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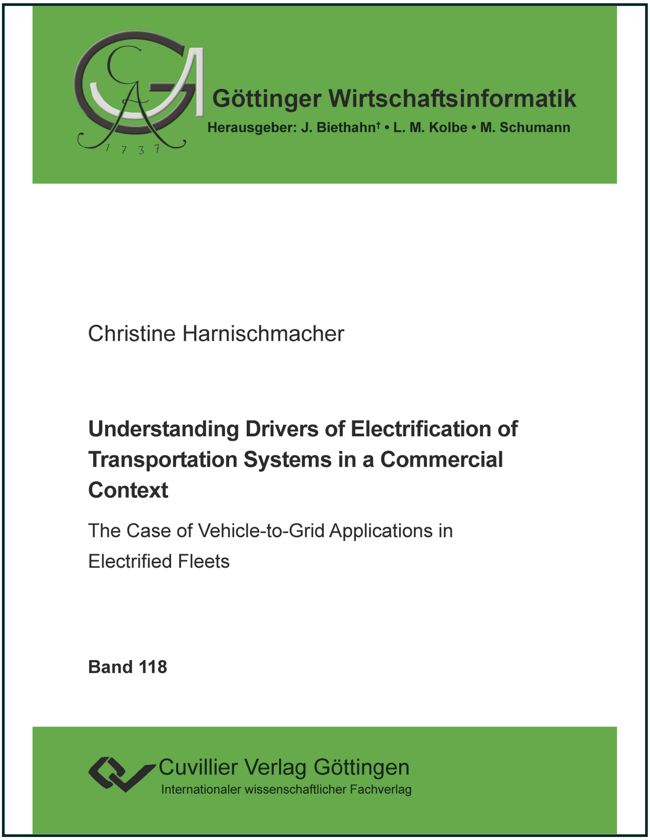
Understanding Drivers of Electrification of Transportation Systems in a Commercial Context

The Case of Vehicle-to-Grid Applications in Electrified Fleets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I. Introduction

This section introduces the research topic and agenda of this thesis. Starting with the research motivation and the relevance of the research endeavor in the first section (I.1), the second section (I.2) highlights the research gaps and questions addressed in this thesis. Subsequently, the thesis' structure is presented (I.3), followed by the positioning and design (I.4), as well as an overview of anticipated contributions (I.5).

I.1 Motivation

The world that we are living in is undoubtedly thriving in numerous aspects. Economies and populations are growing, and people have the ability to become more educated than ever before (de Wit and Altbach 2021). However, these immense opportunities do not come without major challenges (Robinson 2019). While trends such as automation and digitization offer positive chances, one of the most pressing matters that humanity is facing nowadays is global climate change. The depreciation of natural resources and increasing greenhouse gas (GHG) emissions are just two noteworthy developments that have not yet been tackled effectively. These complex challenges concern all of humankind, and thus joint solutions need to be developed and put into practice at a global level (Jordan and Moore 2020; Melville 2010).

One strategy to approach these challenges is climate change mitigation, which aims to prevent the causes of climate change from persisting or arising (Al-Ghussain 2019; Fawzy et al. 2020). As empirical evidence jointly points out the crucial role that increased and anthropogenic GHG emissions play in global warming (Hansen and Stone 2015; Huber and Knutti 2012; Schiermeier 2011), the primary focus of mitigation is on emitting less or no GHGs, for example through burning fewer fossil fuels in the context of energy production or individual and freight transportation. Consequently, a profound paradigm shift in the energy sector of many industrialized countries around the globe has occurred in recent years. Several governments — including Germany's — have committed themselves to establish future energy systems that foster the usage and integration of renewable resources in energy generation, reduce the energy intensity of demand, and lead to more sustainable and effective use of energy (Kitzing et al. 2012; REN21 2020).

The German government, in particular, has formulated ambitious climate- and energy-specific targets that shape the development of the energy system (Bundestag 2021). Energy production was responsible for 30% of GHG emissions in Germany in 2020 and thus the largest source of emissions (Umweltbundesamt 2021). In order to reduce overall GHG emissions by at least 88% compared to 1990 by 2040, a shift towards renewable energies in energy production is inevitable (Klaus et al. 2010). In 2020, renewable energies accounted for 41.1% of total power generation in Germany; however, with a share of 56.8% in installed production capacities, the discrepancy due to the intermittent nature of especially solar and wind power becomes evident (BDEW 2020). Wind and solar power constitute 88.6% of all installed renewable energy generation capacities (BDEW 2020). Due to the fluctuations in their availability and limited predictability, integrating these intermittent renewable energy resources into the energy grid poses significant challenges. These challenges are additionally amplified through increasing power demand leading to a mismatch between generation and demand (Maia and Zondervan 2019).

The transportation sector accounts for an additional 20% of GHG emissions in Germany in 2020 (Umweltbundesamt 2021), making it the second largest source of emissions. Focusing on reliable, economical, and environmentally friendly mobility and transportation while at the same time ensuring the security of energy supply, preservation of resources, and climate protection are central fields of action for the transportation sector. Transport needs to be almost independent of fossil carbon fuels ("decarbonized") and thus be largely GHG neutral by 2050 (Klaus et al. 2010) to achieve the national climate protection targets. The necessary integration of alternative, especially electrified vehicles and their further development, are a technical and economic challenge for the automotive and transportation industry (Bharadwaj 2015). Germany and the EU pursue an active, demand-driven policy to develop this pioneering technology by supporting, for example, the charging infrastructure and strengthening electric mobility technologies fostering globally competitive battery cell production, and advancing research and development work on battery and storage technologies (International Energy Agency 2021a). Additionally, automation and digitization aim to increase mobility and efficiency (Noussan and Tagliapietra 2020). The increasingly automated and connected mobility contributes to energy saving. However, the increasing share of electric vehicles (EVs) also leads to more fluctuating power demand, as large loads can be plugged into the energy grid at any time. Consequently, with power supply increasingly depending on intermittent renewable energies and power demand incorporating more volatile loads, the discrepancy between power supply and demand widens, posing a major challenge for transmission and distribution grid operators (Lopes et al. 2007). The classical energy economics value chain, as depicted in Figure 1, thus, has come under pressure, and calls for adaptations and new perspectives on energy economics are getting louder (Huener and Bez 2015).

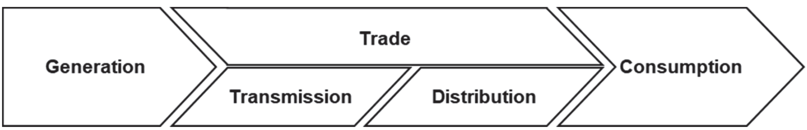

Figure 1: Energy Economics Value Chain (Doleski 2012)

The coupling of the energy and transportation sectors offers a promising increase in energy efficiency (Robinius et al. 2017). Particularly, the strong interconnection between the transportation and energy sector is fostered by policymakers as well as scholars (e.g., Brandt et al. 2016; Brown et al. 2018; Zweifel et al. 2017). In this context, EVs are a valuable resource as they possess the capability for a direct coupling of the mobility and energy sector. Using EVs' batteries as storage for the provision of utility services by supplying power to the grid for stabilization is known as the vehicle-to-grid (V2G) concept (Mullan et al. 2012). Thus, suitable V2G applications can contribute to the security of energy supply while at the same time promoting electrified transportation and the integration of renewables (Lund and Kempton 2008).

The implementation of V2G applications has mainly been researched within the context of individual, privately owned, and used EVs (Andersson et al. 2010; Madzharov et al. 2014; Mullan et al. 2012; Wang et al. 2011). Despite the promising benefits for the energy sector, the realization is obstructed by several barriers, such as the necessary substantial investments for infrastructure, user acceptance problems, and regulatory requirements for market participation in energy markets (Geelen et al. 2013; Noel et al. 2018; Sovacool and Hirsh 2009).

Commercial heavy-duty EV fleets that operate in closed transportation systems, such as airport apron logistics, warehouse logistics, or container transport logistics, are a prospective field of application for V2G concepts in the realm of electrified mobility (Altenburg et al. 2017; Ghandriz et al. 2020; Holly et al. 2020). In closed fleet transportation systems, the application domain of battery-powered heavy-duty EVs promises to have important economic, ecological, and technical advantages, and it advances an innovative technology (Noel et al. 2018, 2021). Furthermore, when multiple EVs and their batteries are aggregated, necessary infrastructure investments can be calculated and executed more precisely. Similarly, EV use and availability can be forecasted more precisely when used within larger commercial fleets so that V2G applications can benefit from economies of scale. Additionally, commercial fleet operators have access to the required information and communication technology (ICT), and by pooling EVs in a specific area, energy and cost synergies can be realized. As a result, the utilization of commercial heavy-duty EV fleets for V2G applications has promising economic and environmental prospects and represents this thesis' central focus.

In this regard, parts of the research included in the thesis are supported by "Flexibilitätsmanagement und Regelenergiebereitstellung von Schwerlastfahrzeugen im Hafen" (FRESH), a project supported by the Electric Mobility Development Fund of the Federal Ministry for Economic Affairs and Energy, located at the container terminal at the port of Hamburg.

From a research perspective, the complexity of making an entire system more sustainable through software, processes, and information technologies is of significant interest to IS scholars (Bradshaw and Donnellan 2013; Watson et al. 2010). In particular, the research field of Green IS focuses exclusively on the economic and ecological aims of sustainability rather than the social dimension, thus differing from Sustainable IS (Kossahl et al. 2012). Green IS research is driven by the facilitation, enhancement, and stimulation of sustainable activities towards operational processes (Bernroider et al. 2013; Dahlinger and Wortmann 2016; Malhotra et al. 2013), as well as the notion to affect individual and community behavior in a pro-environmental manner (Bradshaw and Donnellan 2013; Loock et al. 2013; Malhotra et al. 2013). This work contributes to the research field of Green IS especially taking the perspective of operational facilitation and enhancement (Elliot 2007; Malhotra et al. 2013) by adding new insights into applications such as fleet electrification and V2G that are enabled by IS and contribute impactful to shaping a more sustainable world. It provides useful insights for researchers and especially practitioners since it informs potential adopters of V2G applications about the economic potential and lowers barriers to implementations by ascertaining knowledge regarding the factors influencing the operation and integration.

I.2 Research Gap and Research Questions

This dissertation aims to improve the sustainability of transportation by fostering V2G and smart grid applications and adopting such strategies within businesses, thus contributing to the research field of Green IS. The overall objective of the research endeavor incorporates the derivation of an understanding of the status quo of research in the field of Green IS, the phenomenon-driven research on V2G applications, and research towards furthering fleet electrification.

As the research regarding V2G applications and their impact on a sustainable energy transition can be attributed to the research field of Green IS, it is necessary to establish an in-depth knowledge of the current status quo of the discipline to make a worthwhile contribution to this particular research field. The field of Green IS offers a great number of research foci (vom Brocke et al. 2013; Melville 2010; Watson et al. 2010), e.g., research analyzing Green IS in the context of organizational practices (Deng et al. 2017; Loeser et al. 2011), Green IS design (Piel et al. 2017; Shevchuk and Oinas-Kukkonen 2016), green mobile applications (Kroll et al. 2019; Oppong-Tawiah et al. 2014), and sustainable mobility (Brendel, Brennecke, et al. 2017; Piramuthu and Zhou 2016; J. Schmidt, Eisel, et al. 2015a). This multifaceted structure makes it essential to establish focal points within the research field. Additionally, research concerning the body of knowledge creates value because it does the “housekeeping” within the field, which, if done precisely and extensively, offers insights to all researchers in the field by giving an updated overview and establishing research gaps. Thus, this issue subsumes two interconnected aspects.

First, past literature reviews contributed valuably to the Green IS discipline by providing structure and guidance for fellow IS scholars. However, no study was performed that examined the deeper knowledge structure and relations within the discipline in terms of citations between Green IS articles. Hence, no comprehensive evaluation of the thematic structure of the discipline has been performed, leaving a research gap for thoroughly investigating the intellectual structure of Green IS research. Addressing this research gap by conducting a structured literature analysis and subsequent citation network and content analysis generates valuable new knowledge since analyzing the intellectual structure of a research discipline on a structural level can enable defining moments for a research community (Chen et al. 2019).

Second, determining the most influential articles within the research field at different points in time is crucial in extracting the inner network and interconnections between articles and research foci. Pinpointing influential research streams and identifying thematic research streams within the Green IS research discipline allows to uncover thematic shifts and contribute to research within emerging research streams which are likely to increase and shape the future body of Green IS research. As the further research questions that this dissertation aims to answer should contribute to the field of Green IS, especially research regarding sustainable mobility and organizational practices, it is necessary to not only establish the status quo but also identify key developments in the focus of the respective research fields.

These issues lead to the following research question:

RQ 1: What are the main research foci in current Green IS research?

V2G applications have mostly been researched in the context of privately owned and used vehicles (C. Guo et al. 2019; Mullan et al. 2012). It is necessary to transfer the concept to the commercial context and implement V2G at a larger scale to explore the full economic and ecological potential of V2G because this offers additional benefits such as economies of scale. The field of V2G in a commercial context is not only an emerging research field but also an emerging field of business (Høj et al. 2018; Noel et al. 2019; Sovacool et al. 2020). Many start-ups are developing hard- and software that fosters the use of EVs in contexts beyond transportation and mobility. In order to gain a deeper understanding of the commercial context and benefits of V2G applications, this thesis focuses on answering the following research question, which is addressed in the context of the FRESH project:

RQ 2: How are V2G applications and their implications situated within a commercial environment?

To exploit the potential of renewable energies in container logistics, the electrification of heavy-duty container vehicles provides an important and impactful first step (BESIC-Konsortium 2016). Because automated guided vehicles (AGVs) are not on duty every hour of the day (Steenken et al. 2005), in free time, the batteries can be used for a secondary cause, namely rendering frequency containment reserves (FCR) for the energy grid. The unused battery capacities can be used to store energy and provide FCR, depending on the current status of the grid frequency. Overall, this secondary use of the battery could promote the sustainability of all container logistics and opens up a new source of revenue. Energy grid operators reimburse providers of FCR; however, the provision of FCR also produces new costs, e.g., development and implementation of specialist IS, battery, and infrastructure degradation, amongst others. This makes the decision for or against the provision of FCR for container logistics operators ambiguous. Hence, to view the economic efficiency of such secondary use from the operators' point of view, it is necessary to establish the cost drivers clearly. Thus, by reviewing to what extent current literature has explored and systemized the cost drivers that derive through FCR provision in electrified transportation fleets and subsequently conducting an expert evaluation, a specific cost model is developed to answer the following research question:

> *RQ 2.1: What cost drivers need to be considered when establishing a V2G application with a smart electric transportation fleet?*

Using the batteries of EVs in a transportation fleet for the provision of FCR offers economic potential as the providers of FCR are reimbursed for available capacities. However, especially the additional wear and tear of the batteries that are incurred through the secondary use of the batteries can lead to considerable costs and increased battery degradation (Han et al. 2012; Zhou et al. 2011). Quantifying battery degradation for the specific use case setting, thus determining the degradation and associated costs, is an essential step in the process of researching the application of V2G applications in a commercial context. The following research question can be answered via means of simulation based on real-life data and economic analysis:

> *RQ 2.2: What influence does the deployment of electric vehicles for the provision of frequency containment reserves have on battery life duration?*

As it has been established that the use of EVs in a commercial context yields ecological and economic value (Kahlen et al. 2014; De Los Ríos et al. 2012), it is necessary to evaluate the factors that hinder or foster the actual implementation of EVs and V2G concepts in businesses. Especially the application area of logistical fleets offers promising potential. Thus, this thesis aims to evaluate the adoption process of innovative EV fleets and how the process can be influenced. This contributes to the destruction of implementation barriers and creates insights for business and policy decision-makers. In order to gain profound knowledge about the influencing factors, the following research question is tackled by conducting qualitative research through semi-structured interviews:

RQ 3: What factors influence the adoption of electrified transportation concepts in commercial contexts?

Figure 2 depicts the interdependencies between the research questions described in the above section. Section A.II provides a detailed theoretical background to all relevant topics.

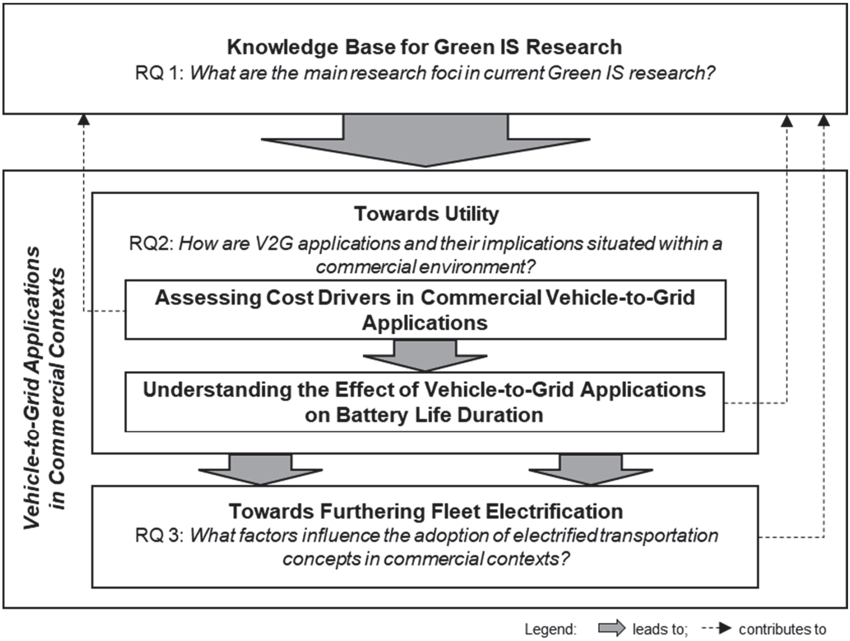

Figure 2: Research Overview

I.3 Structure of the Thesis

Four individual research articles are incorporated in this cumulative thesis to address the research goals. Table 1 provides an overview of the articles. The thesis is structured in three main parts, as depicted in Figure 3.

Part A provides the necessary foundations of this thesis by setting the scene with an introduction (A.I) and research background (A.II). The introduction first provided the motivation of the research endeavor (A.I.1) and highlighted the research gap and research questions (A.I.2) before presenting the thesis' structure (A.I.3). Subsequently, the research position and design (A.I.4) and the anticipated contributions (A.I.5) are delineated. The background section introduces the research field of Green IS (A.II.1) and its subfield Energy Informatics (A.II.2) before providing insight into the role of IS in sustainable mobility development (A.II.3). Finally, the research project FRESH, which serves as a case study for this thesis, is presented (A.II.4).

Part B represents the main body of this thesis, encompassing four studies that address the formulated research questions and thus contribute to the Green IS and Energy Informatics knowledge base (Table 1).

Part C offers a summary and synthesis of this thesis' contribution as it provides an overview of the individual studies' findings and results (C.I). Afterward, implications for research and practice are discussed (C.II), including limitations of the research and opportunities for future research (C.III).

Table 1: Overview of Studies Included in this Thesis

No.	Title	Section	RQ	Outlet	Ranking[1]	Status
1	Yesterday, Today, and Tomorrow – Perspectives in Green Information Systems Research Streams	B.I.	1	ECIS 2020 (Conference)	B	Published
2	Smart Grid in Container Terminals – Systematization of Cost Drivers for Using Battery Capacities of Electric Transport Vehicles for Grid Stability	B.II.	2.1	AMCIS 2019 (Conference)	D	Published[2]
3	Two-sided Sustainability: Simulating Battery Degradation in Vehicle to Grid Applications within Autonomous Electric Port Transportation	B.II.	2.2	Journal of Cleaner Production (Journal)	B	Submitted (1st Revision) [3]
4	(I Can't Get No) Electrification – A Qualitative-Empirical Study on Electrification of Transportation Fleets	B.III.	3	ICIS 2021 (Conference)	A	Published[4]

[1] According to VHB-JOURQUAL 3
[2] Invited and additionally published in "Maritime Informatics" by Richard T. Watson (Lind et al. 2021)
[3] Invited for resubmission in Transportation Research: Part C
[4] Previous version published at ECIS 2019 (VHB B)

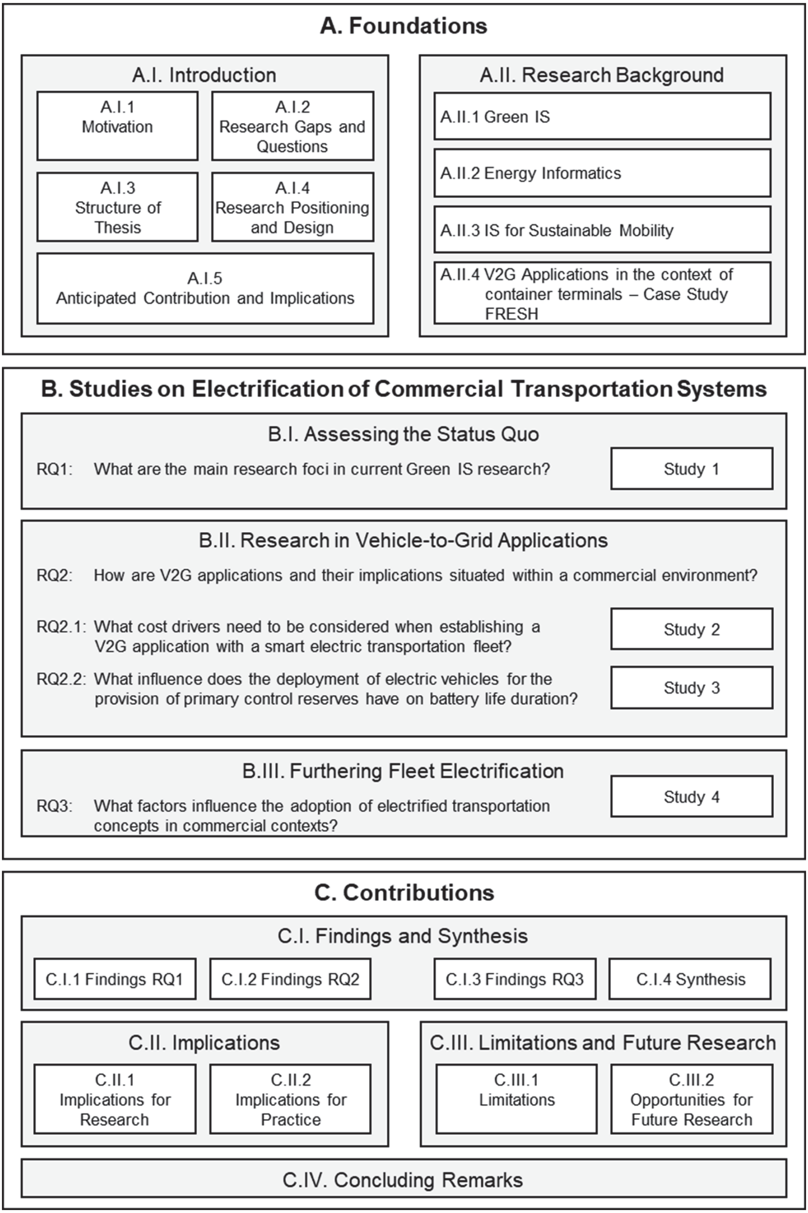

Figure 3: Structure of this Thesis

I.4 Research Positioning and Design

IS research aims to inform researchers and practitioners by exploring emerging technologies and their role and effect on individuals, organizations, and society. (Banker and Kauffman 2004). Ultimately, this thesis establishes a comprehensive insight into how to adapt to, utilize, and manage such technologies. Within the IS discipline, considerable effort has been made to provide structural guidelines which can be applied to position research in the growing IS research body. These guidelines include, for example, an overview of research streams, theory types, and research methodologies (Banker and Kauffman 2004; Gregor 2006; Palvia et al. 2004, 2015). In the following, this thesis' position within the IS discipline is established (see section I.4.1), and the research design of the individual studies included in the thesis is discussed (see section I.4.2).

I.4.1 Research Positioning

Several positioning criteria are established and well discussed in the IS discipline. These are shown in Table 2 and subsequently briefly explained and discussed in the context of this thesis and its four independent studies.

Table 2: Overview of Positioning Criteria in the IS Discipline

Paradigm	*Behavior-oriented*			Design-oriented	
Epistemology	Positivism	Interpretivism	Critical Realism	*Pragmatism*	
Theory Type	I. Analysis	II. Explanation	III. Prediction	*IV. Explanation and Prediction*	V. Design and Action
Research Stream	Decision Support and Design Science	Value of Information	Human-Computer Systems Design	*IS Organization and Strategy*	Economics of IS and IT
Research Method	*Case Study*	*Conceptual Model*	Mathematical Model	*Literature Analysis*	Survey
	Secondary Data	Design Science	Experimental Research	*Interview*	*Content Analysis*

Note: *Italics* indicate Characteristics of Positioning Criteria that are mainly acknowledged in this Thesis

Generally, IS research can be divided into two major paradigms: design-oriented research and behavior-oriented research (Arnott and Pervan 2012; Hevner et al. 2004). Design-oriented research focuses on issues regarding how to design and develop IS artifacts (Gregor 2006) by accumulating prescriptive knowledge that often culminates in the form of a design theory (Gregor 2006; Gregor and Jones 2007). In contrast, behavior-oriented research seeks to provide knowledge about phenomena that accompany IS by providing cause-effect theories that foster the explanation, analysis, and prediction of such phenomena (Gregor 2006). The studies included in this thesis contribute foremost to the paradigm of behavior-oriented research. However, it is noteworthy that the two paradigms are complementary (Hevner et al. 2004), and the design-oriented paradigm