing the research, while other organizations functioned more as an executing force. In this regard, some of the interviewees described that it was easier to collaborate with each other if they already knew how the partners worked and what they could expect from them. This even went so far as to emphasize cooperation with previously known partners as early as the application phase of the project *(I23_RD1_C1).* According to *(I32_DSO_E5)*, expectations existed that, in the end, did not match the outcomes:

> *I would say when you enter European projects, you must be aware that it is question of cooperation. You have to collaborate, you are not in position to use power and you cannot make commandos and give tasks and be like in the company. This is also one of the moments when you more likely want to collaborate with companies, institutes and partners you already know. If you know what you can expect from the partners, then it is much more under control everything. I have quite some experiences with this. It is difficult to collaborate with people of companies that do not support or give enough resources to actors on a project and you have such basis where the management of the company changes. They do not support what the previous management did, that supported cooperation and collaboration of such projects and then they don't give clear assist, they don't give support, they don't allowed it to work, but they don't want to read the project either. So you have a very difficult situation you expect output from such partner, you expect that they will do it, but they do not. However, they also don't quit the project, but I think that [project name] was well managed and partners gave their contribution in due time. (I32_DSO_E5)*

Certain data and information, such as grid data, placed high demands on sharing it with partners and providing it in the common work. However, the interviews revealed that the grid data from the Western, Southern and Eastern European DSOs could not be simply shared in the project, as this type of data was dependent on the organization's approval. The industry partners, especially DSOs were dependent on the policies and rules that the organization imposed for sharing the grid data *(I2_DSO_W2)*. This dependence was shown to be the same across all DSOs in the different countries. However, since the project proposal aimed at modelling the infrastructure with CIM, there were some challenges here, which also influenced the cross-organizational learning.

> *We have strict privacy agreements at [DSO_S4] and in the [Southern country] framework, which allows us to share, let's say theoretical aspects of the algorithms and how do we do it. Then when we go down to grid aspects, then we do not typically share the grid aspects with other partners. We say that right from the beginning at the proposal stage. That's no surprise. When we go down to the grid, it is more difficult. (I5_DSO_S4)*

In conclusion, power relations and competition played a role in sharing expertise, particularly if the knowledge was to be used for a future product or if it was system-critical, but a high level of security and confidentiality was required here.

5.3.3. The intertwining of knowledge bridging and interorganizational learning

My interview results in the area of interorganizational learning and knowledge bridging shed light on how knowledge was actually integrated in the Smart Grid project. The empirical investigation provided the data that addressed H2 with the aim of expanding theory on interorganizational learning and knowledge bridging. H2 postulates that, *"The individual project partners do not need the expertise from all the other partners in the innovation cooperation. Therefore, knowledge bridging takes place in Smart Grid projects instead of real learning."* The hypothesis relates to the extent to which Smart Grid project partners have to learn expertise from other project partners under the guise that knowledge in Smart Grid projects is generally not only heterogeneous and technically complex, but also requires high efforts in learning. In this sense, my own conception suggests knowledge bridging as an alternative to interorganizational learning in order to deal with its challenging and expensive nature.

On the basis of the two strands of research, my research provided a clearer insight into the mechanisms of interorganizational learning and knowledge bridging. To begin with, I identified a number of characteristics that describe interorganizational learning in the Smart Grid project under study. My interview data revealed a clear picture of the content of the knowledge learned between the organizational partners, especially with the regard to the necessity of *method and tool knowledge*. Within this framework, not only was the use case and SGAM methodology introduced, but also the methodology for information exchange with the CIM and CGMES standards, different platform and demonstration software tools, as well as various more conceptions in the Smart Grid area. These methods and tools directly related to the tasks in the project. Most project partners indicated that learning these methods and tools among themselves was particularly intensive. Part of this learning was voluntary and reflected the level of engagement that partners brought to the project. The aim of this interorganizational learning process was to develop a *common knowledge base* for the communication and interaction between the partners. Particularly at the beginning of the project, special importance was attached to the development of a common knowledge base, since the partners had to use the same methods and strategies in the course of the project, which were learned equally by all partners.

Interestingly, my research showed that interorganizational learning consists mainly of the explicit knowledge parts in the area of methods and tools. In contrast to the theory, which assumes that interorganizational learning and innovation development depends on the full acquisition of a body of expertise and, thus, refers to tacit knowledge, my study showed that the learning in the Smart Grid project was rather related to the explicit part of knowledge. Lundvall and Johnson (1994) distinguish different types of knowledge, in which practical or skill knowledge is mostly used for answering *know-how* questions. The expertise part is associated in theory with new ways of combining knowledge and therefore consists of an *explicit and tacit amount* of knowledge (Lundvall and Johnson 1994). My study found that the learning of method and tool knowledge in the project rather concentrated on facts and information. The explicit part of knowledge was very science-based and easy to understand for the partners, while the tacit part of the method and tool knowledge could not be passed on so easily in the project. For example, the software codes of the tools and the specific tool development was not shared. However, the case study showed that method and tool knowledge consisted of tacit parts, which were not relevant to the project purpose. The knowledge of methods and tools acquired in the project was, thus, the result of a shared knowledge base that all partners could draw on equally. Summing up, the learning of method and tool knowledge was mainly embedded in the explicit part of knowledge that did not stick to individuals but could be written down and documented, e.g. in books or deliverables that could be shared more easily. Although a tacit part was included in this type of knowledge, it was not necessary for the organizations to learn it in the project context.

Articulating tacit knowledge in face-to-face interaction for the purpose of learning it, as it is described in theory (Scott 1992), was consequently not mandatory for the learning of methods and tools in the case study. Accordingly, not all underlying conceptions had to be understood in depth, but only to the extent that they could be used and applied in the project. The difficulty of interorganizational learning due to the stickiness of tacit knowledge (e.g. Bush and Tiwana 2005) tended to be less relevant and occurred only in isolated cases when project partners engaged more intensively with the material. Regarding the degrees of knowledge internalization by Wiig (1993), knowledge was learned in the case study in the sense of being "competent". In this vein, the project partners were aware of the knowledge, could use and reason with it, as well as could document it, without necessarily fully comprehending all methods and tools in detail. A more profound understanding was therefore not required.

The fact that the organizational partner learned rather intensively the explicit part of the method and tool knowledge in the project was confirmed by their approach to learning. Clearly, it became evident in the interviews that a large part of the project partners learned for themselves or through deliverables that were created in the project. These deliverables were developed in such depth that even people from outside the project could not always understand the content. In the theoretical basis, it was highlighted that explicit knowledge is often learned independently, while tacit knowledge is more dependent on experiences and personal contact (e.g. Nonaka and Konno 1998). My research findings showed that many partners learned with documents, manuals and instructions or books, which confirms the theoretical propositions and justifies the fact that more explicit parts of knowledge was learned. According to Nonaka and Takeuchi (1998), this type of learning reveals inferences about the "internalization" of knowledge, which relates to the conversion of explicit knowledge to tacit knowledge. As soon as the required knowledge became more difficult, for example, in understanding the use case methodology in its depth, personal exchange and experience were mandatory in the project, showing a tendency to the "socialization" of knowledge. Especially, the use case and SGAM methodology were mostly learned from scratch, which required high efforts and investments in time, since the knowledge not only had to be understood, but also applied and passed on *(I27_DSO_W2)*. Personal interest and individual personality also played a role for integrating knowledge more deeply. For example, a particular interest in certain topics has increased intrinsic motivation for some partners in learning and deeper engaging with specific themes. Nevertheless, the learning of methodological knowledge did not show the greatest difficulties in the case study, as it took place at such a level that all partners, who had to work with the methods and tools, were able to understand and apply them. The case study showed a tendencies towards "combination" in accordance with Nonaka and Takeuchi (1995) approach to knowledge transformation. Knowledge was frequently created in smaller project teams and subsequently disseminated to other organizational members. This was achieved through the recombination of different concepts and existing knowledge, ultimately resulting in the creation of new knowledge. Sharing of documents in task meetings and conference calls is one example of how combination was observed.

It is noteworthy that the methods and tools acquired by organizations were publicly available anyway. Since the method and tool knowledge only had to be applied by the project partners and no further access was needed, there were fewer difficulties in the sense of competition and power positions in interorganizational learning. Confidentiality and trust issues in the acquisition of method and tool knowledge on an interorganizational level were similarly apparent. Since the methodologies and tools mentioned were often open access, it was even seen positively when other organizations incorporated them in their project work. In general, there were rather few confidentiality concerns, as no source codes were needed to be learned. However, a basic trust foundation was important for general communication in interorganizational learning, but an excessive amount of trust was not required for learning this type of knowledge. This was equally justified by the transparency of knowledge and the necessity of learning for achieving common ground.

Interorganizational learning was perceived as very costly and time-consuming, especially since the project time was limited and the partners lacked the resources to extensively familiarize themselves with all individual knowledge fields of the project. Hence, the experts in the project had wide-ranging knowledge on a distinct subject matter. For the sake of incorporating this knowledge from the experts into the project, *knowledge bridging* was observed in the case study project. In further consideration of the knowledge brought to the project by the experts, I have chosen to use the term *domain-specific knowledge*. The term fits the findings of the case study, as the knowledge of experts required a deep technical understanding in a very specialized subject matter of the energy system. Domain-specific knowledge relates in this thesis to the knowledge of experts, who are particularly skilled and knowledgeable in a specific area. In my case study, the partners were not only experts in e.g. computer science, but also in the specific area of energy systems, which again brought further specifications. For achieving this domain-specific knowledge, actors typically need to deliberate many hours of practice within the field. Hence, what matters is the experience that actors need to achieve for reaching the level of knowledge. Domain-specific knowledge is thus difficult to acquire and is the knowledge that distinguishes an individual as an expert. It is also strongly linked to problem-solving, as the experts often have various problem-solving patterns.

In the Smart Grid project, this type of knowledge was not learned between the project partners, as it was bound to the persons and could not simply be shared. In the case study, the expertise was observed in terms of electrotechnical engineering, computer sciences and standardization and architecture modeling knowledge, or was particularly linked to the functions and systems operation in the Smart Grid. As the quote, *"You'll never know everything about anything"* by Julia Child illustrates, the case study project also showed that it was not feasible for the partners to possess complete knowledge of every aspect of the energy domain. However, the majority of project partners also did not perceive the necessity of possessing complete knowledge, which is further emphasized in the following.

Intensive learning was not always required since each expert had a distinct role in the project and was responsible for mapping this expertise. It was therefore more a matter of inserting the respective complementary domain-specific knowledge. In fact, the more specialized the knowledge in electrotechnical engineering and IT was, the less it was actually learned between other partners and knowledge bridging took place. As was made clear in the interviews, codes of tools and software as well as other critical data related to a specific domain were not learned, as most of it was also restricted for the usage in the project. Especially when it came to a deeper understanding in one area, the partners were not able to map and learn this comprehensive in-depths knowledge, especially due to limited time and financial resources. Nevertheless, it became apparent that smaller expert groups, in particular, emerged within or between organizations. Knowledge bridging was therefore used to deal with domain-specific knowledge, such as the network-based knowledge and data from the DSO or the concrete content needed for use cases or web services in computer science and systems engineering.

In terms of the various processes of knowledge bridging, it appeared that the process within the case study was rather an extreme form of weak learning. This weak learning was perceived by the project partners in terms of lower-level knowledge transfer, rather than a complete non-learning as defined by Senge's (1990). Consequently, knowledge bridging took place more at the level of knowing about the existence of different domain-specific knowledge and where it had to be integrated for joint project work. The interviews revealed that it was especially important to find common interfaces in order to bring the different expertise together and to find possible connecting points. However, actual learning or building a deeper understanding did not take place at all. Although a deeper learning of domain-specific knowledge did not take place, the interviews indicated that the project partners still provided their specific expertise to the project tasks. Therefore, each individual expertise was ultimately necessary for the project work to jointly map the necessary complexity and gain innovative project results. In terms of innovative outcomes through knowledge bridging, it became apparent that the focus was on advancing platforms and tools, suggesting that the exploitation of existing technologies has been at the core of this case study, in line with the approach of March (1991). This is also consistent with the fact that intensive learning the different domain-specific knowledge was not necessary (Koza and Lewin 1998).

Drawing on these explanations, the interview results showed that the knowledge that is bridged was not explicit knowledge, as how it was theoretically thought on the basis of Nonaka and Takeuchi (1995), but it was in particular tacit knowledge. In fact, the domain-specific knowledge in the Smart Grid could not always be described in words but was attached to the partner's experiences. A personal contact and a high exchange would have been necessary to learn this specialized knowledge, which for various reasons did not take place in the Smart Grid project. The experts tended to keep their expertise and skills to themselves, but they still brought selected knowledge to the project. The fact that no learning took place in this area predestined that no major efforts had to be made to understand it in depth.

All in all, a high division of work was observed between the partners in the case study, who finally put together the individual knowledge modules for working out the tasks. According to the TOI approach by Schmickl and Kieser (2008), the process of knowledge bridging in the Smart Grid project showed similar traits as described in the approach. Firstly, the case study findings confirmed that modularization was used in the project tasks. Teams of experts worked on various concepts as well as recombined tools and processes. Secondly, the knowledge developed in the expert teams had to be allocated for other partners in such a way that they were able to use it without having to understand the exact design and underlying origins. Thirdly, localization made it abundantly clear that not every partner needed to know where exactly the knowledge came from. Fourthly, the case study showed that the expert knowledge was only made available to a certain extent, why the domain-specific knowledge was always imperfectly transferred. The process of knowledge bridging in the Smart Grid project therefore confirms the characteristics of Schmickl and Kieser's TOI approach.

As Krühl (2018) surmised for the process of knowledge bridging, the case study also indicated that assumptions from experts were often accepted by project partners, without always exploring them further. In this vein, the partners had to trust the inputs from other experts, as there was not always time to verify all expert inputs. All in all, a lot of trust was required, first, to share the domain-specific expertise, which often had confidential and valuable inputs, and second, to trust in the process and knowledge that others brought into the project. Consequently, all partners had to trust the added different expertise, since it was not always possible to look closer in all fields. Hence, knowledge bridging required an overall *high degree of trust between the partners*. This was also repeatedly described in terms of the sharing of confidential data and knowledge that was often associated with the domain-specific expertise. Although an overall shift in the direction of increased sharing was visible in the interviews, many partners were still cautious to provide e.g. network data and other knowledge derived from their specific function in the system. Often, agreements first had to be made and policies established to ensure that data would be used only for research purposes and not released to the public *(I21_RD2_S4)*. In addition to a high degree of trust, power and competition also played a role, as the tacit domain-specific knowledge was mostly knowledge that was confidential and used to develop new innovations. Especially, the domain-specific knowledge was seen as a crucial competence for being competitive in the market.

The following figure 10 shows the interaction of learning method and tool knowledge and incorporating domain-specific knowledge by means of knowledge bridging. All in all, both processes were essential components for knowledge integration, why one only works with the other. In concrete, a common knowledge base consisting of method and tool knowledge was necessary to finally bridge the domain-specific knowledge. Therefore, a common basis of methods and tool knowledge had to be created, especially at the beginning of the project in order to process the data and information of the different functional partners. Consequently, interorganizational learning was needed not only to create a common knowledge base but also *to identify where domain-specific knowledge was needed*. From this perspective, interorganizational learning was also essential to identify and unscramble knowledge gaps, which were closed by means of bridging domain-specific knowledge.

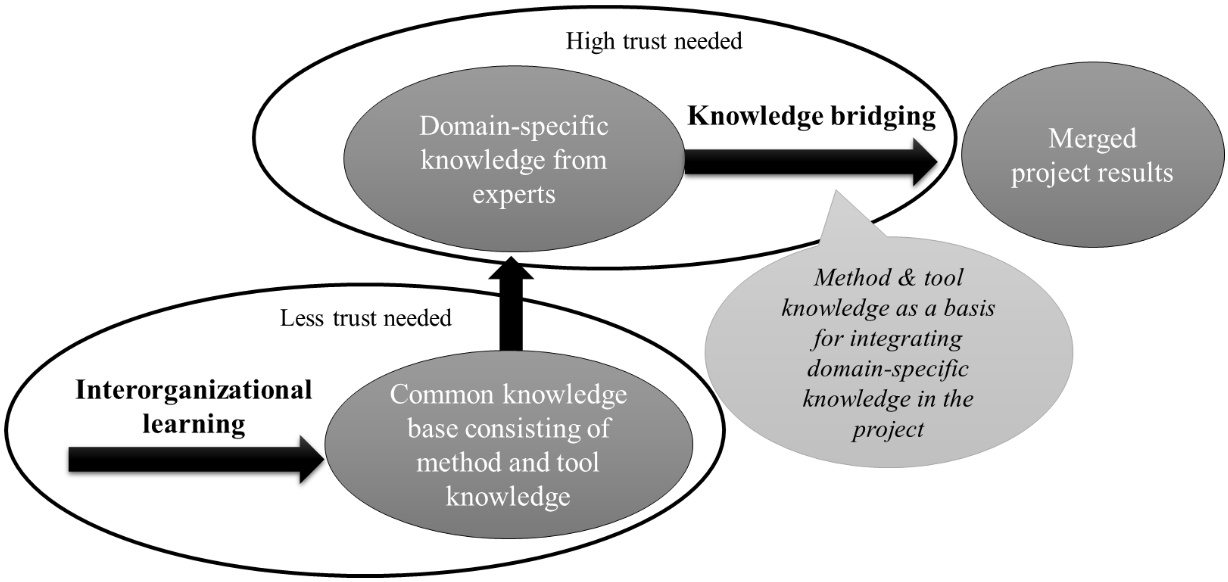

Figure 10 Interaction of interorganizational learning and knowledge bridging

By comparing the findings of the two strands of processes for integrating knowledge in Smart Grid projects, the interview results showed that the project work consisted of a mix of mutual interorganizational learning and knowledge bridging. The interview partner confirmed that different levels of integrating knowledge existed in the project work, ranging from a deeper understanding to a superficial perception of the knowledge in the project. This mixture of both, interorganizational learning and knowledge bridging was shown in various statements. Most of the partners had to deeper learn certain method and tool knowledge, but did not necessarily deal with the expertise of other partners.

> *I think it was a deeper and specific knowledge for the web services because it was for a really specific area of knowledge that I don't think most people work on. I would rate the language of programming that I had to learn for doing it as a basic level of knowledge. However, for the web service, it was more specific and a higher level of knowledge. (I25_RD2_S4)*

While the method and tool knowledge was easier to learn, it was found that the subject related domain-specific knowledge required more commitment and learning effort to understand and apply it in the project. In the latter, most partners therefore reverted to knowledge bridging because there was not enough time to go deeper into the topics from experts. Only a few exceptions of the project partners have actually dealt with specialized knowledge, e.g. electrotechnical engineering knowledge, as it was necessary to develop the tasks and understand functions in the power grid.

> *I think it is a mix of both. For me, for example, it goes also quiet deep because of this whole power engineering part that I am learning. I have to go deep into the matter of how far it will function. However, there is also this basic learning, for example, where I just have to figure out some tools, what I am going to click somewhere, which I would say is more basic knowledge, but also this deep knowledge where I have to understand why these classes are needed in the power grid. (I17_RD_E5)*

To sum up, it was observed that it was not just one or the other process that took place for knowledge integration, but it was a mixture of both. Therefore, knowledge integration was only possible in the interplay of the two processes. Depending on the tasks and the type of knowledge, the project partners differentiated individually as to how deeply they actually learned or merely bridged the knowledge. Drawing on the hypothesis, the interviews revealed that Smart Grid projects were not just about interorganizational learning OR knowledge bridging, but both processes are necessary. Especially due to limited time and financial resources, but also due to the technical complexity of domain-specific knowledge, it was not always necessary, nor needed to delve deeper into the expertise of other partners. It can be concluded from this that both processes were still crucial for knowledge integration in Smart Grid projects. Method and tool knowledge led to a common ground for the partners to communicate and identify the interfaces on where domain expertise could be brought into the project for assembling new knowledge. Although no real learning of expertise in the project was needed, the interview findings showed that expertise was still integrated and highly required for developing common results in the project.

To sum up, knowledge in Smart Grid projects is usually not only heterogeneous, but also technically complex. To address this challenge, knowledge bridging has been established as a mechanism to achieve knowledge integration. In the interviews, knowledge bridging was described as a kind of pragmatic merging of disciplines at interfaces. Thus, knowledge bridging is the mechanism by which projects function not only on the basis of interorganizational learning but also on the basis of incorporating complex areas of knowledge. The concrete merging of the knowledge will be further considered in the following chapter.

5.4. Boundary objects as a heuristic tool for innovation development

Building on the findings on interorganizational learning and knowledge bridging, this chapter examines how boundary objects emerged in the case study and whether they have been used as a heuristic tool to circumvent knowledge boundaries and to develop innovations. The interview findings on the development of boundary objects and innovation are described in this chapter.

5.4.1. The merging of expertise in the project

The investigation on interorganizational learning and knowledge bridging within the knowledge integration process served as an ideal starting point to determine how boundary objects emerged in the case study. As shown in the previous chapter, knowledge was both learned in terms of methodologies and tools; as well as bridged in terms of the domain-specific expertise. Since the interview data showed several similarities regarding the emergence of knowledge bridging, it is necessary at this point to explore at how boundary objects may be perceived as the result of knowledge bridging. The main interest of these case study results is, consequently, to derive further attributes for the theoretical foundation of boundary objects.

Star (2010) observed in her field work that institutional differences generally lead to difficulties, which often prevent a common level of interaction. The interview results also exposed that there was a high degree of specialization among the three institutional partners. The starting point for the collaboration was therefore a *wide-ranging field of knowledge* that was almost impossible for the individual partners to keep track of and which nevertheless had to be used effectively for the creation of the tasks. It was consequently not possible for every project partner to understand the domain-specific knowledge of all other partners. Nevertheless, the partners had to work together and find a common denominator for cooperation in order to use the expertise in the project. Taken together, the technical specification and different backgrounds of the diverse institutional actors were a first indication for the emergence of boundary objects. For example, *(I14_RD2_S4)* stated:

> *You didn't have the background. That is the wide range of topics that we are addressing. You can't expect that one person is expert in this wide range of knowledge, such as communications, analysis, protocols and standards. You need a broad knowledge to understand things like this and I say that the project was a success. The deliverable was technically amazing (I14_RD2_S4)*

For describing this wide-ranging field of expertise and heterogeneity of actors, the term *"different worlds"* was used in the interviews. The expression of the different worlds emphasized the professional distance and diverse character of the partner's knowledge. One arena where "different worlds" was palpable was between the DSO and TSO partners. In the interviews, it was shown that low commonalities made it more difficult for the partners to immerse themselves in the different viewpoint and achieve a (fragile) mutual consent *(I16_RD_E5).* However, compromises were seen as necessary by *(I10_RD1_S4)* for the convergence of both worlds, for example, on the decision of future information exchange. The interviewee stated:

> *[…] We, engineers, are much more in the TSO world because of foreign companies owned by [TSO_S4]. So, we feel much more the pains from the TSO world. We need to work with the DSO because the objective in this project is the interoperability between TSOs and DSOs. We need to communicate, we need to find out a middle point to reach the objectives of the projects. I think that the main challenge is to find out a way that the TSO is happy [TSO_S4] and the DSO is happy [DSO_S4]. Normally it's not easy because there are completely different worlds. The objectives of one [TSO] are probably not the same of the object of the DSO. Normally, it's not easy to deal with these differences. For example, [TSO_S4] is working with CIM and the DSO doesn't want to work with CIM. This is not easy for the project and its focus on the standardization. It's not as easy to*

bring the DSO to this world and try to do standard things. This is probably the main challenge of this project. (I10_RD1_S4)

Just as with the different worlds of DSO and TSO, the interviewees also referred to a gap between the industry and the research organizations. This was attributable to the fact that the world of research would not always match the actual implementations required by the world of the industry *(I2_DSO_W2; I10_RD1_S4)*. Therefore, the gap between what was developed and what actually met the requirements of industry was not always closed. In general, these two worlds of research and industry were identified in the elaboration of use cases. Knowledge translations and bridging activities were necessary here to identify the different information needs. This was evidenced in the following quote from *(I2_DSO_W2):*

When we pass to a concrete implementation in the real system, normally, it is something that we do not care about. We can test the things in the simulator, but when we need to do something to implement and use it in real life, I think then there exists a gap within these two worlds. This project allows me to merge and link a little bit between them. These links start within the system use cases and because of this, it is a little shock for me (I2_DSO_W2)

More specifically, it was emphasized in the interviews that this various expert knowledge was on the one hand difficult to catch up on, but on the other hand indispensable for the project work. Technical developments and designs could only be compiled with the help of individual experts, which were needed on both sides to combine the knowledge fields in the project. A research partner from an Eastern European country *(I1_RD_E5)* elaborated this point in the sense that it was very important for the project to have *experts on both "sides,"* meaning IT and electrotechnical engineering. Accordingly, the project used knowledge translators or mediators from both knowledge fields to translate the knowledge for the respectively other experts in order to bring the two sides together.

You must have the knowledge from both sides. This is very important and you usually don't find enough experts, which have both: the power systems engineering and the IT knowledge. This is a leak because you can put it in together, which consist of power system engineering and IT engineers, but you also need people, which are on both sides. This is really important and it is hard to get such people. In addition, the educational system will not provide such education. The problem is that mostly the power systems engineers leak IT knowledge. This is very obvious and of course, the IT guys do not have any knowledge about power systems. I was maybe lucky because I have a strong background in IT, but then I was also in all kinds of power systems engineering projects. (I1_RD_E5)

The challenge of the project was therefore to compile the individual domain-specific knowledge in a meaningful way in order to create innovative new knowledge. This task of piecing together disparate knowledge was referred to as a *kind of puzzle* in the project *(I32_DSO_E5)*. Like a single puzzle piece, the body of knowledge also showed individual sides and corners that have to be combined with the matching pieces. In the case study, the compilation of expert knowledge also turned out to be a puzzle of complementary knowledge. These pieces of different knowledge had to be stitched together not only between the project organizations, but also the competencies within the organizations as different experts were selected to work on the project. For example, *(I1_RD_E5)* explained that especially in the development of use cases, different knowledge was added by the certain experts. Each project partner thus added a certain piece of their expertise to the joint development process of use cases. The partners indicated that only in the common process something meaningful emerged between them. *(I32_DSO_E5)* summarized these observations:

> *I think that from partners that perform those tasks and use cases, it was a* puzzle of know-how. Each *partner brought some knowledge, for example, companies [have people] that work in IT and communication, who brought some information about the protocols. We brought very much information about what we actually need, what should be done, how it should be done and for which purpose. Then you slowly build a use case where you connect real problems to technology, software, hardware, organizations and procedures; and you make something that is useful. (I32_DSO_E5)*

The necessary *complementarity of knowledge*, which was already addressed in the use case development, was a key issue in the interviews in order to finally create a basis on which new innovative ideas can be developed. The merging of domain-specific knowledge was frequently highlighted, although this consolidation was seen as neither simple nor always easy to accomplish. Indeed, complementary knowledge was deemed all the more important by the project partners who highlighted that not every project partner could be an expert in each field. Although some general definitions, terminologies and main rules for developing use cases etc. had to be acquired, the partners mainly relied and trusted the complementary expertise. Nevertheless, a common level of communication was still needed for a certain basic understanding of the contents as well as the terms. Accordingly, not every expert had to understand everything, but the project was set up in such a way that it was clear who involved which expert knowledge. *(I2_DSO_W2)*.

> *[…] as I mentioned the use case methodology, but afterwards we should have all the definition of UML. We should know the standards. I know some standards, but not all of them. In addition, I am also not an expert in the object-oriented programming. I understand something, I can do some comments and I did some exercise, but I am not an expert. I think for the project it is important. […] I think the complementarity is important and not that everyone knows everything about all the topics. I think this is something that is working very well internally in [DSO_W2] because we are trying to have different knowledge and we do not need everything to know. We only need to understand what people are doing and afterwards we have a lot of conflicts between the persons. For example, if you are saying that something is like this and I know that it is like this. I know I can pull some questions why you do this, but I know that the answer will be the correct one. This is something that is working very good and because of this, when you ask me, you need this competency. I say I need to understand, but I do not need to have it because we know that we have someone on our side who can support us and this is the main advantage. (I2_DSO_W2)*

Regarding the consensus that the partners wanted to reach by combining the complementary expertise, it is interesting to identify that knowledge was only combined to a minimum way.

The interview data revealed that the partners did not necessarily saw the need or did not have the will to integrate more knowledge than was necessary *(I5_DSO_S4)*. In this sense, *(I32_DSO_E5)* stated that none of the project partners was able to understand all the details of the knowledge needed in the project, nor did anyone want to achieve a level of expertise in every field of knowledge. For this reason, the partners relied on the preparation of expertise, which involved synthesizing and organizing their knowledge in a manner that was understandable and straightforward for other partners to integrate. By tailoring their expertise to a certain extent, knowledge could be made more easily accessible for common project work. In this sense, *(I32_DSO_E5)* stated:

> *I think it is a very important part that you understand that nobody is perfect and nobody knows everything. But to achieve and make some progress, you have to be able to combine knowledge in a minimum way, so that you get some results. For this purpose, you need people, who are not experts in details, but who are able to bundle this knowledge in a way that everybody is happy. (I32_DSO_E5)*

Taking a closer look at the meaning of *use cases* in the Smart Grid project, the interview data investigated that they have played a special role in bridging the gap between the different worlds, especially when speaking about the combination of different expertise. Based on these considerations, the interviews showed that most of the collaboration between different experts took place for the creation of use cases. For example, *(I2_DSO_W2)* stated that one use case was developed by a partner who provided the real time simulation, while another organization delivered the operational planning, both of which was merged within the use case. To develop the use case template, partners had to insert their expertise and commonly fill out a specific formalized word template. According to the interviewees, the difficulty here was to find the limits of the respective expert knowledge and to recognize what actually needs to be shared for the other partner. *(I2_DSO_W2)* explained this in the following quote:

> *[…] The thing of the boundaries is not clear in some cases and sometimes with some partners; you need to share more, because it will impact activities. We have, for example, the use case that is, on the one part, about real time simulation and, on the other part, about operational planning, which is [R&D_S4]. Of course, we have to share more because we will compare the two things and we need to share. However, these limits are really difficult to define on what we share or not. However, not because it is personal, but because of the company. (I2_DSO_W2)*

Another example of merging domain specific knowledge in the use cases was provided by *(I32_DSO_E5)*. The interviewee explained that experts from IT brought knowledge for the protocols to the use case, while DSO and TSO partners contributed the information needed for the implementations in the networks. By gathering and merging this knowledge into the standardized template, the partners established the use cases together. In this process, real problems were identified between the partners, which were meaningfully brought together and discussed. The establishment of use cases thus served as boundary objects in the project. *(I32_DSO_E5)* summarized this as follows:

> *Each partner brought some knowledge, for example, the institutes brought some information about the protocols to the companies that work in IT and communication. We brought very much information about what we actually need, what should be done, how it should be done and for which purpose and then slowly you build a use case where you connect real problem to technology, software, hardware, organization and procedures; and you make something that is useful (I32_DSO_E5)*

The interview data indicated that the *development of CIM and CGMES profiles* required different levels of expertise, suggesting the development of boundary objects. This expertise mainly involved the CIM and CGMES methodology, the network operation and the integration of the standards in the systems, all of which were required for the project tasks. Other partners, mostly from the research institutes, explained that they are even members of IEC 57 or were involved in different CIM user groups *(I1_RD_E5)*. According to the interviewees, the main difficulty in this knowledge field was that the different organizations had to agree on how the information exchanges with CIM and CGMES should be mapped in the project *(e.g. I10_RD1_S4*). As with the use cases, the CIM profiles had to be created jointly, which required different expertise from various partners *(I1_RD_E5; I7_RD2_C1)*. For example, *(I7_RD2_C1)* explained that they have made suggestions for CIM and CGMES profiles that have been forwarded to some TSO experts for revision and improvement.

> *[...] And otherwise the CIM profiling we have done; that would now also be a draft and suggestions for improvement for [TSO_W3] (I7_RD2_C1)*

For this purpose, sequential steps between the different organizations were planned and specific roles ascribed. The different expertise in CIM and CGMES was also required to avoid misinterpretation, especially with the new standards or data models. This required effective communication with those who were familiar with it. *(I7_RD_C1)* explained this as follows:

> *We definitely need the expertise of other project partners in the field of standardization. [RD_C1] are as well versed in the standardization topic, but also [DSO_W2]. If we need help in the area of standards and generally for answering the question of which standards are necessary, then these are good contacts. Concerning CIM in general, we also need the knowledge of [TSO_W3] [...]. In this area, we make profile suggestions and of course, we are happy about their feedback. [...]. These are just examples about the knowledge that we need from other partners. If we do simulations and the simulations are supposed to reflect a use case or a field test somehow, then we need the knowledge of the people who developed the use case. So it must be iteratively decided whether the simulation now represents the use case correctly or not (I7_RD2_C1).*

Several experts also had to work simultaneously on the *demonstrations and simulations* as different components had to be merged for their implementation in the project. The domain-specific knowledge from various partners was necessary, for example, to define the framework conditions for the demonstrations at the DSOs and TSOs premises. Likewise, a joint library had to be established for creating the common information model. However, the actual implementation of the demonstration did not require much more cross-organizational communication and interaction as was needed for the use cases. This was because both the setting up of the demonstration environment along with the integration of the DSO and TSO systems and the performance of the tests that were carried out by different organizational expert teams *(I1_RD_E5)*. For example, *(I2_DSO_W2)* stated:

> *I think in the demonstration, […] we don't have a lot of exchange. Before in work package 1 activities, I think it was like that because we have a set of use cases and each use case was developed by a different entity, but we arrived having a common library, a common information model. This is great that everyone contributes different types of tasks. (I2_DSO_W2)*

In a similar way, different expertise was merged for the development of time series simulation. The time series simulation uses specific modules for the time-based operation that are connected to control modules. In the project, time series simulations were applied with a tool for power system modeling, optimization and analysis. In particular, data sources were needed from the DSO and TSO partners in order to perform this simulation by a research partner. Again, it can be seen that the simulations were dependent on the addition of the DSO and TSO data *(I30_RD2_C1).*

> *Yes, well, I would not necessarily say learned, but when we were doing these time series simulations that I was talking about, we really worked together very intensively. For example, one partner provided the network; the other then provided the time series. We then implemented a control system, on which we worked very closely together. (I30_RD2_C1)*

The interview data showed that the use cases, the common CIM and CGMES profiles and the simulation in the project served as boundary objects for the integration of domain-specific knowledge. My research revealed that a particularly large amount of expertise had to be combined for these specific tasks. In this way, knowledge from different worlds met and merged for this purpose. The following statement sums up well that collaboration among different expertise was the deciding factor:

> *I think that all partners together have this knowledge. With good collaboration among us, this is of course achievable. Advising that, we are doing well. (I1_RD_E5)*

Having described how knowledge was merged for the final project results, the following chapter will introduce the innovation that characterized these outcomes.

5.4.2. Innovative outcomes of the project

Upon identifying how knowledge was merged to fulfill the objectives of the project tasks, the research will now examine the sorts of impressions formed by the actors who actively collaborated to develop new solutions in the project. Referring to the research question on: *How* *and to what extent knowledge is integrated for developing innovations in Smart Grid projects*, this chapter takes a closer look at innovation development in the case study.

In the light of the interviews, different *methodologies and tools* were observed e.g., in the area of semantic web or Internet of Things that were adapted to new Smart Grid applications. According to the interviewees, new technologies enabled an increasing number of entities and units to communicate with each other *(I13_RD_E5).* For example, different protocols, such as Message Queuing Telemetry Transport (MQTT), an open network protocol for machine-to-machine communication, Advanced Message Queuing Protocol (AMPQ), a binary network protocol, or Inter-Control Center Communication (ICCP), a protocol for communications of power grid control centers, were introduced and adapted for the specific usage in the Smart Grid project. Also, the use and operation of different software tools, such as a tool for testing CIM profiles [tool_3][4] and a tool for modeling interoperable data exchanges [tool_1] were seen as innovative as deeper knowledge had to be built for using and applying it for the project purpose. Such software tools were seen by *(I16_RD_E5)* as a way to broaden the horizons for the project partners. The power of innovation was particularly evident in the fact that the implementation and use of various technologies in the field of Smart Grids were repeatedly applied in new ways, disseminated and further utilized within the organizations *(I32_DSO_E5).* For example, *(I32_DSO_E5)* described different communication protocols as innovative in the project:

> *I think that the implementation of MQTT and AMPQ; those protocols were innovative that gained some interests also with other partners and I am also happy that secure ICCP connection was established and basically I must tell you that after that use case, we did implementations for normal operation in the Eastern European country. We have now some partners already connected over the secure ICCP and this is for us important that it was proved during the project that this is possible and that it can be used for our purposes. (I32_DSO_E5)*

In the context of the DSO-TSO communication, new software tools were developed from scratch or tried out in a new way in the project *(I16_RD_E5; I31_RD2_S4).* For example, in case of the software tool [tool_4], research has already started before the project and continued during the project within the organization. Although the organization was not the first one discussing the topic of [tool_4], they claimed to be the first one approaching the topic within the Smart Grid domain. New developments of the tool showed its usefulness for automation of distributed resources on an international scale. With the increase of research on this topic within the project, other external publications followed in the same direction, demonstrating the importance of the tool *(I31_RD2_S4)*. This was also stated by *(I29_DSO_S4)* as follows:

[4] The tools have been anonymized to preserve the anonymity of the organizations that develop or use the tool.

So for us, it was very nice to see that the tools developed by the [Southern European country] partners are being applied in our demonstrator and this was a proof that the tool can be applied in different countries to solve a similar problem regarding the automatization of the distributed resources in the distribution and transmission systems. (I29_DSO_S4)

However, new developments did not emerge all at once, but often through trial and testing of already existing technologies that were used in new functions. The analysis of the interview data suggests that the value of technologies was realized only when they were employed within the novel context of Smart Grids. For example, *(I19_TSO_E5)* stated that innovative ideas were frequently advanced through the further development of pre-existing groundwork. As a result, tools that had previously been considered marginal proved valuable and useful over the course of the project and beyond *(I19_TSO_E5)*.

I am not looking for some out of the blue innovation in such projects. For me the greatest achievement at [project name] is that we really set the stage and strengthen the path for the data exchange protocols, which we actually have developed and enhanced. When we started [platform_2], we first felt it is a corner technology, now it is really a carrying power. It is really going to prevail against other options on the table and I feel that this technological level was really necessary. It was not explored before and I do not always look for out of the blue innovation or TRL1 [technology readiness level 1] innovation. I think what we have done here was a very valuable contribution for a widespread use of this technology. (I19_TSO_E5)

In addition, the technical development or expansion of data exchange or communication platforms were an important and particular innovative component of the project. With these innovative platforms, practical use cases could not only be implemented and tested for their usage, but also further developed. For example, completely new use cases, such as in the area of balancing services, were established and then integrated onto the platform *(I16_RD_E5)*. Taken together, the platform extensions and developments were groundbreaking for future exchange of information between the system operators *(I10_RD1_S4)*.

Now it [Platfom_2] has been pushed or it has been dictated in a way to all TSOs in Europe […]. This is a general platform, which can be used for such purposes all over Europe and it is now already used for practical use cases, not just in our project. This is innovative. What I also think is innovative are the use cases that we have been implemented for balancing service providing, for example. This is also quite new. It has been around for a year or two, I think.
(I16_RD_E5)

The interviewees also acknowledged the *importance of use cases* for future Smart Grid developments, as they served as a guideline and standardized framework for defining different interactions between actors and systems. For example, the interviewees explained that multiple use cases have been developed, serving as blueprints for future application in the Smart Grid *(I12_TSO_S4; I23_RD1_C1)*. The interview data indicated a scarcity of prior use cases in the area of DSO-TSO coordination, necessitating the collection of additional examples throughout the course of the project *(I28_RD_N6; I31_RD2_S4)*. The collaborative establishment of use cases was seen as a particularly innovative part of the project results that set directions for the future project developments and beyond within further spread in the domain *(I16_RD_E5)*.

> *Now these use cases have already been implemented on the field; not just in our project. When our project started three years ago, there were not many examples from the real world. Now there are already quite a few. Not as a consequence of our project, but it seems that we are doing the right thing. (I16_RD_E5)*

In addition to the employment of use cases as a standardized format, the *advancement and advocacy of standards* were also seen as innovative. While standards for information exchange between DSOs and TSOs had not been used consistently before, the assertion of standards in the project helped to create a new awareness of the necessity of standards in the energy system. The standards were also more widely adopted and implemented by the project partners as the project progressed. For example, this was stated by *(I14_RD2_S4)* as follows:

> *Because power systems are evolving and we see that in five years, these standards are everywhere. If you want to keep to a reference, design tools and provide services to the companies and continue to work with [DSO_S4 and TSO_S4] or other DSOs or TSOs, you need to follow the treats by learning the communication infrastructure, i.e. web services. It is a great advantage for us. (I14_RD2_S4)*

Similarly, it became clear in the interviews that the *relationship between DSO and TSO* partners has changed, which was perceived as very positive by *(I8_TSO_W3)*. A clear illustration of this phenomenon was the development of a common approach for defining the scope of the observability area. In this way, interfaces and boundaries of the DSO-TSO cooperation were elaborated and determined *(I10_RD1_S4)*. Likewise, cooperation was further defined in other areas and new solutions of DSO-TSO communication were created. For example, the project has clarified where gaps in collaboration occurred, where new approaches arose and where further reflections were taking place. While the interest of cooperation between TSOs has always been high due to common cross-country networks, the role of DSOs and their collaboration has also gained prominence in the project *(I32_DSO_E5)*.

> *Yes, I think the overall goals of the project were reached. The community of partners learned how to do what is next, what is difficult, what is easy, where the gaps are […] within the knowledge and with the procedure and what is the maturity of different models, like the CIM model at the DSO. Because you know the life cycle or history of DSOs and TSOs is quite different (I32_DSO_E5)*

Furthermore, the definition of the actor roles emerging in the Smart Grid was considered as innovative by the project partners. For example, the role of actors in regard to new market models and future business objectives for future data exchanges was discussed in the project, resulting in new innovative insights for future interaction in the Smart Grid *(e.g. I8_TSO_W3; I32_DSO_E5; I4_DSO_S4)*. For example, *(I19_TSO_E5)* described that the TSOs and DSOs have to further define their role in the future Smart Grid. In this sense, *(I8_TSO_W3)* explained the innovativeness of the new business model for data exchanges as follow:

We have, for example, with the [Central European] partners and with the [Eastern European] partners, developed a very new, technical business object for data exchange between TSOs and DSOs. This is really important because we brought the solution to the TC57 committee and we brought this solution to the group of 13. Those are international bodies from IEC, which main purpose is to discuss new ideas for the standardization in the world. This is really good because we have submitted this preposition of the new governance to the IEC for discussions. I see a very good development for new prepositions. (I8_TSO_W3)

The information exchange according to the standards CIM and CGMES was tested in the demonstrations of the project. The new developments in the area of DSO-TSO information exchange were mainly perceived as innovative within the project, as there had been little research or practical implementation on this topic in the daily operations between DSOs and TSOs. CIM and CGMES were previously unknown to some project partners *(I17_RD_E5).* As an example, the standard was unfamiliar to the DSOs in Southern European prior to the project, indicating that its adoption and application in the project constitutes a genuine innovation for the communication among the system operators in that region *(I29_DSO_S4)*. Some interviewees even stated that they were proud to be part of a project that is going to implement something new to the "engineering world" *(I17_RD_E5).* Although change was not always immediately apparent, it was perceived as a transformation over a somewhat longer period of time *(I17_RD_E5).* The innovativeness of the CIM model was stated by *(I29_DSO_S4)* as follows:

I think [project name] provides some guidelines regarding these cooperations between DSOs and TSOs. One of the difference that I detect is the type of data because as I said you before, we are not using, at least in the [Southern European country] the CIM model, at least at the DSO side. The [Southern European] TSO has been doing some work on the CIM model and we see some differences regarding the data exchange because we use the data exchange for specific cases that are different from [Eastern European] and from the [Western2 European] demonstrator, because they intended to show different things compared to us. (I29_DSO_S4)

The case study showed that the information exchange between DSOs and TSOs was tested based on use cases that stimulated and reflected actual processes between the two entities. The tests of the information exchange were based on actual day-to-day operations and therefore had real benefits for the system operators. Therefore, most of the project partners perceived the use of CIM and CGMES in the demonstrations as innovative *(I11_RD1_S4).* The project work has facilitated the development and refinement of the standards. According to the interviewees, this was recognized by the maturity models within which the technologies and their progress over time were reviewed. The analysis of the maturity models showed that the toolchain of CIM and CGMES has been expanded by the application in the project, showing that the standards have been further developed. The application of the standards on the joint exchange platform was therefore seen as particularly unique and innovative in the Smart Grid domain *(I23_RD1_C1).*

Of course you have to measure it somehow (to see) what is innovative. For me, the right answer would have been to look at the Technology Readiness Level. Then we will see from which level to which level we just jumped. You can always argue that this is pioneering and I believe that we have improved the tool chain and the extension of CIM for CGMES in the project and I believe that we have improved this platform connection and data models. We have provided an overview of the processes involved. (I23_RD1_C1)

According to the interview data, the project partners perceived the common elaboration of use cases as well as the application of CIM and CGMES for standardized communication between DSO and TSO as especially innovative in the project work. However, other interviewees contested that it was *not entirely new knowledge*, but the partners rather made use of existing knowledge, recombined and expanded it in an innovative way *(e.g. I29_DSO_S4)*. These interviewees claimed that they have been doing the same thing all along, but the implementation and realization in the energy domain was actually new. As a result, some partners did not necessarily need to learn new domain expertise, but had to apply their knowledge in a new area and with new actors in the Smart Grid *(I12_TSO_S4)*.

I mean, theoretically, it is not new. New is that we are putting it in operation. We are really exchanging on a daily basis or in real-time and we are improving the way we work with more information. (I12_TSO_S4)

It is not totally new in saying that we are not addressing the European projects with completely new ideas. We try to see what we have done in the previous one in order to build the new things on top. (I29_DSO_S4)

Overall, a general technical exchange between the DSO and TSO was encouraged, as was the motivation to work more closely together. However, the interview results showed that the scope of the Smart Grid project was often extensive, precluding a comprehensive understanding of all results and advancements generated within the project. Nevertheless, certain topics emerged that were perceived as particularly innovative. Even though some methodologies, tools and standards were developed from scratch, the majority were subsequently refined and adapted for their specific utilization within the field of Smart Grids. In summary, the advancement of existing knowledge and approaches demonstrated a strong exploitative approach in the project.

Taken together, the collected interview data, pertaining to the development of boundary objects and innovation, exhibited comparable characteristics. These similarities will be subject to further analysis in the next chapter to deduce conclusions regarding H3. The hypothesis suggests that the boundary objects concept can be a means for innovation development and for overcoming knowledge boundaries.

5.4.3. Boundary objects - A panacea for innovation creation despite heterogeneity?

The empirical description of boundary objects and innovation development in the Smart Grid project showed how exactly knowledge was gathered between the partners in the project, which, in turn, further clarifies the outcomes of the knowledge integration process. Against this background, H3 aims to identify if, *"Boundary objects serve as a heuristic tool, which allows the actors to overcome knowledge boundaries and to develop innovation without learning. Actors, therefore, do not strongly integrate external knowledge."* The findings from section 6.3 revealed that the knowledge integration process in Smart Grid projects consists of the learning of methodologies and tools as well as the bridging of domain-specific knowledge. It is, thus, necessary to verify whether boundary objects have been created through these processes and what role they have played in the project work. Accordingly, I examine whether boundary objects can be used as a general heuristic tool to bridge knowledge boundaries and enable innovation in Smart Grid projects.

The theoretical concept of boundary objects is based on the assumption that actors work together on a common object although they often have conflicting interests and differing definitions of that object (Star 2010). This phenomenon was also evident in the case of the Smart Grid project, where heterogeneous actors came together to create common solutions for the energy transition, but held different viewpoints on its implementation. Star (2010) highlights the different institutional functions of groups, which was equally observed in the case study in terms of TSOs, DSOs and R&D partners. Given the different viewpoints and conflicting opinions from their functions, knowledge boundaries were identified in the interviews and analyzed within the scope of H1. Star and Griesemer (1989) anticipate the absence of consensus as a starting point for the boundary objects theory. The case study revealed that the presence of knowledge boundaries led to disagreements on certain topics, thereby impeding the attainment of a consensus.

As noted in the analysis for H2, partners have often relied on other knowledge integration strategies to manage the sharing of expertise without causing knowledge boundaries. Knowledge bridging as a form of cross-learning between different experts (Schmickl and Kieser 2008) was just one way of coping with expertise and boundaries in the knowledge integration process. The descriptive evaluation of the interviews showed that recourse was made to knowledge translators who were engaged in the different worlds (Johansson et al. 2011). Regarding the theoretical bridging-mechanisms (Tell 2017), *knowledge search* was also evident in the local regions of the organizations, as partners from one region often collaborated more closely. This was also reflected in the understanding of innovative outcomes in chapter 6.4.2, which rather showed that existing approaches have been exploited, based on local knowledge search. The interview data also confirmed that knowledge was assimilated in particular through R&D methodologies and tools. Tell (2017) suggests boundary objects as a boundary-bridging mechanisms emerging in the acquisition of knowledge. The interview data also indicated that different boundary objects were established in the scope of the Smart Grid project. How these boundary objects were actually designed in the project work and how they might have served as mechanisms for the overcoming of knowledge boundaries will be further clarified. Merging different expertise by only sharing the necessary part for building the object played a key role in the theoretical view of boundary objects (Star and Griesemer 1989). When developing new solutions in the tasks of the case study project, each expert added their domain-specific knowledge while remaining in their own field of expertise. Based on the theoretical characteristics for boundary objects and the anomalies for their detection, two key boundary objects were identified in the Smart Grid projects that have occurred in the form of use cases and CIM and CGMES profiles within the demonstration activities.

Regarding *use cases,* the filling out of the use case word template occurred collaboratively as the knowledge from different functional experts was needed. In the process of use case development, experts from three to four organizations came together for commonly filling out the use case template. The use cases, therefore, required not only IT or standardization knowledge, for example, for describing the communication, function and information layer of the use case, but also expertise in the field of electrotechnical engineering, such as on how components or businesses work in the energy system. Owing to the intricate nature of the information that had to be compiled for the use cases, it was not possible for one partner to create the use case on their own, but rather they had to be created collectively to ensure consistency in the project. The interview results indicated that during the development of the boundary object, the system or domain experts, such as DSOs and TSOs, were introduced to the methodology and guided by the IT research partners to the point where they were able to independently insert their content into the use case template. This was potentially one arena where a boundary object was developed. The domain or system experts, therefore, had to weigh up for themselves which knowledge was actually relevant for all project partners in the use case. In this sense, the template had to be written down as abstractly and briefly as possible, but at the same time as detailed and concretely as necessary, so that it would be understandable to all participating organizations. The creation of the use cases also required the partners to immerse themselves into different perspectives, meaning that the organizational actors had to shed their own uncertainties and open themselves up to new insights, or new “worlds”. The interview results also showed that different opinions on the content within the use case templates evolved, which is why the partners had to find the minimun common denominator for certain scenarios or methodologies in the use case template. In these situations, a certain *passage point* had to be reached between the partners, thereby achieving a fragile agreement. During the use case development, the interviews demonstrated that some partners acted as knowledge translators, possessing expertise both in the IT and in the electrotechnical engineering field. The interview findings showed that some translations between the partners took place, but mostly only to the extent that there was a general understanding of the different topics within the use case.

Given the specific *characteristics of boundary objects,* use cases can be seen as a structured aggregation of diverse knowledge used to develop innovative outcomes. The use case template provided a certain structure for the collaborative work, but also left room for interpretation and flexibility. Consequently, content was understood and filled in differently, which was evidenced, for example, in the required diagrams of the use cases. The flexibility of the template resulted in a general high degree of interpretability, meaning that the template was adapted to the different structures and circumstances of the actors. The template, therefore, provided a formal structure, while still leaving room for informal discussion and individual input from the project partners. This structure between formality and informality could be another new point for the theorizing of boundary objects. Regarding the material and organizational structure, the template provided a documented way for information needs. The results also showed that there was generally more to the use case template than was apparent at first glance; in the sense that some information also appeared between the lines and in shared communication, suggesting unseen work. Considering the evolvement of an edge message, the common use case template attempted to restrict data to only the information needed, but also gathered unrelated data. Both aspects equally reinforced the references to the use cases as boundary object. On a platonic level, the utilization of the pre-defined use cases showed inconsistencies in the functionality of the actors' systems, indicating that not all content could be seamlessly inserted into the pre-defined template. Hence, the different knowledge content and messages were not necessarily understood in the same way by everyone, leading to double blinds. Equally consistent with boundary objects theory was the fact that the use case template came from action and derived from human activity. The project partners actively collaborated on the use cases template by bridging and contributing their domain-specific knowledge. The focus of the boundary object was not on the methodology of the use cases, but on the actual innovative and newly developed content. This also highlights an important new characteristic of boundary objects in my case study.

For answering H3, the analysis showed that the use case template was helpful for *leveraging various knowledge boundaries*. In a syntactic way, it became evident that the interviewees had to agree on common technical terms with which to fill in the templates. These jointly agreed technical terms were then included in a glossary. At the semantic level, the use case templates were used to discuss different interpretations of the terminology in order to place the content in the same context and establish the most consistent usage. Some knowledge boundaries could also be circumvented on the pragmatic level. For example, when completing the use case templates, different energy infrastructures and architectures in the countries were discussed, together with a clarification of the different objectives of the use cases. The standardized template helped to ensure that the use cases were completed in a similar way and that the workload and type of work was almost the same between the partners. Despite the usefulness of the template in revealing gaps between them, it was often not sufficient to overcome organizational or institutional boundaries. For example, the use case template was processed within the individual organizations, which worked under different circumstances that could not always be influenced within the project context. In addition, power dynamics emerged during the creation of the use case template, necessitating the establishment of agreements regarding the contents of the templates. In some cases, the use cases also required very specific information and data, which entailed a high degree of confidentiality. To summarize, the use case template was an appropriate tool to increase communication between heterogeneous actors and to enable a lively exchange between them. In this sense, new discussions between the organizations have been initiated that did not exist before.

From the foregoing, it can be inferred that use cases can serve as a heuristic tool that encourages experts to collaborate on a common cause. Use cases, therefore, seem to represent a rather strong boundary object in the Smart Grid project. The template provided a standardized format in the knowledge integration process and enabled the partners to have a common way of working. The template delineated the requisite knowledge for the use case and the location for experts to insert their domain-specific knowledge. Compared to the boundary objects theory, however, it became clear that the partners did not contribute their knowledge to the templates completely independently, but had to find common interfaces at which the partners could share and synthesize their knowledge. Therefore, the partners were compelled to make concession towards one another, precluding the possibility of staying entirely within their respective field of knowledge. The standardized use case methodology facilitated the attainment of a common denominator among the partners, as it forced them to approach each other and make compromises. The partners, therefore, needed to know where and how they could find common ground.

The joint development of CIM and CGMES profiles were also identified as boundary objects at the peripheral of different experts in the Smart Grid project. The application and use of the CIM and CGMES standards for the future information exchange in the project was discussed intensively during the project. During these deliberations, it was not only a question of whether CIM and CGMES should be used within the demonstrations within the project, but also how it should be designed for the common platform usage. Difficulties arose, especially because of the disparate circumstances and objectives of the actors for information exchange, but also because of quite different working practices. The acceptance of the implementation of new standards for the communication between DSO and TSOs, therefore, played a major role in the project. Consequently, both technical as well as organizational consideration had to be negotiated and agreed upon in order to facilitate the use of the common standards for information exchange.

In order to create common CIM and CGMES profiles, it was generally necessary to consolidate the different knowledge from the various organizational actors. For example, the interviews indicated that the TSOs had already worked with the international standard before the project and, thus, brought an expertise in applying the standards in the project. In contrast, the regionally or nationally based DSOs brought in their expertise to bear on the information that needed to be exchanged with the TSO. Additionally, research partners were often experts in the field of standardization, but they also brought expertise, for instance, in the development of CIM profiles and testing. In the project, a common agreement had to be negotiated regarding the application of standards in certain scenarios or cases in the power system. This was done in order to find a lowest common denominator for the implementation of the standards in the partners' organizations. This again emphasizes the CIM and CGMES standards as boundary object.

However, the interviews also showed that the CIM profiles had to be adapted to the local needs of the project partners so that they could use them in their social worlds. With respect to the CIM and CGMES standards, there was a consensus that highly individualistic interpretations were to be avoided. The ideal goal was to harmonize them throughout the different organizations in the overall energy system. However, it became apparent that even though the standards provided a formalized structure for the exchange of information, they still contained a certain amount of room for interpretation. For example, the project partners indicated that individual aspects could also be involved in the standards. Another aspect is that the project partners still had to engage in the alternative perspective of partners as part of the information exchange. For this purpose, the project partners had to reduce their local uncertainty for a specific time in the common project work. According to the platonic aspect, the profiling made clear that not everything worked the same way between the project partners. Therefore, not all aspects of each respective contribution from each individual partner could fit into all categories. The elaboration of CIM and CGMES profiles also involved a considerable amount of invisible work, which depended on the background efforts and expertise of the partners. These profiles were not always worked out in detail by all partners, but some parts were worked out by individual experts, whose contributions were not always widely shared. In fact, the CIM and CGMES formats provided a way to restrict data to the specific purpose of information exchange. Thus, CIM and CGMES profiles showed a way to diminish misunderstandings, given that the profiles aimed at showing messages in a standardized way. Star (1989) notes that boundary objects can transform to globalized used standards, which was also evident in the case study in terms of the utilization and development of use cases and CIM and CGMES standards. However, the project did not employ the boundary objects intentionally, but rather produced them as a result of the project circumstances.

Likewise, new insights could be seen with regard to innovation development. The interviews showed that especially the use cases, the CIM and CGMES profiles and the activities in the demonstrations were seen as particular innovative. The literature has shown that innovation can be based on recombining existing knowledge in new ways (Lincoln and Guba 1985) or through producing entirely new ideas and perspectives (Edquist 2001). The interview results showed that a high combination of different but existing knowledge led to new innovations. In the case study, primarily existing knowledge was built upon and further extended. Hence, knowledge was used in new ways and was expanded to novel domains and contexts. In terms of the use cases, it was not necessarily the methodology itself that was new, but rather the composition of the domain-specific knowledge of the various experts. The CIM methodology was also not reinvented per se, but filled with content from the DSOs and TSOs, which was seen as particularly important for the future exchange of information.

My empirical case study reveals new aspects for conceptualizing *the development process of boundary objects*. The analysis identified that boundary objects mainly consisted of the sharing of different expertise, while in the overall consortium of the project, the partners rather needed to learn the different methodologies at a basic level. It was, therefore, not possible for the project partners to develop boundary objects completely independently of each other, as they needed a common foundation. The key new aspect of boundary objects is that experts must identify and agree on common interfaces. Without knowing where common interfaces exist between the partners, it is not possible to meaningfully bring expertise into the boundary object. These interfaces allow heterogeneity to persist when bridging and compiling knowledge for boundary objects. Consequently, there is no need to achieve an overall alignment for the development of the boundary objects. Knowledge boundaries, thus, do not play a major role during knowledge bridging, despite the continued presence of heterogeneity.

The following figure 11 reflects the entire knowledge integration process that led to boundary objects. The figure highlights the need of both processes interorganizational learning and knowledge bridging that was necessary for the development of boundary objects as innovative outcomes.

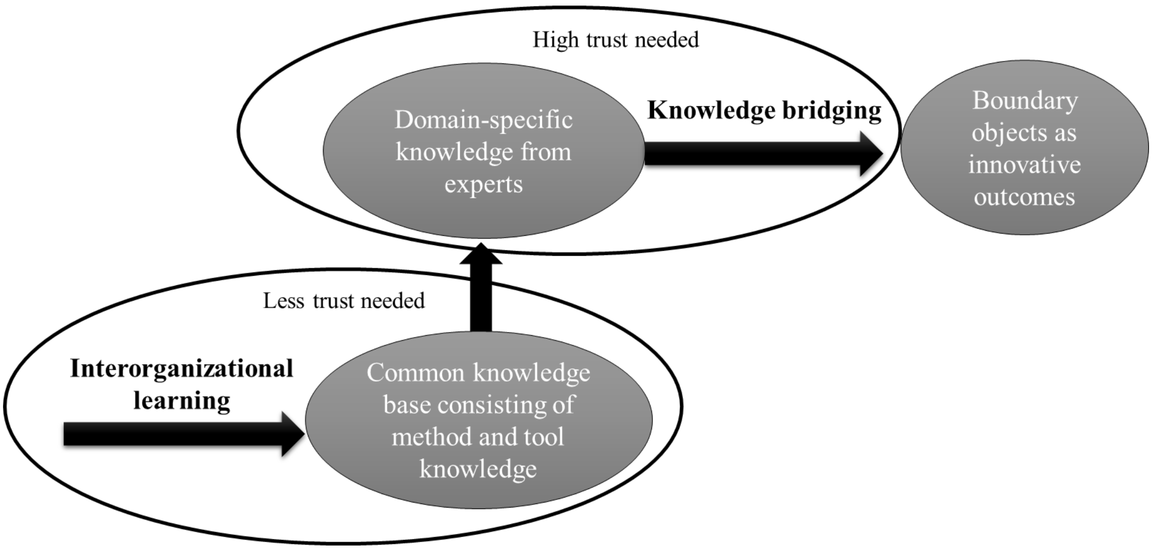

Figure 11 The development of boundary objects in the case study

The empirical analysis offered further characterization of the boundary objects in Smart Grid projects and provided new insights for extending the theoretical foundations. My observations suggest that a boundary object can be compared to a black box, which, in system theory, is a closed system that neglects the internal structure. The knowledge behind this system is not relevant to all actors, but can be used specifically by the experts who require the knowledge. In this complex system, such as the Smart Grid, internal structures are only partially known to most of the parties. Only a few actors can overlook the complexity of the system in its entirety. The empirical investigation of the dissertation elucidates how the methods and structures of the boundary object are known to the partners, such as the methodologies on the use cases and CIM and CGMES standards. Yet, the core content remains very specialized and barely accessible to most of the partners. What exactly the individual actors contribute in terms of content and whether all other actors possess the knowledge are initially irrelevant for its development. The boundary objects can, therefore, be seen as a heuristic tool, as it is an approximation rule upon which a potentially good decision might be made. Even during conflicts over the definition or contents, boundary objects can, at least, be used to determine a common direction, even if a good compromise that satisfies all cannot always be found. Nevertheless, it can serve as a kind of decision support for the course of the project and the implementation in the project.

6. Discussion of knowledge integration

In this chapter, the theoretical accounts around knowledge integration will be analyzed in the light of the empirical data offered here. This chapter will summarize the empirical results of the case study, unravel the existing approaches to knowledge integration with the empirical findings and offer a new perspective to the concept of knowledge integration in Smart Grid projects. Finally, implications and conclusion for further research of knowledge integration in Smart Grid projects will be drawn.

6.1. Summary of empirical results

The results of the case study findings are summarized in a concise and clear manner. This overview serves as a basis for a critical examination of the existing approaches to knowledge integration with the purpose of providing a fuller perspective on them. Table 3 summarizes the empirical results according to the scheme of my own approach to knowledge integration.

Table 3 Summary of empirical results

Own approach to knowledge integration	Empirical Results
Heterogeneity	
Organizational proximity	• Differences in hierarchies, control and formality • Smaller organizations are rather loosely coupled with shorter decision-makings paths compared to strongly coupled organizations
Institutional proximity	• Different national regulation; European organizations are subject to GDPR • Differences in informal aspects, e.g. cultural norms and working habits
Cognitive proximity	• Different knowledge in the area of electrotechnical engineering, computer sciences, standardization and architecture modeling • DSO, TSO and R&D knowledge
Social proximity	• Different social relationships, trust and reliability
Geographical proximity	• Communication and face-to-face contacts are higher in the same region
Knowledge Boundaries	

Syntactic knowledge boundaries	• Different language/mother tongues • Technical terminology, different databases
Semantic knowledge boundaries	• Interpretation of technical terms, methodological and procedural information • Comprehension and processing of data
Pragmatic knowledge boundaries	• Different energy infrastructures and architectures in the EU countries; political and legal regulations • Bureaucracy, hierarchy and other organizational boundaries, power relations • Project objectives, working habits and approaches, confidentiality and feasibility of data, interpersonal boundaries and communication
Interorganizational learning	
Knowledge type	• Use case and SGAM methodology, information exchange via CIM and CGMES, UML modeling tool, platform tools, demonstration and simulation tools
Process	• Learning for themselves, learning from deliverables and publications, learning between different organizations
Trust and confidentiality	• Methods and tools to be learned were mostly publicly available; less confidential knowledge was learned • Trust was generated in learning, although an exceptional high degree of trust was not essential for the learning process
Power and competition	• Power and competition did not play a crucial role for learning between the partners, as knowledge was publicly available or the knowledge learned was not necessarily a core competency of the organization
Common knowledge base	• The common knowledge base consisted of methodologies and tools that were learned
Knowledge bridging	
Knowledge type	• Domain-specific knowledge in electrotechnical engineering, computer sciences, standardization and architecture modeling
Method	• Partners remained experts in their field and expanded if possible the own expertise • Internal expert teams collaborated, while a lot was going on in parallel • Common knowledge interfaces at project meetings and less familiarization with new knowledge fields

Trust and confidentiality	• Trust is even more necessary as partners have to agree and accept the bridged expertise without being able to assess it in more detail • Knowledge and data was often particularly confidential
Power and competition	• Expertise rarely conflicted, but domain-specific knowledge reflected core competencies of the organizations
Application in project	• Limited time in the project and financial bottlenecks
Boundary objects	
General	• Expertise was combined and put together like a puzzle • Processes of interorganizational learning and knowledge bridging were both necessary • Interfaces had to be found in the different worlds of domain experts
Boundary objects in case study	• Boundary objects were perceived in use cases and SGAM, CIM and CGMES profiles as well as demonstrations and simulations
Innovation	
Innovation development	• New technologies and methods • Use cases, platforms knowledge and information exchange with CIM and CGMES standards were perceived as particularly innovative • Enhancement of DSO-TSO relationship

Table 3 provides a recap of the core results identified in the case study. These outcomes will be further used for comparing and substantituting the different theoretical approaches of knowledge integration with new insights from the case study. The summary yields a basis for exploring new perspectives on knowledge integration and for extracting valuable lessons learned for future Smart Grid projects.

6.2. Unraveling the multi-faceted nature of knowledge integration

While chapter 6 presented the descriptive empirical results, which focused on answering the three hypotheses, this chapter illuminates the interview findings with regard to the existent theoretical approaches to knowledge integration. In order to do so, the different theoretical approaches are discussed and compared with my case study results to interrogate existing theory in the light of my data. These insights aim to shed light on the research question of: *How and to what extent do heterogeneous Smart Grid actors integrate specialized and distributed* *knowledge in order to develop innovation in Smart Grid projects?* Overall, the chapter aims to stress the particularities of the new knowledge constellations in Smart Grid collaborations and marry this detailed analysis with a revision of existing theory. In doing so, I consider aspects that do not yet fit into theory and which form the basis for the new perspective adopted in this study.

Sharing and transferring knowledge

The first approach to knowledge integration, "*transferring and sharing of knowledge",* refers to a simple exchange of knowledge between the partners (Bechky 2003; Carlile 2004; Scarbrough et al. 2004). Knowledge integration is seen as fundamentally challenging, leading to the effect that knowledge can only be exchanged in a simple way by transferring and sharing it. The findings in chapter 5.2.2 acknowledged a broad emergence of various knowledge boundaries on a syntactic, semantic and pragmatic level. These ranged from difficulties arising from the use of differing terminology from technical specializations and mother tongues, to varying interpretations of the information, to difficulties regarding the organizational and institutional circumstances of actors involved, as well as their different power relations, project goals, working habits, data sharing approaches or interpersonal conflicts. Many parallels are evident from my case study findings to the first approach, as my studied Smart Grid project seems to be an equally difficult undertaking. The occurrence of knowledge boundaries in my case study, thus, provides initial evidence supporting the validity of the first approach.

The uncovering of H1 in chapter 6.2.3 showed that knowledge boundaries in Smart Grid projects developed as a result of different proximity dimensions between the partners. According to Wahlstedt (2014), the challenges of integrating knowledge arise from different personal interests and beliefs, as well as various routines and practices. The theoretical underpinnings suggest that knowledge boundaries are mainly driven by cognitive and institutional differences. While Wahlstedt (2014) focuses on the different knowledge backgrounds, educational levels and experiences, Dougherty (1992) describes how actors are part of different worlds of thought. My case study revealed many parallels and demonstrated in more detail that the different worlds developed from the distinct functions and associated knowledge backgrounds within the energy system. For example, the participants came from the three types of organizations, namely DSO, TSO and R&D. Each organization, with its own structures and raison d'etre, was a driving force for the emergence of difficulties during collaboration. In particular, the different functions and knowledge backgrounds of the organizations form the basis for the cognitive proximity dimension, which is reflected in the different technical competencies of the project partners. While a wide range of expertise was important to cover the technical complexity of the project tasks, it also complicated the integration of knowledge because of different technical terminologies and concepts. Dougherty (1992) describes that different labor standards, routines, persuasions and preferences are potentially problematic. The case study also revealed these difficulties in terms of the institutional dimension, such as the impact of the regulatory framework *(I5_DSO_S4)*, the various energy infrastructures and architectures *(I11_RD1_S4)*, as well as the different working habits and routines *(I21_RD2_S4)*.

While the cognitive and institutional dimensions affected the arise of knowledge boundaries, my research identified that specialization had a stronger influence than the rather narrow dimensions mentioned in the existing literature review. Hence, my study made observations *beyond* these two highly relevant origins for difficulties in knowledge integration. I found that the dimensions of proximity, specifically organizational, social and geographical proximity, played a more determining role in terms of both the organizational relationships and the process of knowledge integration than previously theorized. Given the difficulty posed by organizational differences, in-depth knowledge was not shared by default. Knowledge integration was structured according to factors, such as a lack of time, financial and other organizational resources, which were indications for a simple sharing and transferring between the partners *(I30_RD2_C1)*. This was reflected in the fact that, for example, the interviewees often encountered knowledge for the first time and were not always able to learn it in the short period of the project. Different social relationships also led to interpersonal conflicts, communication barriers, discussions on the handling of data or to conflicting project goals. At the geographical dimension, difficulties arose from the different energy architectures and infrastructures, which hindered a knowledge integration beyond simple transfer and sharing of knowledge.

Carlile's (2002) approach argues that knowledge boundaries are both *"a source and barrier of innovation"*, which also became valid in my case study. My research was rich with evidence suggesting that this well characterizes the trajectories involved. Since heterogeneous relations brought diverse expertise for innovation development into the project, it also led to difficulties in the collaboration process. Scarborough (2004) argues that the first approach "sharing and transferring of knowledge" *serves to solve problems* in knowledge integration. However, in my empirical analysis, the simple transferring and sharing of knowledge was seen more as an avoidance strategy, as knowledge boundaries were not addressed in depth, but rather disregarded. Similarly, a simple sharing and transferring of knowledge was found in the more straightforward problem solving that occurred through virtual communication, such as e-mail contact *(I6_RD2_C1)*.

The difficulties that developed in the process of knowledge integration within my case study were indicative of a simple sharing and transferring of knowledge at a more rudimentary level, as a deeper internalization of domain-specific knowledge was not possible. The project partners in the case study demonstrated a preference for the simplest mode of knowledge exchange, resulting in an integration of method and tool knowledge that mostly stayed at a level of a general understanding. In line with the first approach to knowledge integration, the interview findings indicated that less domain-specific has been exchanged in depth *(I11_RD1_S4)*. Accordingly, a deeper exchange was often not necessary at all and some interviewees stated that they did not even need the expertise from others for the accomplishment of their tasks *(I5_DSO_S4)*. The focus of the knowledge integration approach was based, therefore, on the *ease of sharing* knowledge, as the strong influence of knowledge boundaries inhibited a deeper integration of knowledge from other partners. This was explained by *(I5_DSO_S4)* as follows:

> *We share some experiences with [R&D2_C1] and [R&D1_C1], but we do not need the inputs from that expertise. At the point of saying, yes we need this company to help us with doing that. However, at the other point: no, we have the knowledge, but sharing experiences and better ways to do things. (I5_DSO_S4)*

According to the literature, the first approach to knowledge integration surmises that there is *less interaction between the organizations*, leading to a modest knowledge integration without learning all details. The less in-depth involvement with other actors' expertise showed that an *intimate relationship* was not necessarily required between the partners. For example, the exchange of knowledge through the writing and reading of deliverables suggests that knowledge integration was less personal *(I1_RD_E5)*. The organizing of work through the exchange of deliverables did not necessarily require verbal communication and further discussion *(I10_RD1_S4; I3_RD_N6)*. As a result, new insights into the first approach to knowledge integration could be made regarding the *way of organizing work* within the collaboration. The study also revealed individual variations in the extent and nature of knowledge integration, for example, the sources used and the level of knowledge that was integrated at all. Interestingly, this was within the discretion of the individual project partners. The following quote shows that an Eastern European country DSO shared data sets and information, but also did not necessarily provide explanations that are more detailed. Hence, *(I8_TSO_W3)* stated a missing deeper exchange:

> *For example, we have the integration of [DSO_E5] with [TSO_E5], which one is the TSO and one is the DSO. [DSO_E5] has a very large information from the DSO side. So, they share data sets, they share information. From the TSO side, [...] we are not used to work with this kind of information, because it is really the transmission part, so from [DSO_E5] it is the distribution part. This is an example. (I8_TSO_W3)*

My case study also aligns with the approach of transferring and sharing knowledge in relation to boundary objects mentioned by Carlile (2004). In particular, the cooperation without consensus by going back and forth between the different forms of the object was one of the main characteristics of boundary objects, which was also noted in the case study through the sharing of *"jointly authored documents back and forth" (I7_RD2_C1)*. For example, when creating the use cases, documents had to be exchanged between the project partners in order to supplement the missing knowledge. During the development process, the use case documents were repeatedly modified and adapted by various partners.

In the theoretical assumptions of the approach, a *basic sameness* for knowledge integration is proposed (Tell 2011). Looking further into this stream, Bechky (2003) assumes that expertise should be transformed in order to develop common ground. Huang and Newell (2003) also emphasize the requirements of shared believes and, thus, an approximation of the actors. However, the case study did not observe a transformation of expertise and only identified common ground by integrating common methodologies and tools in the project. The basic sameness could be seen in the case study within the creation of a common knowledge base, which, however, did not include domain-specific knowledge. In the case study, the project partners shared their beliefs or perspectives, but did not necessarily adjust them based on the feedback from others. Therefore, an adaptation of heterogeneity or the transforming of expertise did not take place in the sense of the first approach. Therefore, it remains questionable to what extent knowledge integration remains a simple transferring and sharing without further convergence, as well as to what extent a basic sameness is needed for integrating knowledge.

Overall, the first approach to knowledge integration highlights the difficulty to integrate knowledge, but shows only few ways of how knowledge can nevertheless be integrated. Knowledge translators and brokers are used here to address the difficulty of knowledge integration. Both, knowledge translator or broker were identified in the case study, which were mainly used for overcoming knowledge boundaries on a syntactic level, e.g. for explaining technical terms *(I14_RD2_S4)*. The interviews showed that the high level of knowledge complexity did not facilitate a deeper integration at every stage of cooperation, but rather resulted in knowledge boundaries in the project.

To conclude, the first approach, "*transferring and sharing of knowledge,"* focuses on the difficulty of knowledge integration and creates greater awareness of the knowledge boundaries, which were also identified in the Smart Grid project. However, the approach stipulates that difficulties of knowledge integration must be solved but provides only few concrete recommendations on how to actually accomplish this. Sharing and transferring is, therefore, a simplification of knowledge integration due to difficulties within heterogeneous projects. Although it is not specified more clearly how exactly the process is designed, the various indications mentioned suggest that the simple knowledge transferring and sharing can be seen as a kind of *knowledge bridging*. The approach highlights important points for the challenges of knowledge integration, but leaves out key aspects regarding its process. Despite these gaps, the first approach to knowledge integration is very valuable because it takes a sharp look at the difficulties and uses them as a starting point for stating that knowledge integration is generally challenging.

Use of similar and related knowledge

Whereas the first approach adequately identifies boundaries as a key facet of knowledge integration, the second approach highlights the *specialization of individuals* when integrating knowledge. Accordingly, the approach stresses the need of specialized networks for creating complex new products. This is primarily done by acquiring knowledge, particularly in the area of one's own specialization (Tell 2011). This aspect of specialization also played a key role in the Smart Grid project. My research identified specialization mainly in the field of electrotechnical engineering, computer sciences, standardization and architecture modeling, which, combined, form the basis for innovation in the project. The interviews showed that the project partners often acquired further knowledge in their own field of expertise. According to Kodama (2009), specialized actors often integrate knowledge in *their own small world*. This is supported by my own empirical findings, which showed that Smart Grid project partners often integrated knowledge from their own familiar sphere. The interviewees explained that it is easier for them to assimilate knowledge that is relatively similar to their own knowledge base or that is rather effortlessly connectable *(I31_RD2_S4)*. The interviews evinced that partners often opted for the easiest way to exchange knowledge with each other, which was usually the knowledge pertaining to their own specialization.

Similarities to the second approach were also evident by the fact that the *communication* between the partners from the same knowledge field was much more frequent. Consequently, the interviewees described that communication was often more lively within the internal organization or between experts from one field than with project partners of different organizations. This was explained by *(I31_RD2_S4),* for example, who commented that the same expertise within one specialization enabled an easier discussion with partners from the same organization *(I31_RD2_S4).* Likewise, my research showed that actors were primarily interested in the knowledge of other partners that match their area of expertise and that they could use to enhance their professional growth and development. This reflects the fact that partners not only had similar knowledge, but above all similar approaches and strategies to work, allowing them to reach a common denominator in their collaboration more quickly *(I17_RD_E5)*.

> *We work now with the same tools. What I like is, for example, that [name of R&D2_C1] and I have a similar approach to problems. So, we kind of think alike in that part. When I told them that I worked in a specific way, it is usually that they did the same things. We had luck to be parallel in that way. (I17_RD_E5)*

The mechanisms of *organizational routines and directions* of common specialized partners in projects (Grant 1996b) are also reflected in my research. Specialization within the same organizational routines of the actors was equally evident in the use of comparable methods and tools, but also in the ways of working that facilitated collaboration. In particular, when the methods and proprietary tools were already known, communication was generally straightforward between the partners. In such cases, no additional learning of new methodologies or tools was deemed necessary, as the essential basis for understanding was already given, which allowed jumping right into the project tasks. For example, the interviews revealed that certain software, such as for measuring the short circuit operation, had previously been used by many project partners, leading to an immediate prevailing knowledge base among the partners *(I11_RD1_S4)*. Equally, the knowledge between project partners of the same specialization was perceived as relatively technically demanding, which became clear, for example, when reading the deliverables and documents *(I14_RD2_S4)*. This indicates that groups of specialized partners existed in the project.

Overall, the findings established that many project partners perceived *more personal benefits* from integrating knowledge in their own domain than in an unfamiliar knowledge area that they generally lacked points of reference with. For this reason, most partners sought to deepen their knowledge of specialization. In this case, project partners explained that it was more difficult to understand and integrate knowledge from a different specialization in the short time frame of the project. Here, intrinsic motivation was also decisive for getting involved in new specializations. For this reason, most partners did not go further into a new specialization field relating to partners' organizations. Only a few isolated interviewees explained that they had knowledge in several areas, were broadly positioned and, therefore, searched in the breadth of different knowledge fields.

Although, the theoretical foundation of the second approach to knowledge integration provides fewer ways to cope with the, *"use of similar and related knowledge,"* my research showed that conducting research solely within their own field of expertise proved to be insufficient in achieving innovative results in Smart Grid projects. Given in particular the need to learn common methodologies and tools for project work, the case study project did not allow partners to acquire knowledge only in their own specialization. My research showed that the development of Smart Grid innovations required partners, who were prepared to expand their understanding in their own small world, but who were equally willing to glimpse into other areas of knowledge, even if the insights were not always deep ones. While most partners did not acquire in-depth understanding of new fields of knowledge, they were still proficient at recognizing the interfaces to other disciplines and the necessity to learn those. As *(I1_RD_E5)* explained:

> *Yes, I gained the knowledge about what is the operation side. Yes, I am the man who knows both sides. This helps me a lot with this integration project; because usually you have also network models. You must know the Use Cases from the power system engineering, which are then models in this IT semantic way. (I1_RD_E5)*

Summing up, the second approach to knowledge integration addresses the core issue of specialization, which is critical to the development of innovative solutions in Smart Grid projects. The interview findings uncovered that specialization plays an important role in mapping the complexity and enabling the development of new in-depth knowledge. Expert teams were available to assist in identifying the interfaces for knowledge exchange among partners. Most interviewees preferred to exchange knowledge within these expert teams from the same specialization. However, while the second approach, "*use of similar and related knowledge*," focuses on innovation development within the specialization; my research showed that, above all, interdisciplinarity from different specializations was essential for innovation development, as well as the leveraging of these different disciplines within collaboration. Similarly, learning knowledge of another specialization was hardly possible between the partners and was rather uncommon. Specialized knowledge from other project partners was, thus, often accepted and integrated into the project without having the partners to understand it at a deeper level.

To conclude, my findings showed that project partners were challenged to search for knowledge across disciplines. Thus, the evidence for the second approach to knowledge integration was not sufficient to demonstrate the broader theoretical claims and holistic nature of knowledge integration as it neglects the contemporary need for interdisciplinarity.

Combination of specialized differentiated but complementary knowledge

Deviating from the focus on a simple sharing and transferring of knowledge in the first approach and the emphasis on specialization of knowledge in the second approach, the third approach highlights that *knowledge complementarities* are needed for integrating knowledge (Enberg 2007; Lin and Chen 2006). This approach highlights the *distinctiveness of knowledge* as a decisive influencing factor for knowledge integration (Huang and Newell 2003). Recognizing the importance of specialization as one of the key mechanisms for knowledge integration, the difference with the second approach is the general view that specializations had to be combined.

The usage of diverse specializations was also at the heart of the case study, in which knowledge complementarities played a key role for integrating knowledge into the Smart Grid project. The case study revealed that contradictory, but *exclusive knowledge* existed in the Smart Grid project. As identified in the interviews, domain-specific knowledge from experts of electrotechnical engineering, computer sciences, standardization and architecture modeling was the basis for combining the distinctive knowledge. However, specialization alone was not sufficient for knowledge integration in the project, which is why a process of combination was also necessary. My research revealed that complementarity was very important in technically complex projects, where the knowledge required for the project could not be mapped by one organization alone. In this sense, the organizations of the case study often did not even see the need to know everything and relied on the knowledge of other experts *(I2_DSO_W2).* In summary, the Smart Grid project consisted of cross-functional teams of contemporary organizations with complementary knowledge.

In comparison to the second approach, specialization is used in this approach more as a necessary factor affecting a process or activity of knowledge integration (Tell 2011). The third approach goes beyond looking at the specialization of actors by addressessing *the process of integration*. This knowledge integration process rather focuses on the recombination and modification of knowledge, which was also identified in my research. The studied Smart Grid project used the process of combining domain-specific knowledge for the overall project aims. This allowed the partners to remain in their in their own areas of expertise and yet combine the different domain-specific knowledge within the framework of the joint tasks. Thus, knowledge was not deeply integrated in the partner's logic *(I10_RD1_S4).* Knowledge complementarities were used to recombine knowledge for innovation development. With regard to my findings, parallels could be seen in the case study outputs, such as the need for combining heterogeneous knowledge in order to reach a common denominator and for creating innovative solutions. This was evident, for example, in the development of the use cases, where it was important to combine the different knowledge by filling in a word template together *(I32_DSO_E5).* The interviewees highlighted that the knowledge should be combined to a minimum way for achieving the needed results. For this purpose, knowledge had to be bundled together for its combination. Experts often facilitated this process by overseeing how the knowledge was combined *(I32_DSO_E5).* From the angle of the third approach, this research demonstrated that new knowledge was created through recombining and modifying existing knowledge, thereby speeding up the research process. This modification process in the project is exemplified in the following statement by *(I27_DSO_W2),* who explained the UML modeling process between different partners.

> *[…] for this, we choose to use the UML approach. The use case was generated automatically from some UML model. At work, we regularly exchange the UML document. Thus, we see modification from first partners, then we made some modification, we synchronized and we met the synchronization from the partner to get, at the end, a comparison of the correct list of use cases without contradiction. (I27_DSO_W2)*

The linking of complementary domain-specific knowledge was also evident in the development of web services. A research partner with a background in electrotechnical engineering explained that the communications part of creating web services required expertise that was provided by a partner with a background in computer sciences, who correctly placed the data. The knowledge elaborated between different partners was compiled and checked between both parties *(I11_RD1_S4).*

> *For the web service, we had to do the server part - the communication […]. He [name] also provided me with information for how I could mediate a web service, so that I could insert that into the message that went from our server to the [DSO_S4] or [DSO_W2] server with our data. For the process form [DSO_W2] or [DSO_S4] server, I asked […] how I could manage to make it run from their side and then respond with the optimization solution. That was what he really explained and teached me. (I25_RD2_S4)*

According to Bredin et al. (2017), the third approach suggests that agile methods and feedback loops can be used to achieve this complementarity. My research showed that common methods and tools had to be learned, which were used as a basis for combining the different specialized knowledge. In the Smart Grid project, the outputs from one task were used as inputs for future tasks, supporting the occurrence of feedback loops and agility. In a broader sense, the methods and tools enabled the attainment of interdisciplinarity within the project. In this sense, the third approach suggests that certain commonalities paved the way to enable the use of domain-specific knowledge (Wahlstedt 2014). The knowledge of methods and tools can be seen here as this certain commonality between all partners. My research, thus, confirms that the organizational actors needed something in common, since completely different knowledge bases were impossible to combine. The partners, first, had to identify certain interfaces for collaboration. The commonalities, thus, provided access to the new resources and expertise in the project. However, in contrast to the third theoretical approach discussed in the literature, which states that relevant knowledge is imparted and stored by one person for transfer to another (Carlile and Rebentisch 2003), my case study shows that the combined knowledge is not necessarily shared or acquired by all individual project partners.

The mentioned linking mechanisms of Johansson et al. (2011) in the third approach were also identified in my research, as specialized workforces had to be bundled and organized for the project tasks in order to combine the different knowledge bases. According to Schmickl an Kieser (2008), this combining takes place in cross-functional teams, by knowledge brokers or by documenting knowledge. All three ways of combining knowledge were observed in my research. This included partner referral to expertise in cross-functional teams, the use of knowledge brokers from different fields and combined knowledge based on shared documentation, such as deliverables. In particular, deliverables were the most frequently method used to share and combine knowledge in the case study.

> *Sometime when there is mutual interest, people start to find common ground of understanding. But still it is difficult. I believe, people are more focused on this project on data models, communication infrastructure, protocols and tend to be on the comfort zone […]. There is one partner in this consortium that really can mix best of it. I think it is [R&D2_C1]. They have expertise on both sides and I guess they can understand. […] Someone is needed in the project to combine the different knowledge. (I14_RD2_S4)*

In general, the third approach to knowledge integration, *"combination of specialized differentiated but complementary knowledge"*, evolved to minimize costs of collaborative work (Tell 2011) and recombine knowledge for developing innovation by a local search (Katila and Ahuja 2002; Rosenkopf and Almeida 2003). Smart Grid projects have proven that it is critical to work as efficiently as possible because not only do experts have little time, but also collaboration is also costly, why the process for developing innovations should be as efficient as possible. The third approach therefore shows in principle many essential aspects that are also of utmost relevance for Smart Grid projects.

__Theoretical inferences for dealing with knowledge integration in the Smart Grid project__

By bringing together the theoretical basis with the empirical analysis, various aspects of the case study can be found in all three approaches to knowledge integration. The first approach, *"transferring and sharing of knowledge"*, highlighted the difficulties of knowledge integration, which were also expressed in the case study through various knowledge boundaries that affected the project process. The second approach to knowledge integration, *"use of similar and related knowledge"*, emphasized specialization among organizational actors, which was also a key factor for the Smart Grid project, given its technical complexity and need for specialized experts. Finally, the third approach, *"combination of specialized, differentiated but complementary knowledge"*, accentuated the specialization, which was also the core task in the Smart Grid project in order to leverage different expertise in the project. The following figure 12 provides an own visualization of the three approaches to knowledge integration.

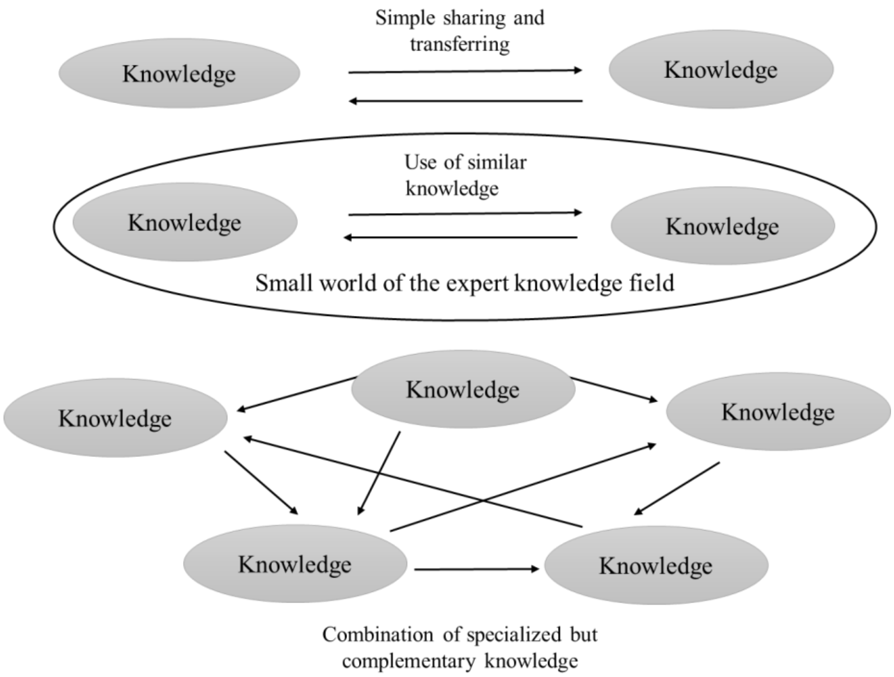

Figure 12 Own visualization of the three approaches to knowledge integration

The breakdown of knowledge integration into theory and practice shows that most similarities occur in the *"combination of specialized, differentiated but complementary knowledge"*, which can be seen as a key way to understand collaboration in Smart Grid projects. Thus, this theorization showed most parallels with my data, particularly in terms of adapting to new realities in project work, such as high specialization and the need to combine distributed knowledge. The idea that collaboration works through various combinations of expertise helped to illuminate the function of interdisciplinarity and new linkage mechanisms. However, substantiating the approaches with my research findings revealed significant gaps in all theoretical approaches to knowledge integration. While the first approach leaves open how the actual process of knowledge integration can be designed, the second approach is more concerned with the nature of the knowledge and neglects the collaboration between heterogeneous actors. Although the third approach describes knowledge integration as an activity or process during which the specialized knowledge is combined, the approach still fails to specify this process. My research findings have also reiterated that the third approach does not further address the difficulty of combining expertise, nor does it provide clearer ideas about how the combination process should be designed. This again raises the need to develop a new and broader perspective on knowledge integration to address these gaps.

To conclude, the case study findings evidenced that knowledge integration in Smart Grid project incorporates elements from all three theoretical approaches to knowledge integration. Generally, all three theoretical approaches to knowledge integration have their raison d'être, but focus on different aspects. Although my empirical findings agree in some areas, all three existing approaches do not yet comprehensively illuminate knowledge integration, making the existent approaches not only unclear, but also inconsistent. For example, the heterogeneous influence on knowledge boundaries in the knowledge integration process as a whole has been inadequately elucidated. The existing approaches, thus, are not able to capture the complexity and particularities of Smart Grid projects. The approaches are, consequently, not wrong per se but show a high dependence on the particular perspective of the authors conducting research in the area. Thus, the unraveling of the multi-faceted mystery knowledge integration served as an interesting starting point to further extent the identified required elements and to provide some new insights into the knowledge integration processes.

In chapter 7.3, a new perspective is presented that incorporates the aspects of knowledge integration from the three approaches and extends them with new insights from the empirical findings to fill the research gaps. Knowledge integration is, therefore, further underpinned by observations from my research results, yielding a new perspective on knowledge integration.

6.3. New perspectives on knowledge integration in Smart Grid projects

The discussion chapter 6.2 evaluated the three existing theoretical approaches to knowledge integration and linked them with the case study findings. By disentangling the three theoretical approaches, the result of my case study offered a more precise insight into the knowledge integration process – insights that have not yet been considered in the existing theoretical debate. Based on this discussion and the empirical findings, this chapter introduces a new conceptual perspective by reinterpreting the process of knowledge integration. The empirical analysis of the interview results can be used to explore knowledge integration in new ways, enabling new theorizing of knowledge integration by adding innovative artifacts from my case study results and deriving general propositions.

The new perspective of knowledge integration shows that the process consists of an interaction of interorganizational learning, knowledge bridging and the development of boundary objects. To enhance this insight into the process, I decipher a step-by-step approach of how the knowledge integration actually takes place. This interrelationship is often based on creating a common foundation of interorganizational learning, on top of which the domain-specific knowledge can be added by means of knowledge bridging and; thus, finally boundary objects can be developed. The sequence of steps is mostly the same in the project, with repetitions of the process taking place in parallel. Knowledge integration is, thus, not a rigid process, but can be adapted according to the depth of integrating new knowledge between the project partners as needed. Therefore, knowledge integration takes place at different points and times in the project. This process of knowledge integration also reveals the different influences of heterogeneity and difficulties in the form of knowledge boundaries, which have different meanings in the individual steps of the process. Figure 13 briefly summarizes the interrelations and various influences on the new perspective of knowledge integration presented here.

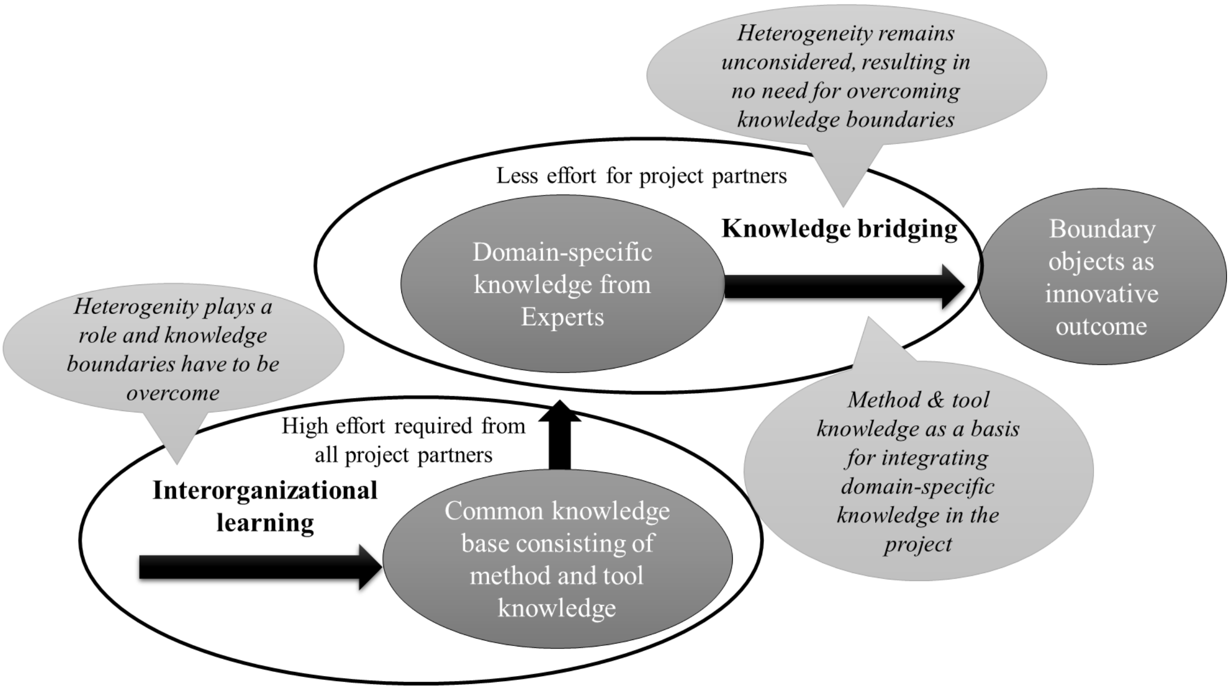

Figure 13 Identified knowledge integration process in innovative Smart Grid projects

The first step of the project work consists in the interorganizational establishment of the common methodologies and tools to be learned by the partners of the participating organizations. These methodologies and tools were required by all partners to create a common knowledge base for the work in the project. This first step of interorganizational learning, thus, assists in identifying common interfaces needed by all partners, especially to decide where domain-specific knowledge can be integrated into the project. This base of common knowledge is the minimum required to bridge the knowledge gap in the next step. The first step of learning the methodologies and tools is intensive in terms of intellectual labor and requires high effort from all partners. Learning takes place independently and largely voluntarily with the help of documents and books and, as well as on a personal level, such as in workshops or conferences calls. Specifically, face-to-face meetings were held mostly between organizations of one region due to the geographical distance of the organizations in the project. Consequently, interorganizational learning requires intensive communication to integrate knowledge at a level of common understanding. This research has identified new mechanisms through which the interaction of experts and non-experts occurs among project partners. Since methods and tools have to be equally understood between the partners, references to experts are a common way for a better understanding. However, existing theory has neglected to consider that organizational actors must acquire a sufficient level of understanding of the methods and tools in order to apply them pragmatically to the project tasks. The notion that collaboration requires complex, broad-based expertise to be integrated by each partner is simply not evident in my case study.

A new perspective of knowledge integration derived from the findings suggests that in interorganizational learning, explicit knowledge does not need to be transformed into tacit knowledge for the project to proceed. Rather, explicit knowledge is transformed to explicit knowledge for a rough understanding of another specialist's area. Tacit knowledge is transferred only in those rare cases where the partners voluntarily sought a deeper integration of knowledge or in the case of expert teams in a specialized area. This new perspective suggests that in innovative digitization projects, such as Smart Grid projects, there is routinely no direct learning of expertise, as was theoretically assumed by Lundvall and Johnsson (1994). In fact, the learning of method and tool knowledge simplifies the process of collaboration, in such as technically complex and multi-faceted international projects.

This first step of interorganizational learning is also characterized by *heterogeneity* of project partners. The learning requires the organizations to engage more with the other partners from a wide range of knowledge specialisms, where each brings deeper understanding of their subject matter. The process of learning enables the partners to get to know each other better on a personal level. However, it also underlines the disparities between them and, as a result, differences between them are more likely to evolve in frequent communication. To cope with this, particular cognitive skills are required. The methodologies and tools from the particular fields have to be translated and packaged in such a way that commonalities could be found at the required level of complexity. The organizational partners, thus, require a cognitive ability to understand other technological knowledge at a high level and recognize possible knowledge combinations with their own knowledge base. In that sense, a certain degree of cognitive proximity generally facilitates communication.

In addition to the cognitive differences between the organizational partners, interorganizational learning of methodologies and tools is also *influenced by further dimensions of proximity*. The proximity of organizations at the institutional, organizational, social and geographical level is of significant importance. For example, organizations in Smart Grid projects have different institutional frames, such as regulations and policies. In particular, DSOs and TSOs in the energy sector are highly regulated, which severely impairs knowledge sharing, for example, with research institutes. Various organizational structures of the project partners also affect the relationship and, consequently, the knowledge integration process, particularly as flatter hierarchies shorten the decision-making paths and promote agile project management. The organizations have equally diverse working habits and informal norms that influence the collaboration. In particular, the DSOs, TSOs and the research institutes that have previously worked together in the energy sector or come from the same region often have a closer social bond between each other, facilitating the building of trust and communication. This new perspective on the influences on knowledge integration shows that not only the knowledge specifications of actors according to their cognitive knowledge fields are influential, but also the organizational and institutional, social and the geographical proximity between the project partners. All dimensions can be controlled differently by the project organizations and can have a positive or negative impact on the process of knowledge integration. The new perspective on knowledge integration, therefore, reflects the complexity of Smart Grid projects and suggests considering far-reaching heterogeneous influences.

When learning methods and tools in innovative Smart Grid projects, *syntactic, semantic and pragmatic boundaries* are likely to develop in the knowledge integration process when transferring knowledge. General interferences can be drawn that the partners in international

Smart Grid projects not only have different technical terminology, but also different language specific vocabularies, which needs to be interpreted correctly and placed in the right context. The main difficulty of learning in the collaboration is seen at the pragmatic level, as the purpose and consequences of knowledge are handled differently, leading to diverse project goals, organizational hurdles, and a different use and application of data, which are just some of the reasons for the difficulties encountered in knowledge integration. Boundaries also develop because of different policy directions and technical implementations in the project. Since the energy sector deals with many safety-critical and complex subjects, there is not always an agreement on where the project should be heading. Difficulties in integrating knowledge also arise from the inadequate implementation of standards, for example for information exchange at the system operators. However, for the establishment of the Smart Grid, all kind of system components must be equipped with an interface conforming standard. Agreement at an international level between the organizations is, therefore, necessary in the standardization process, which enables organizational and technical interdependence. As it becomes evident, prerequisites for the establishment of the Smart Grid are the technical interfaces between all systems, such as the facilities, installations or assets of organizational actors in the energy systems. For constructing the Smart Grid, it is, therefore, particularly important to create standards for establishing communication and interaction of these different heterogeneous systems. However, it can be often recognized that the definition of technical interfaces leads to problems in project work, resulting in a lack of agreements between the project partners. Ultimately, the agreement of the technical standards occurs again at the organizational level between the project partners, as they have to agree on technical interfaces of the respective systems (Köhlke 2020).

This research offers new insights regarding the functioning of heterogeneity. Heterogeneity, in the form of different proximity dimensions, has a particular impact on specific knowledge boundaries. A trend can be identified here. While the cognitive and geographical proximity dimension play a crucial factor for the formation of knowledge boundaries on the syntactic and semantic level, knowledge boundaries on the pragmatic level have multi-layered causes. A prevailing pattern of the influence at the organizational and institutional level on pragmatic knowledge boundaries is evident. For the theory of knowledge integration, this means that knowledge boundaries have different origins, whose identification is an important first building block for understanding collaboration in innovative Smart Grid projects.

From my new findings on the knowledge integration process, the second step is to integrate *the domain-specific knowledge* of the experts by merging the complementary knowledge. The term domain-specific knowledge is newly added in the context of Smart Grid projects, which focuses on the independent as well as specialized knowledge structure included in a particular domain. The term seeks to capture the fact the knowledge is mainly dedicated for solving of problems and completing tasks within a specific domain. It is argued here that generic knowledge is rather unable to overcome the difficulties that partners face between multiple knowledge areas, while domain-specific competencies are used for problem-solving in specific domains. The knowledge is, therefore, sophisticated and must be learned through a cross-domain process, like the knowledge integration process. The domain-specific knowledge is, contrary to method and tool knowledge, rather complex and particularly difficult to learn in a short period. However, the learning of common methods and tools generally provides a basic framework to leverage domain-specific knowledge in the Smart Grid project. Since not one partner can cover all the required knowledge, the domain-specific knowledge is used to fill the knowledge gaps of other partners. For this bridging to take place, a certain common knowledge base of methods and tools is necessary.

Knowledge bridging exposes that project work in Smart Grids is particularly dependent on the collaborative collection of domain-specific knowledge. Since the knowledge in energy systems is far too complex and demanding to be learned in the short project duration, bridging is an alternative to using domain-specific knowledge in projects. The domain-specific knowledge is characterized by the fact that this knowledge cannot be easily found on the Internet or in books, but can only be passed on with the help of such experienced experts. These specialists facilitate knowledge sharing by determining where their domain-specific knowledge needs to be applied in the project. However, learning domain-specific knowledge would require a great deal of effort that cannot be mapped in the project. Thus, knowledge that is merely bridged in the project is organized by what is necessary to learn and the demands of time and cost, rather than by a comprehensive acquisition of a complex area of expertise.

The respective knowledge gap that exists between the project partners in the overall project frame can be filled by the respective expert who is involved in the required knowledge specialization. Interestingly, while interorganizational learning requires certain experts to guide other partners, domain-specific knowledge can be inserted independently by the experts. What is striking here is that knowledge boundaries have to be overcome in the upstream learning process, but do not play a crucial role for knowledge bridging. Thus, the second step of knowledge bridging can take place despite the difficulties described above. When bridging knowledge gaps, knowledge boundaries are, therefore, unlikely to emerge, as no deeper familiarization and immersion in the other partner's expertise is required. Hence, the process of knowledge bridging is much more straightforward. The domain-specific knowledge of other partners does not have to be learned in any special depth or deeply integrated in the logic of its actors. Due to the fact that domain-specific knowledge is not learned, the risk of the occurrence of knowledge boundaries is at least prevented. Knowledge bridging, thus, offers advantages, as it is less likely that the partners will clash due to disagreements. Since every organization only adds the specific missing piece of knowledge to the project, there is less need to explain and coordinate all details. At the same time, more trust is required between the partners, as each organization must rely on the experts and their own domain-specific knowledge. The domain-specific knowledge is difficult for non-experts to verify and review in depth. Similarly, it appears that not all knowledge boundaries can be resolved for knowledge integration. In this vein, knowledge bridging offers an opportunity to handle knowledge boundaries that can hardly be issued in the short time frame of the project and, therefore, remain present during the collaboration.

However, domain-specific knowledge, summarized between different organizations, is rather difficult to grasp. The knowledge base is somehow immaterial and difficult to verify, since it is composed, in a large part, of tacit knowledge. This only becomes visible through the codification and articulation of knowledge, such as in the form of documents or through communication in conversations. The difficulty here lies primarily in the identification of the existing tacit knowledge. However, tacit knowledge is problematic to measure, as it is often not apparent and identifiable at first glance. Thus, the knowledge base consists of various forms of complex knowledge from which the common basis is finally formed.

The third step can be seen in the development of boundary objects, which points to a new perspective on the outcome of the knowledge integration process. My research revealed that some of the outcomes of the Smart Grid project under study could be interpreted as *boundary objects*. Thus, the results of the project tasks are equally the product of combining different domain-specific knowledge. The concept of a boundary object generally facilitates the project partners in translating, negotiating as well as transforming their specific knowledge. While learning leads to a common knowledge base, consisting of the methodologies and tools, boundary objects are seen from my perspective as a result of knowledge bridging. Like a puzzle, domain-specific knowledge is used for the development of the innovative results in the project.

Only once the partners identify their interfaces in order to see where their knowledge can be inserted into the project can the boundary object automatically assemble the knowledge without much outside help. However, this was only possible when the partners identify their interfaces in order to see where their knowledge can be inserted in the project.

The concept of boundary objects is particularly suitable for explaining the integration of knowledge between heterogeneous experts. Boundary objects emerge in projects as an artifact that bundles various domain-specific knowledge together, which is required to develop innovations. What is new regarding the theory of boundary objects is that it not only consists of the domain-specific knowledge that is bridged, but also requires the learning of a certain conceptual basis, such as common methods and tools. Hence, the common learning is fundamental to knowledge bridging. Consequently, interorganizational learning is the upstream process and a necessary condition for knowledge bridging. Likewise, the development of boundary objects is linked to certain prerequisites, such as common structures and schemas that are used across platforms by the partners in order to insert the domain-specific knowledge.

Boundary objects can be generally seen as a heuristic tool to facilitate the knowledge integration. It acts as a means of approximating all potentially good decisions and ideas that can be brought together between the partners. The partners only have to converge to jointly assemble their domain-specific knowledge. The boundary object, therefore, consists of both the common structure and framework developed by the joint learnings as well as the more particular inputs by the experts. Boundary objects can, thus, create a joint development without having to discuss all topics in detail. As long as there is an understanding and agreement on the methodologies used, common results can be assembled in the boundary object because of the collaborative project work. In this respect, boundary objects can be compared to a black box, as it is more important for the partners to understand the interfaces between them and where to insert their domain-specific knowledge than to delve deeper into the overall project parts. Knowledge acquired beyond what is necessary to accomplish the project tasks may even be misleading, as the project's orientation and goal pursuit may be lost or partners may become mired in other expertise. Therefore, boundary objects can provide a structural framework for the project that facilitates collaboration between different experts.

Finally, innovation development plays a significant role in the sense of the higher purpose of knowledge integration. The innovation that developed in this Smart Grid project has many parallels to the concept of boundary objects. Boundary objects are a means to illuminate the intersections between diverse fields of knowledge, while new constructs emerge through their compilation. The innovativeness was especially seen in the combination of the different content of domain-specific knowledge that was captured within the boundary objects. For example, the new knowledge combination for the creation of the use case content was seen as particularly innovative for the overall project, but not the use case method itself, which is more of an established method in requirements engineering. However, the tools and methods learned between the partners still expanded the knowledge bases of individuals and, in this sense, were innovative for the individual partners. The tools and methods to be learned and their applications in different fields are of particular interest to the organizations in order to be able to adapt the knowledge also for other contexts. Consequently, the learning elements and their use in new domains are clearly important for the knowledge integration process, as the partners are able to take away something tangible for themselves and the organization.

This dissertation provides new evidence that seeks to elucidate the knowledge integration in terms of heterogeneity, knowledge boundaries, interorganizational learning, knowledge bridging, and boundary objects. However, knowledge integration showed itself to be a rather difficult and complex concept, especially due to the fact that tacit knowledge is difficult to grasps. Since the existing approaches are generally too narrow, there is a greater need for further work on the knowledge integration concept, which is presented within this dissertation. Accordingly, new and valuable further insights have been created for the debate. To capture the emerging perspective of knowledge integration in a concise formulation, it can be described as follows:

The prevention of knowledge boundaries through the learning of method and tool knowledge and bridging the complementary domain-specific knowledge at the interfaces of the boundary objects.

This new perspective showed that the knowledge boundaries can be prevented by bridging complementary domain-specific knowledge and learning only the method and tool knowledge needed for the development of a common knowledge base. The implications and lessons learned from this research for collaboration and knowledge integration in future Smart Grid projects will be considered in the next chapter.

6.4. Implications for future Smart Grid projects

The analysis offered here has shown that Smart Grid projects entail special characteristics. They are not only characterized by a high degree of complexity resulting from the heterogeneity of partners and the required domain-specific knowledge for the joint accomplishment of the tasks. Rather, the project partners must also possess qualities such as a high degree of flexibility in communicating with a wide range of partners and the ability to adapt to rapid developments and frequently changing requirements in Smart Grid projects. In particular, the increasing digitization and usage of ICT in the Smart Grid projects are changing power arrangements, creating a new area of tension between organizations. Altogether, it can be ascertained that the high demands of project work often stand at odds with the fact that projects are limited in terms of time and resources. The nature of Smart Grid projects pose particular challenges for collaboration. The dissertation has not only addressed those challenges, but also analyzed the knowledge integration process and its outcomes. The aim of this chapter is to derive consequences for future project work by inferring sustainable value from the results of the dissertation. For the design of future project work in Smart Grids, tailored measures for dealing with knowledge integration are addressed here, based on the empirical findings.

To begin with, projects in the Smart Grid area are becoming increasingly *interdisciplinary*, requiring from the different actors new competencies. For example, the thesis has shown that while different specializations of knowledge were needed for the technical development, projects were also dependent on social factors and processes. For the success of the project, not only electrotechnical engineers but also computer scientists and architecture modelers were needed to reflect the increasing digitalization of the energy system and transform it into a "smart" system. This heterogeneity of actors leads to new challenges for future project work, which if ignored, can lead to multi-faceted knowledge boundaries in the common work. To deal with this heterogeneity in future Smart Grid projects, the following implications can be identified from this dissertation.

The dissertation showed that *heterogeneity plays predominant role* when it comes to learning between organizations. Here, the partners need to work closely together, which potentially increases the influence of heterogeneity. As a way for dealing with it, heterogeneity should not be treated as fixed or static, as if it could not be changed anyway. The project partners should become aware of it by consciously including differences and not ignoring them. It is recommended to communicate with each other, to exchange views about differences and prejudices and to avoid pigeonholing. However, the analysis showed that not all heterogeneities are able to resolve in project work. Accordingly, organizational and institutional differences between organizations often remain during the project since rigid organizational and institutional structures cannot be dissolved for the duration of the project. Nevertheless, project partners can take actions on heterogeneous influences, especially regarding the social, cognitive and geographical proximity dimensions, which are able to adjust during the project work. Another recommendation made here is that actors need to strengthen their social relationships in the interorganizational learning process. With effective communication, project partners can benefit from building trust, which facilitates learning with and from each other. Communication is generally useful for a bonding of the actors on the social dimension. Even on the cognitive level, an adaptation of knowledge can be established through learning and openly exchanging common terminologies or concepts, leading to an rapprochement on the cognitive knowledge base. Geographical distance can also be handled with frequent interaction. Face-to-face communication was particularly valuable, especially at the beginning of the project, enabling collaboration and knowledge integration over long distances as the project progressed. To this end, it is quite important for future Smart Grid projects to understand diverse perspectives, to gain insights about the partners and build mutual trust and general understanding. This demands extensive effort to build relationships in projects.

For future Smart Grid projects, it is important to take into account the interdisciplinarity, which adds new ideas to the project, but also makes the project work particularly interesting and wide-ranging. At a certain point, the various visions, aims and strategies for the project must cohere together so that all partners pursue the same goals and the shared knowledge can be embedded in the project framework. However, this does not imply that the partners must generally agree on every subject matter. In this sense, a good dose of heterogeneity is fruitful for the quality of collaboration, leading to it being less likely to be faltered by knowledge boundaries. Approaching heterogeneity too narrowly prohibits productive communication and new ways of combining knowledge; approaching it too broadly, however, can hinder discussion by insisting on difference. Individual factors, such as personal openness to partners' competencies, especially their different ways of thinking and behaving, have an impact on improving or worsening the possibility of effective knowledge integration. At this juncture, it must be weighed up to what extent the partners moved closer together or keep their distance. Thus, this research has concluded that too little, but also too much heterogeneity can be harmful for the project work, as both can cause communication deteriorate and knowledge integration between the partners to fail. Regarding future Smart Grid projects, this means that an awareness of heterogeneity should be built into the planning of Smart Grid projects.

Despite this attention to heterogeneity, the rise of *knowledge boundaries* needs to be addressed in Smart Grid projects. Knowledge boundaries need to be assessed differently depending on the occurrence and nature in the project. Regarding the syntactic knowledge boundaries, difficulties with various technical terms, especially across European regions, can be addressed, e.g. by defining them in a glossary or discussing them with partners. Linguistic deficits caused by different native languages are usually difficult to resolve in the short project duration, but my research showed that these did not play the most important role in the Smart Grid project. In order to cope with knowledge boundaries on the semantic level, there must be a common understanding, particularly regarding the methods and strategies used in the project. To this end, it is necessary that the partners put the contents into the right context and interpret the information correctly. For the syntactic and semantic knowledge boundaries, learning can be seen as a strategy for coping with the difficulties. Syntactic and semantic boundaries, therefore, require a lot of communication and exchange between experts to solve any potential boundary. However, it is up to the personal will to learn as well as to the constraints of time to overcome these knowledge limitations. However, syntactic and semantic knowledge boundaries are generally less challenging, as they are solvable through the intensive communication and joint learning.

Comparatively, the dealing with diverse pragmatic knowledge boundaries is more challenging. Pragmatic knowledge boundaries are of complex nature, as they often relate to the overarching institutional framework, organizational boundaries, project-related goals and working conditions, as well as interpersonal difficulties. In this sense, it is rather unlikely that all pragmatic knowledge boundaries can be resolved in Smart Grid projects. For example, institutional or organizational boundaries are often not within the control of the project partners and are usually linked to overriding regulations or organizational goals of the partners. When pragmatic knowledge boundaries target the behavior of organizational actors, project partners are able to respond and solve them. Accordingly, different working strategies, goals and opinions, but also the exercising of power and withholding of data can possibly be addressed through intensive discussions. Although an intensive exchange about different views, goals, etc. can have a positive effect on collaboration, fundamental differences cannot be eliminated in most cases. The situation is different with institutional and organizational differences between partners, which have to be accepted in the short project duration, since little influence can be exerted on them in the project. Nevertheless, a certain degree of understanding, transparency and the ability to compromise towards other views is generally essential and advantageous for dealing with knowledge boundaries on the pragmatic level. Knowledge bridging can be seen here as a coping strategy of pragmatic knowledge boundaries that allows organizations to avoid deeply interfering with the social world of partners.

My case study findings also allow deriving lessons learned for future Smart Grid projects regarding *interorganizational learning*. Initially, my research highlights the importance of building working relationships and intensive familiarization between the project partners at the beginning of the project. The development of common methods and tools enables the partners to communicate intensively with each other and find common ground, for example in writing down all requirements necessary for the subsequent incorporation of domain-specific knowledge in the project. At these points, the project partners are asked to immerse themselves into the partners' perspectives in order to understand their instruments and conceptions for the common tasks. My research shows positive effects of mutual learning by letting partners get to know each other on a personal level. This is usually constructive for the joint project work, as a common level can be created for dealing with difficulties and integrating method and tool knowledge. Learning can be seen here as an enabler for facilitating organizational relationships and for building trust between them. For future Smart Grid projects, the learning of methods and tools does not require a particular high level of trust or effort from the partners to reduce the exercise of power. Most of the knowledge that needs to be learned is not of tacit nature and, thus, does not hinder business competitiveness; rather, the knowledge is publicly available or intended to be shared.

Interorganizational learning in the project can be facilitated by the individual and voluntary learning, as well as by mutual exchange with partners from other organizations. The learning in my case study project was largely undertaken independently via the acquisition of knowledge in the form, for example through deliverables or books on certain topics. This means for future Smart Grid projects that it is generally useful for project partners to look things up in written materials, but for more complex issues, my research suggests to rely on the experiences of the relevant experts. However, due to the complexity and technically challenging nature of Smart Grid projects, these projects often lack materials and documentation. Learning for themselves is, therefore, often not enough to answer further inquiries in the project work. This means that some topics can only be worked out in joint discussions with experts from the various fields. However, it is generally advisable for the partners to learn only enough to create a general understanding of the methods and tools, while leaving the domain-specific knowledge to the experts.

Equally, a certain degree of proximity is necessary for learning. The closer the partner's relationship is to each other, the faster they are generally able to establish a joint relationship as a basis for exchanging knowledge in the project. Another advantage is when project partners are able to build on existing prior collaborations that already have a certain social proximity and, thus, simplify communication. The question arises under which conditions communication and learning can be counterproductive in that they lead to negative effects on implementation and developments. Risks can develop from gathering too much information and a strong involvement into other disciplines so that a critical distance can get lost, negatively affecting collaboration and potentially leading to less productive results. Generally speaking, however, actors from similar knowledge fields or European regions tend to collaborate more frequently. For example, in the demonstration activities, the actors originated from one region, which facilitated collaboration, but at the same time it increased the risk that synergies and new input were not necessarily used by the different organizations. Again, allowing the right amount of heterogeneity in the project is essential to gain new knowledge and insights.

Unlike interorganizational learning, *knowledge bridging* does not require the building of intensive relationships and joint learning processes. In other words, domain-specific knowledge generally remains the specialty of the respective experts. Only the relevant knowledge should be bridged with the result of constructing the boundary object. However, it is prudent to discuss on how to deal with knowledge bridging in future Smart Grid projects. An important question here is on how to coordinate joint research so that *only necessary information* is shared. My research shows that this requires a high degree of responsibility and good judgment on the part of the expert to assess what is actually necessary for the other project partners to learn or synthesize. Therefore, project partners have to find common interfaces between them to ensure that expert knowledge matches and complements each other in a meaningful way. In this context, translations become central to providing the partners with a rough understanding for the identification of edges of other expert knowledge. The identification of interfaces also influences the decision-making process, which determines the data and information needed for the base knowledge from which the innovation can flow. Knowledge bridging may, thus, assist in making faster decisions for future projects without always having to include all perspectives and opinions of all project partners.

Communication among each other is therefore of central importance in order to ascertain what knowledge the project partners have already integrated and what knowledge should be bridged in the project. Accordingly, the collaboration in future Smart Grids requires an analysis of which knowledge areas still need further input from experts. Nevertheless, my research results show that it remains difficult to adopt a different perspective - not only because of the extent of knowledge specialization, but also because knowledge is very context-bound and may not be transferred easily. In particular, the technical complexity of the different knowledge bases can only be used with the help of bridging, as not all domain-specific knowledge can be learned in terms of resources and strategies.

However, the basis for consensus remains problematic. My research shows that partners are not always interested in learning certain knowledge and are partly pursuing their own goals in the project. For future projects, it is therefore even more crucial to get the partners on the same boat to ensure that they equally pursue the overall project goal. On the contrary, there is a risk that partners grasp too much knowledge from another expert field, thereby potentially disrupting the effectiveness of the collaboration. Accordingly, much constructive time can get lost by trying to involve each project partner in decisions made by rather particular experts. For this reason, partners should be incentivized to stay within their own area of expertise and only reach the lowest common denominator. In practice, my research suggests that it is rarely practicable to reach a consensus between all projects partners. Although a lot of time and effort is given trying to reach an agreement between *all* the actors involved, it often turns out that, despite many discussions and communications, minimal consensus cannot always be reached. When this becomes apparent knowledge boundaries are erected which inhibits the formation of the essential knowledge base. This is why this research has theoretically prioritised knowledge bridging for future Smart Grid projects because it emphasizes that project work can be conducted more efficiently when not every partner is involved in every element of the decision-making, project directions, strategies etc. Nevertheless, the project work cannot be arranged only by bridging knowledge, but a more intensive exchange in form of learning methods and tools is always necessary at some points in the project.

Having described the implications for dealing with heterogeneity, knowledge boundaries, interorganizational learning and knowledge bridging in the project, the case for theorizing projects of this complexity via the concept of *boundary objects* will now be made. My findings imply that not all partners need to deeply integrate the expertise of the other partners in order to fulfil their project tasks and roles effectively - decisive here is the identification of common interfaces between the actors' knowledge. As knowledge will continue to become more specialized and interdisciplinary in the future, joint interfaces and points of references of the respective research of each partner is becoming increasingly important. A rough understanding of the area in which the other partners operate and what this means for the joint project work may be sufficient, for example, if the system operators fill in the step scenarios in the use case, a CIM expert can use them to derive profiles. Thus, a general understanding can help to reduce prejudices and promote a commitment to the methodologies used so that all partners represent them jointly in the project. Boundary objects combine and bundle domain-specific knowledge and, thus, act as a kind of repository for the knowledge of the experts. Combinations of this kind are only possible through the creation of a common basis of methods and tools knowledge; without this, boundary objects cannot be developed and, therefore, neither can the project benefit from them.

Boundary objects are used to initiate a convergence of the actors in a way that it is necessary for commonly elaborating the project tasks without compelling the partners to reveal or discard too much of themselves in the collaboration. Therefore, the organizational actors can come to a common denominator without having to agree on everything. Likewise, boundary objects facilitate innovations development due to a faster determination of interfaces between partners, more efficient translations and the addition of the appropriate knowledge. These interfaces are particularly required to enable the development of an interoperable energy system. The development of common use cases and the interoperable exchange of information with standards, such as CIM and CGMES is becoming increasingly relevant to handle the heterogeneity and complexity in future energy systems. Specifically, the standards CIM and CGMES are critical to ensure future data exchanges in the Smart Grid. Most partners already recognized a vision of the standards beyond the project. Both use cases and CIM and CGMES should ensure the connection of different actors and systems in the Smart Grid, which is imperative to make the energy system more efficient and drive the energy transition. The efficacy of the demonstrations and simulations varied across countries, contingent upon the level of expertise possessed by the different organizations. By amalgamating their expertise, the organizations were able to enhance the overall effectiveness of the demonstrations and simulations.

Boundary Objects can also play an important role in future Smart Grid projects as an rapprochement rule for potentially good decision-making between heterogeneous actors, since not all partners have to be involved in the process. The utilization of boundary object can serve as a means for the experts to more effectively determine what will ultimately be enforced in the project. The experts can, therefore, find a common denominator and decide on the common strategy. This not only facilitates communication, but also leaves the project decisions to the experts. Hence, the number of discussions can be reduced, if partners do not engage in all areas of knowledge, but only in those that are relevant to them. The use of boundary objects can, therefore, be seen as a strategic tool for integrating domain-specific knowledge between heterogeneous actors. Similarly, boundary objects can help to ensure that projects are not managed too narrowly and an overview of the project results can be presented clearly to each organization. In this way, boundary objects can facilitate recognition as far as partners can identify what particular role they play in accomplishing the task. In summary, boundary objects will become increasingly important in future Smart Grid projects as these collaborations become more heterogeneous and complex, necessitating the identification of a common denominator between them. Boundary objects can, thus, facilitate collaboration by identifying common learning content, clearly distinguishing domain-specific knowledge of the partners and more quickly establishing interfaces between them.

Finally, a discernible shift in the project landscape is emerging. At present, a multitude of organizational actors, representing a wide array of specialized fields, are engaged in collaborative efforts. This suggests that new strategies are required in order to deal with the new conditions and requirements to ensure that the project succeeds. Today’s project structure shows that different partners collaborate on new tasks and provide feedback through a review. However, experts in a specific domain still have to think creatively, engage in diverse perspectives and learn to produce that fundamental common basis of knowledge. Therefore, experts in one area cannot deploy knowledge only in one specific area, but must at least find common interfaces between them. Building a closer relationship and communicating frequently in order to learn common methods and tools that form the basis for integrating domain-specific knowledge is especially important at the beginning of Smart Grid projects. This thesis argues that both processes are essential for successfully integrating knowledge and for overcoming difficulties between heterogeneous organizational actors in future Smart Grid projects.

7. Conclusion

Even though knowledge integration is one of the key processes of collaborative project work and indispensable for the development of innovations, the concept has been severely neglected in sociology until now. The findings of this thesis suggest that knowledge integration itself remains inadequately understood, with its heterogeneous influences, limitations and outcomes yet to be fully comprehended. Against this backdrop, I have argued that new knowledge constellations emerged in Smart Grid projects, making the integration of specialized and distributed knowledge even more important, especially in the context of increasingly interdisciplinary collaboration.

My dissertation considered knowledge integration at the project level and addressed the particularities of organizational collaboration within Smart Grid projects. Zooming further in, Smart Grid projects proved to be heterogeneous in nature, characterized by actors from various domains and with different cognitive knowledge backgrounds, organizational and institutional frames, geographical distances and social bonds, all of which have to be merged and combined in a coherent way. This thesis demonstrates that Smart Grid projects face major tensions from heterogeneous actor constellations, as different objectives, working habits or power relations in the project come into play. This requires highly complex and technically demanding solutions, which are dependent on the knowledge of experts that cannot simply be acquired and inserted in the project. Despite the growing influence of ICT on Smart Grid projects, its handling at various organizational legal levels has not yet been conclusively clarified. Likewise, given the intricate and critical infrastructure of energy systems, data sharing in Smart Grid projects is subject to certain conditions to ensure adequate protection of sensitive data. Thus, a rethink by the current system operators is needed to deal with confidential data and knowledge in the energy system. All of these points, ultimately, play an important role with regard to knowledge integration.

The main part of this research was devoted to the question on: *How and to what extent do heterogeneous Smart Grid actors integrate specialized and distributed knowledge in order to develop innovation in Smart Grid projects?.* To answer the question an extensive analysis of the concept of knowledge integration was undertaken in order to examine the theoretical basis explored so far. Chapter 2 evaluated the current theoretical accounts of knowledge integration in the literature and identified the three main approaches (Tell 2011), each offering insights into the different perspectives and research streams on organizational collaboration. Although I identified different theoretical emphases, they all concurred in the point that integrating knowledge is inherently complex and challenging. While the first approach highlights the distinctiveness of partners and argues for a simple sharing and transferring of knowledge, the second approach emphasizes the integration of knowledge in a similar and related area, which develops from an easier search of knowledge by partners within their own specialization. Conversely, the third approach to knowledge integration focuses on the combination of specialized differentiated, but complementary knowledge. Even though the different emphases of the approaches all had their rationale at first glance, the dissertation revealed gaps in the theoretical foundations. One of the main criticisms offered here is that existing theory missed the actual underlying processes of knowledge integration.

In chapter 3, I introduced a new concept to decipher the process of knowledge integration more accurately by using different theoretical concepts. My own approach starts at the origins of heterogeneity, which was analyzed with the help of Boschma's proximity concept (Boschma 2005; Boschma and Frenken 2010). Since heterogeneity is a broad concept and can be determined by a wide variety of characteristics; the proximity dimensions provided a suitable approach in the context of learning and innovation development. The analysis of organizational, institutional, cognitive, social and geographical proximities shed light on the coordination among actors and broke down the multi-faceted nature of their organizational relations. Based on the factor of heterogeneity, my approach concentrated on the analysis of knowledge boundaries, which I argued in H1 as a hindrance of knowledge integration. For this purpose, the concept of syntactic, semantic and pragmatic knowledge boundaries, as argued by Carlile (2002) was used. The three levels of knowledge transformation made it possible to examine the knowledge boundaries from the initial mapping of the terminology to their interpretation and contextualization, to their use and purpose in the project. Thus, a comprehensive picture of the occurring knowledge boundaries was possible to describe in accordance with Carlile’s concept. The next step in my approach concerned the identification of the underlying processes of knowledge integration. In chapter 3.2, I argued for the importance of interorganizational learning as a possible concept for the knowledge integration process, which led to a common knowledge base. The concept of knowledge bridging (Mattes 2010) was introduced in chapter 3.3 as an alternative to interorganizational learning, whose outcome was examined as a boundary object in chapter 3.4. The concept of boundary objects was theoretically elaborated to find a common denominator between the partners with conflicting opinions (Star and Griesemer 1989). Based on my conceptual framework for knowledge integration, I formulated three hypotheses that offered further insights for knowledge integration debate.

A qualitative approach was used to answer the research question of the dissertation and to draw conclusions about knowledge integration. For the empirical component of the study, an appropriate Smart Grid project was selected, enabling to conduct interviews with nearly all participating actors. The qualitative empirical design consisted of 32 interviews with experts involved in the common Smart Grid project. The number of interviews provided exclusive insights into the different perspectives of the DSO, TSO and R&D organizations, their relation to each other as well as their common handling of specialized and distributed knowledge for the development of innovation. Generalizable patterns were identified from the transcriptions and codification of the interview responses from which an elucidation of the underlying processes of knowledge integration was described. In particular, the qualitative approach enabled a deeper look into the internal processes of the project work and enabled, at the same time, an openness towards unanticipated content from the questionnaire guides.

H1 identified the influence of heterogeneity on the emergence of knowledge boundaries in Smart Grid projects. The case study showed how different dimensions of proximity in the actors' organizational relationships affected the emergence of knowledge boundaries between them. The dissertation ascertained that cognitive and geographical proximity mainly influenced syntactic knowledge boundaries, such as a common use of language, terminology or data in the project. In addition, the interpretation of the language and data at the semantic level revealed dependencies on the dimension of cognitive proximity, as knowledge was contextualized within a particular knowledge field. At the pragmatic level, all five proximity dimensions influenced knowledge boundaries, disclosing multi-layered reasons for the impact of heterogeneity on knowledge integration. Nevertheless, organizational and institutional dimensions had an influence on the pragmatic knowledge boundaries, especially through the functions of the actors and their organizational structure and strategies, which given the short time span of the project, proved difficult to address.

My research created a general understanding and awareness of the influence of heterogeneity in joint Smart Grid project work and showed different ways of dealing with it across a number of knowledge fields. The analysis of the empirical data offered a significant contribution as to how interdisciplinary work was conducted in Smart Grid projects and allowed a look behind the scenes of collaborative projects. The study unveiled that heterogeneous projects provide significant potential for combining different knowledge and tackling complex problems within the energy sector. It also showed that collaboration introduces new challenges arising from the different proximity relations among actors. While knowledge boundaries on the syntactic level developed due to different technical terminology, linguistic differences and databases, knowledge boundaries evolved on the semantic level because of different interpretation of technical terms, methodological and procedural knowledge, as well as varying comprehension and processing of data. Pragmatic knowledge boundaries in Smart Grid project mainly arose from different energy infrastructure and architecture across the regions of Europe, different political and legal regulation, hierarchy and bureaucracy, but also because of project objectives, working practices and habits, confidentiality and feasibility of data sharing, power relations as well as interpersonal boundaries. Overcoming pragmatic knowledge boundaries, especially those arising from the institutional and organizational contexts, proved challenging. However, difficulties at the individual level, stemming from cognitive, social, or geographical dimensions were more readily addressed due to the potential for the personal influence. As stipulated in H1, this research concludes that knowledge can be integrated, despite the threat of knowledge boundaries. Thus, the dissertation brought an important perspective to the consideration of the knowledge integration process, as the project partners found ways to integrate knowledge despite increasing heterogeneity and the threat of knowledge boundaries.

Regarding H2, the dissertation identified how knowledge was integrated even if collaboration in general was not always straightforward. H2 related to the possible process of knowledge integration, which was seen in terms of interorganizational learning as well as knowledge bridging. The hypothesis addressed the question of the extent to which project partners needed to learn the expertise of others. Even though these two strands of processes are entrenched in different research fields, both turned out to be relevant for the knowledge integration. The analysis found that interorganizational learning was especially important for building a common knowledge base that consisted of method and tool knowledge. In the light of the study observations, these tools and methodologies employed comprised the use case and SGAM methodology, the method behind CIM and CGMES standards, UML modeling, platform tools or simulation and demonstration tools. It was imperative for all project partners involved in the respective tasks to learn the methods and tools for their collective application within the project. The methods and tools formed the basis upon which a common knowledge base was built. What is striking and new for the knowledge integration debate was that common methods and tools were inevitably and, therefore, had to be understood on a deeper basis in order to establish a common base. With this basis in place, it was possible to bridge the domain-specific knowledge, such as those belonging to electrotechnical engineering, computer sciences or standardization and architecture modeling and integrate it into the project work. The project showed that it was not necessary for all experts to learn and deeply integrate the domain-specific knowledge. It was, therefore, possible to use the basics in a systematic and structured way and create added value for other project members who come from a different domains. This was evident, for example, in the creation of use cases. Here, it was necessary for the partners to understand the methodology of use cases in order to be able to fill in the templates together. In the end, the use case templates were able to leverage the expertise that was provided by each partner. Bridging domain-specific knowledge was particularly interesting, since Smart Grid projects are not only very limited in terms of time and resources, but are also characterized by a high degree of technical complexity, which made the learning of the domain-specific knowledge even more difficult. Consequently, learning the fundamental knowledge of other experts was not always feasible but, simultaneously, the partners also did not consistently recognize the need of deeply integrating domain-specific knowledge. Despite this difficulty and reluctance, knowledge bridging was still required in order to integrate domain-specific knowledge in the project, which was not possible to learn between the partners. The importance of knowledge bridging can be seen in the merging and combining of different domain-specific knowledge, which is central for the development of innovations.

Considering H3**,** the dissertation analyzed if boundary objects served as a heuristic tool that allowed actors to overcome knowledge boundaries and to develop innovation without extensive learning. The hypothesis, therefore, built on the second hypothesis by seeing the concept of knowledge bridging as the crucial element for the development of boundary objects. Indeed, the analysis of the case study showed that boundary objects were identified in the form of use cases, in CIM and CGMES profiles or in the demonstrations and simulations. My research revealed that for the development of the boundary objects, the combination of different expert knowledge was necessary. Boundary objects, therefore, reside in the actual outcomes of the combined domain-specific knowledge and do not only consist of the underlying tools and methodologies. Although the partners came from different "social worlds", they still had to delve deeper into the knowledge of other experts. Nevertheless, interorganizational learning was used here as a framework for the boundary objects. For instance, upon understanding the conceptualization underlying the creation of the use cases and its specific template, the partners could independently decide where their domain-specific knowledge was needed. Interestingly, most partners found this process of creating the use cases to be quite effective, which was met with general acceptance by the partners.

Like a puzzle, the knowledge from different domains, such as electrotechnical engineering, computer sciences, as well as standardization and architecture modeling could be merged to the boundary object. With this understanding, the partners could add the knowledge without further discussion. This also reflects that trust played an important role since the partners had to rely on the project partners to produce accurate and effective content. The boundary objects, thus, furnished a more comprehensive representation of the Smart Grid developments, as most of the domain-specific knowledge was amalgamated within them. All in all, the boundary objects served as an heuristic tool for dealing with knowledge boundaries. Most knowledge boundaries were most prevalent during intensive interorganizational learning at the beginning of the project. If the limitations of the knowledge boundaries were not identified during the first intensive exchange of knowledge, the remaining boundaries could remain rather unnoticed when bridging knowledge in a later step. In bridging, knowledge boundaries, thus, played a rather subordinate role, as the partners did not have to delve deeper into each other's knowledge and could simply ignore and bypass stumbling blocks. Finally, innovations in the form of boundary objects resulted from the interaction of both processes of interorganizational learning and knowledge bridging

The aim of my empirical analysis was to gain new insights for knowledge integration in Smart Grid projects and address the research question of this dissertation, namely: *How and to what extent do heterogeneous Smart Grid actors integrate specialized and distributed knowledge in order to develop innovation in Smart Grid projects?* The dissertation provided an important step in untangling the knowledge integration process and giving it new perspectives. While the foci of the previous approaches to knowledge integration were not wrong per se, my research has shown that they tended to be rather incomplete in terms of influences, actual processes and their outcomes. My research further disaggregated knowledge integration based on empirical examination of different theoretical concepts.

Starting with the first sub-question: *Which boundaries of knowledge integration develop in Smart Grid projects due to heterogeneity?,* the empirical analysis showed that heterogeneity plays an increasingly significant role in knowledge integration, especially in terms of growing specialization of roles and knowledge and a stronger integration of ICT. My empirical data revealed that the influence of heterogeneity differed in the two processes of knowledge integration and was mainly existent within interorganizational learning. In terms of interorganizational learning, the syntactic and semantic levels of knowledge boundaries were found to play a rather minor role, while knowledge boundaries at the pragmatic level exhibited a multi-faceted nature. The syntactic knowledge boundaries mostly referred to the technical terms, languages as well as different databases. Semantic knowledge boundaries were identified by the interpretation of these terms, the compression and processing of data, as well as the interpretation of method and tool knowledge. The empirical analysis unveiled that pragmatic knowledge boundaries derive from the complex structure of the different energy infrastructure and architecture, political and legal regulation, hierarchy, bureaucracy and other organizational boundaries, project objectives, working practices and habits, confidentiality and feasibility of data sharing, power relations and interpersonal boundaries. What was new to the knowledge integration process was that knowledge boundaries played less of a role in knowledge sharing, as experts remained within their area of expertise.

Regarding the second sub-question: *To what extent do actors have to integrate expert knowledge from other actors in order to develop Smart Grid innovations?,* the analysis showed that the process can be carried out in three steps, namely the interorganizational learning of the methods and tools, the bridging of the domain-specific knowledge and the development of the boundary objects, as a result of the first two steps. The analysis also highlighted that knowledge integration often occurs in parallel, allowing common learning and bridging to emerge at different points. However, at the beginning of the project a common knowledge base of method and tool knowledge is needed to create a basis of trust and a social bond for collaboration.

In the empirical analysis, power dynamics were found to be influential, as the domain-specific knowledge of project partners was often correlated with the core competencies and expertise of the organizations. Hence, power relations mainly showed up in the project when bridging the domain-specific knowledge. This domain-specific knowledge was not only of tacit nature, but often included content that could only be shared selectively within the framework of the project. A high level of trust was, therefore, required for sharing the specific content of domain-specific knowledge. Interestingly, trust did not play a major role in interorganizational learning, as method and tool knowledge was mostly relatively freely available and designed to be shared. Regarding expertise and related confidential knowledge, it was necessary for the project partners to acknowledge that the benefits of sharing knowledge outweighed the potential drawbacks of withholding it. Once this acknowledgement was made by the partners, trust had to be built between them. Thus, the preservation of the organization's domain-specific knowledge, such as network configurations or software codes etc., had a strong influence on the project in terms of competitiveness and power positions. Consequently, core competencies were not learnt by the project partners. Finally, the boundary objects point to the interfaces for bridging domain-specific knowledge, leading to the social world of DSO, TSO and R&D colliding at the interfaces of knowledge integration. This new perspective of knowledge integrating can be described as follows:

The prevention of knowledge boundaries through the learning of method and tool knowledge and bridging the complementary domain-specific knowledge at the interfaces of the boundary objects.

The dissertation provided different lessons learned for the collaboration within future Smart Grid projects. One of the most important implications was that the project partners should not neglect heterogeneity as it is particularly necessary for the creation of interdisciplinarity and innovation development. To address the issue of heterogeneity, different measures were suggested. These included the building of a common terminology and the fostering of closer social relations between the partners. Although different specializations were seen as crucial in order to create new synergies and recombine expert knowledge, too much or too little proximity between partners was seen as potentially negative for knowledge integration. In particular, the independent acquisition of knowledge was often preferred in learning, while knowledge was also added quite independently when bridging domain-specific knowledge.

To conclude, this study developed a new perspective on collaboration and knowledge integration in Smart Grid projects, which is strongly influenced by heterogeneity due to the opening of the market to new actors. As a result of these developments, knowledge is becoming increasingly specialized and distributed. This trend towards greater technical specialization is also reflected in the development of joint innovations that depend on the combination of knowledge shared by heterogeneous actors. Knowledge integration as the basis for the development of innovation was, therefore, identified as complex and multi-faceted. However, the study showed that the required expertise could not be contributed by a single organization, but by the combination of different complementary expertise. Thus, learning as the only process cannot represent knowledge integration because actors are not able to achieve the depth of specialization required for innovation development. Likewise, the willingness to exchange new knowledge and to find common solutions by making compromises appeared to be particularly challenging in Smart Grid projects, in part, because of the old-established structures of energy companies. Thus, knowledge bridging provided a new approach for the integration of domain-specific knowledge, while experts can remain in their own expert field. Partners only have to collaborate for achieving a common knowledge base, which serves as a framework for identifying interfaces between them. Generally, the dissertation revealed a growing shift in awareness that knowledge integration brings more benefits than risk of knowledge flowing away to competitors. Knowledge integration is, consequently, not a nice side effect, but is indispensable for developing innovations.

Where to next?

The need to understand knowledge integration more deeply is crucial for innovation development, in particular in the face of rapidly changing organizational environments and increasingly complex and multi-faceted processes. To further strengthen my new perspective to knowledge integration, more empirical studies of Smart Grid projects would be needed. My concept to knowledge integration, including the three steps of *interorganizational learning*, *knowledge bridging* and *the development of boundary objects*, defines the underlying process in a new way, but leaves room for future studies in order to sharpen these different processes and their relation to each other. For example, a stronger focus could be placed on the impact of new power relationships, trust and acceptance of technology developments in projects, further heterogeneous influences or the use of open source and confidential data in order to gain new insight into the integration of knowledge. Next to the qualitative approach that I used, quantitative studies could be conducted in the form of surveys and tests, which could, for example, query a broader mass of knowledge integration strategies. Similarly, the results of the study could also be reviewed in a broader setting in other domains. Taken together, the knowledge integration debate still offers much potential for further studies in the field.

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ANNEX

The interview guideline

Introductory questions

- What are your tasks in the project?
- What is your specific expertise in the project?
- With whom in the project do you communicate for elaborating your tasks?
- How often do you communicate?

Keywords: ICT, methods for communication

Heterogeneity of actors

- What do you think are the biggest differences between your project partners?
- How do you deal with these differences?

Keywords: Organizational, institutional, geographical, social, organizational proximity

Knowledge boundaries

- Which challenges develop in the project tasks and what causes these problems in the cooperation? Do you have examples?
- To what extent do you share knowledge? Why and under which conditions?
- Which role plays trust for knowledge sharing?

Keywords: Syntactic, semantic, pragmatic boundaries; confidential knowledge

Knowledge integration and knowledge bridging

- What kind of knowledge do you need to meet the tasks of the project?
- What kind of know-how do you additionally need in the project?
- Do you see dependencies in the project tasks in terms of knowledge from others?
- Why is it necessary to get this new know-how?
- How do you get this additionally needed know-how?

Interorganizational learning

- Which importance would you give to learning in the Smart Grid project?
- Do you have examples for learning? Do you remember a situation that you learned from your project partners or vice versa?

- If you have different layers of learning from a basic level to a deep layer, where would you rate the level of learning you are experiencing?
- Would you say that each expert needs the expert knowledge of another project partners for the tasks or is it necessary that relevant knowledge is bridged?
- Which new innovation/ or innovative solution could you already develop within this project work?

The code trees from MAXQDA

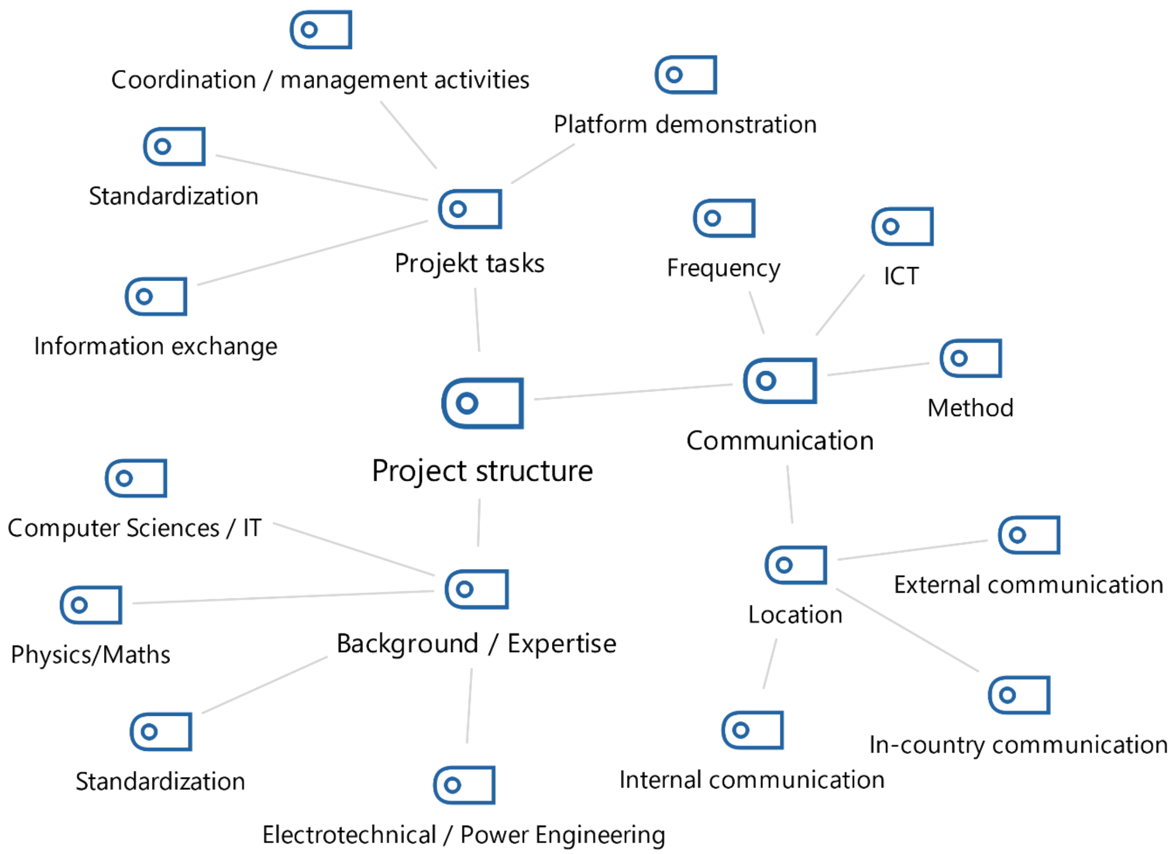

Figure 14 Code tree "project strucure"

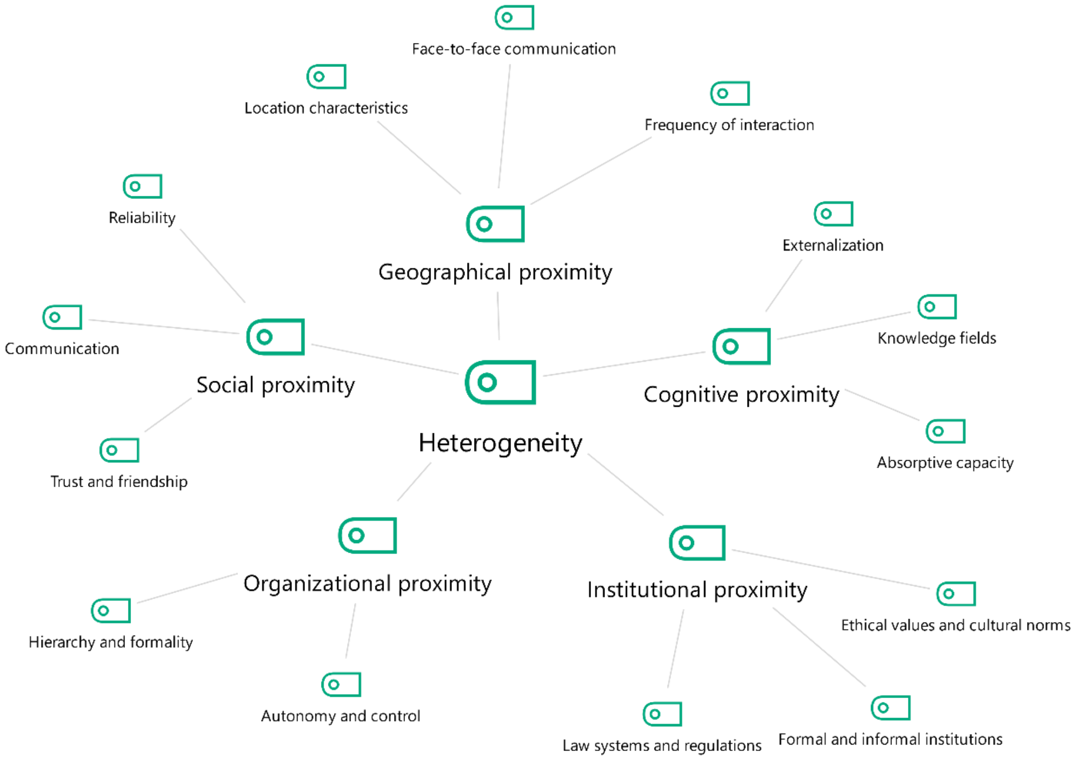

Figure 15 Code tree "heterogeneity"

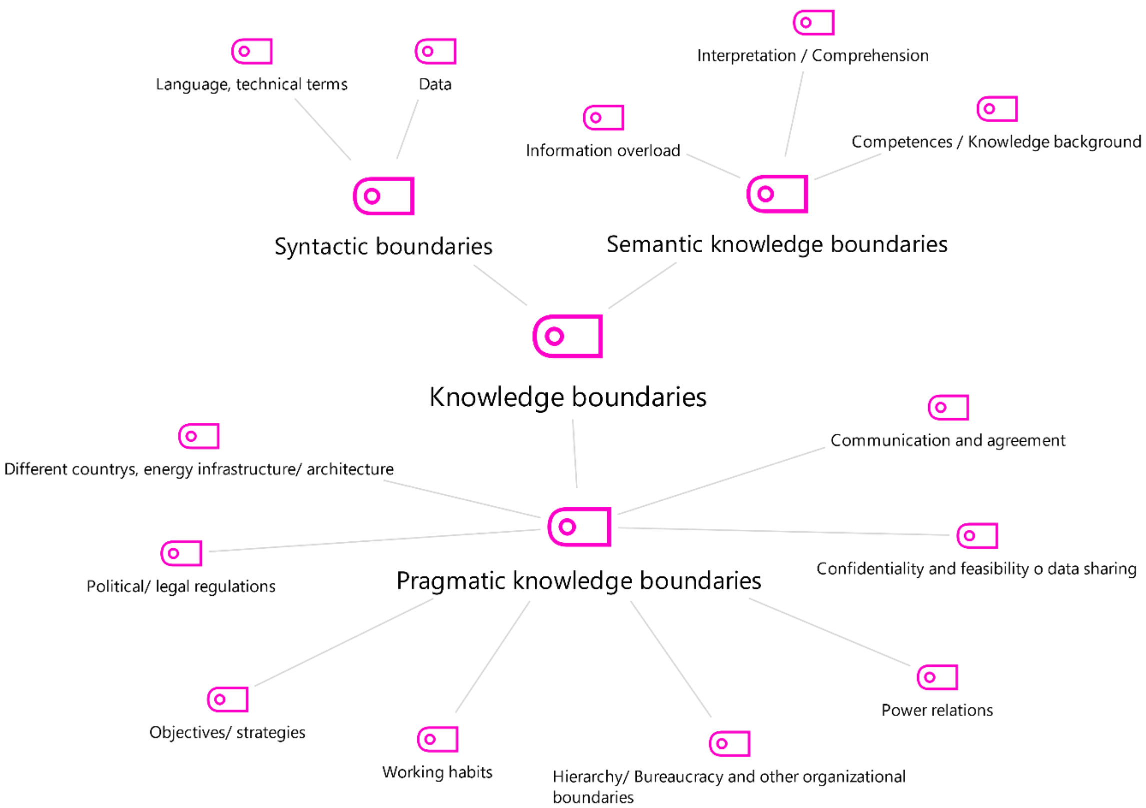

Figure 16 Code tree "knowledge boundaries"

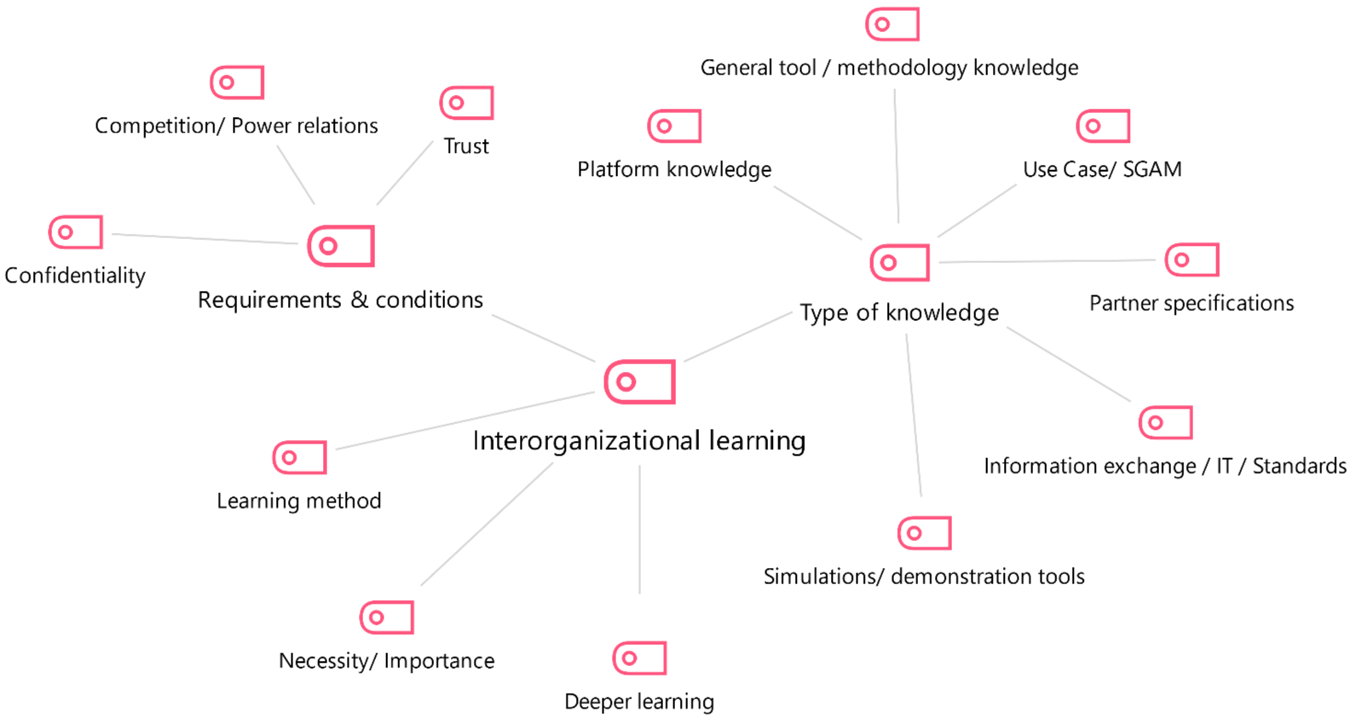

Figure 17 Code tree "Interorganizational learning"

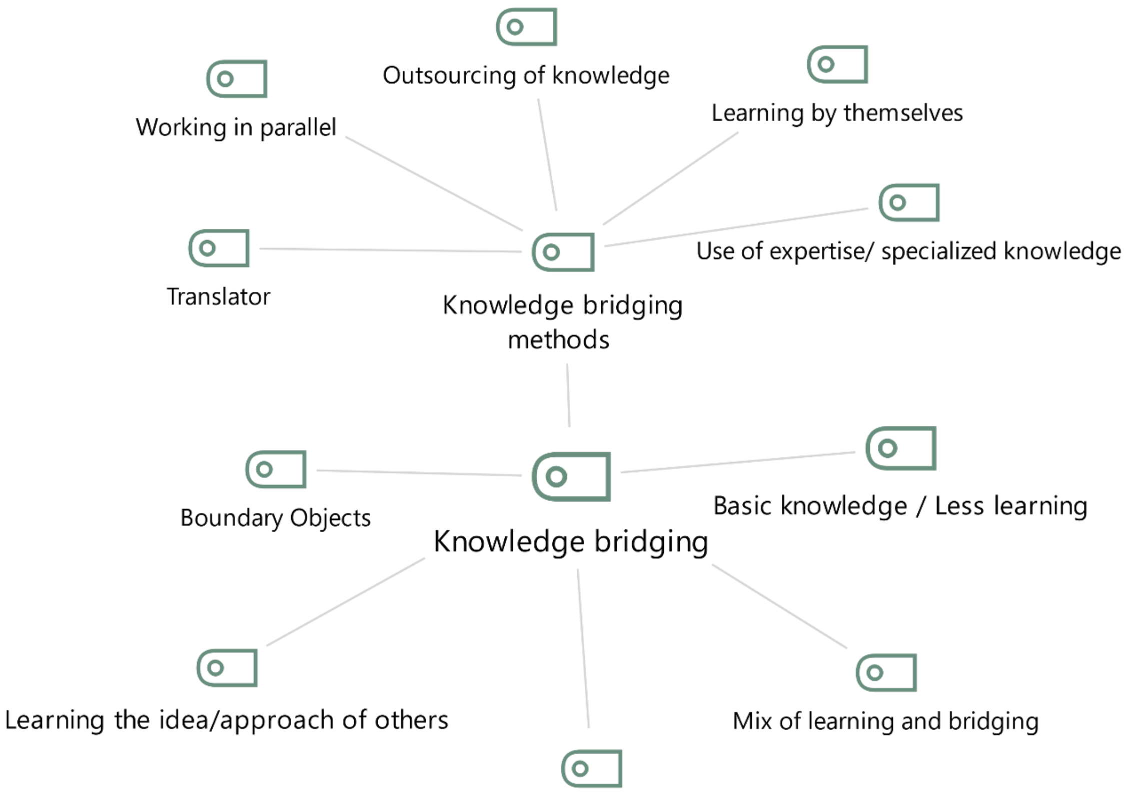

Figure 18 Code tree "knowledge bridging"

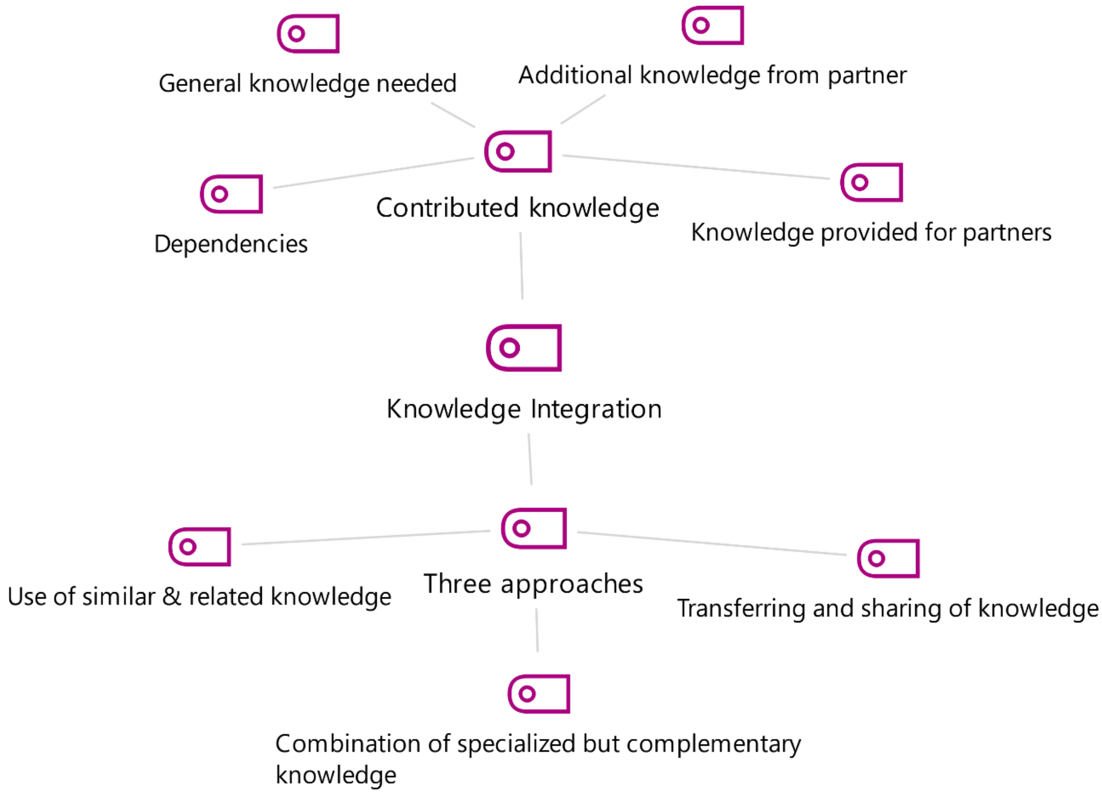

Figure 19 Code tree "knowledge integration"

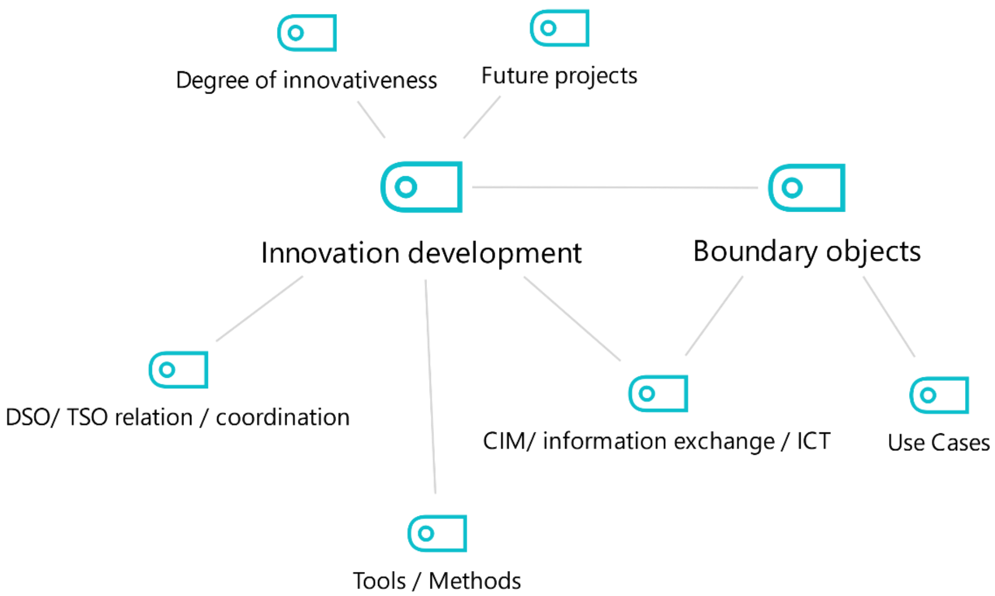

Figure 20 Code tree "innovation development and boundary objects"

Code system dissertation

- **Codesystem** — **1835**
  - In some cases it is easier, because sometimes with a simple cal — 1
  - Schöne Zitate — 70
  - Project structure — 8
    - Communication — 2
      - ICT — 6
      - Method — 14
      - Location — 121
      - Frequency — 29
    - Smart Grid project context — 24
    - Concept and aim — 18
    - Projekt tasks — 1
      - Information exchange — 13
      - Coordination / management activities — 22
      - Standardization — 9
      - Platform demonstration — 25
    - Background / Expertise — 2
      - Physics/Maths — 1
      - Standardization — 4
      - Electrotechnical / Power Engineering — 24
      - Computer Sciences / IT — 9
    - Project challenges — 2
      - Project guidelines / Deliverables (+) — 12
      - Lack of resources — 5
  - Knowledge Integration — 0
    - Contributed knowledge — 72
    - Three approaches — 31
  - Heterogeneity — 0
    - Proximity Type — 1
      - Organizational proximity — 17
      - Institutional proximity — 61
      - Cognitive proximity — 44
      - Geographical proximity — 25
      - Social proximity — 24
    - Generalisation — 20
    - Coping strategies — 7
      - Externalize knowledge e.g. in deliverables — 11
      - Standards / Templates / common methodology — 4
      - Developing synergies between TSO-DSO — 8
      - Ask/contact people or delegate — 14

- Knowledge Boundaries — 0
  - Syntactic boundaries — 1
    - Language, technical terms — 9
    - Data — 3
  - Semantic knowledge boundaries — 1
    - Information overload — 1
    - Interpretation / Comprehension — 8
    - Competences / Knowledge background — 32
  - Pragmatic knowledge boundaries — 0
    - Confidentiality and feasibility o data sharing — 46
    - Methodology / Tool knowledge — 26
    - Working habits — 17
    - Objectives/ strategies — 41
    - Different countrys, energy infrastructure/ architecture — 18
    - Power relations — 37
    - Communication and agreement — 19
    - Hierarchy/ Bureaucracy and other organizational boundaries — 27
    - Missing documentation / Faults in work done — 10
    - Political/ legal regulations — 9
    - Implementation of technology — 36
- Interorganizational learning — 4
  - Requirements & conditions — 0
    - Trust — 14
    - Competition/ Power relations — 12
    - Confidentiality — 45
  - Deeper learning — 31
  - Type of knowledge — 1
    - Platform knowledge — 18
    - Electrotechnical / Power Engineering knowledge — 8
    - General tool / methodology knowledge — 35
    - Partner specifications — 7
    - Information exchange / IT / Standards — 31
      - CIM/CGMES and profiling — 20
    - Management / Coordination knowledge — 1
    - Simulations/ demonstration tools — 8
    - Use Case/ SGAM — 20
  - Learning method — 75
  - Necessity/ Importance — 38

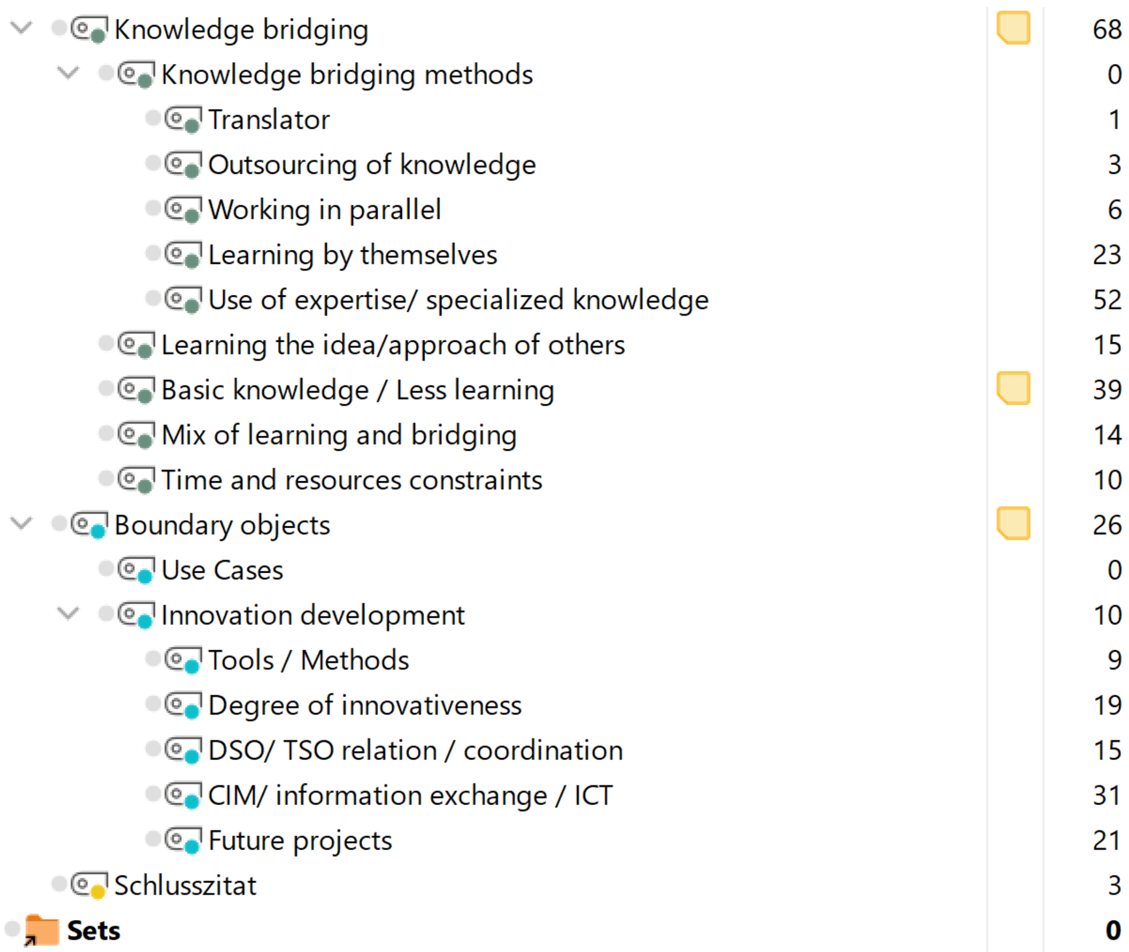

Figure 21 Code system dissertation

Selbstständigkeitserklärung

1) Ich versichere, dass ich die vorliegende Arbeit selbstständig und ohne fremde unzulässige Hilfe angefertigt und die aus fremden Quellen direkt oder indirekt übernommenen Gedanken als solche kenntlich gemacht
2) Ich versichere, dass der Inhalt der Dissertation nicht bereits für eine Bachelor-, Master- Diplom- oder ähnliche Prüfungsarbeit verwendet wurde.
3) Ich versichere, dass ich die allgemeinen Prinzipien wissenschaftlicher Arbeit und Veröffentlichungen, wie sie in den Leitlinien guter wissenschaftlicher Praxis der Carl von Ossietzky Universität Oldenburg festgelegt sind, befolgt habe.
4) Ich versichere, dass ich im Zusammenhang mit dem Promotionsvorhaben keine kommerziellen Vermittlungs- oder Beratungsdienste (Promotionsberatung) in Anspruch genommen habe.

Julia Petra Köhlke

Oldenburg, 04.01.2023