A Blueprint – Constructional Fundamentals

The first part of this cumulative dissertation thesis is divided into seven individual sections. Section A.1 starts with a short introduction explaining the general motivation for this work and the role of the information systems (IS) discipline in electric mobility research. Afterwards, Section A.2 introduces the central research questions. Subsequently, the structure of this cumulative dissertation thesis is explained and the anticipated contributions of this work are clarified. This segment ends with a discussion of the underlying research methodology, a literature analysis providing the reader with a decent overview of existing work in this field of research and a section elaborating on the challenges and potentials of the IS community for future sustainable transportation.

1 Introduction

Global climate change is one of the most – if not *the* most – trending and important topics for modern society. The Industrial Revolution in Western countries had a strong impact on global emissions levels, which in turn influence the global climate. Nowadays, with emerging countries such as Brazil, Russia, India, and China (the so-called BRIC countries) striving to reach the same industrialization and quality of life levels as Western countries, this problem has been intensifying. The global community of states continually agrees on further countermeasures to reduce or at least limit global emissions levels in the final documents of the United Nations Climate Summits, such as the Copenhagen Accord, which endorses the set goal of taking measures to keep the increase in global temperature below 2 degrees Celsius.

To be able to accomplish these ambitious emissions-reduction goals, it is necessary for all major polluters to take on measures that work against current emissions levels. One major polluter is the transportation sector, which accounts for roughly a quarter of total greenhouse gas emissions. Thus, the transportation sector is clearly a key player that must make a strong contribution in emissions reduction to successfully reach the set goal.

Speaking in numbers, the transportation sector has to reduce its average greenhouse gas emissions levels from approximately 200 grams per kilometer to 20 grams per kilometer by 2050 (see Figure A.1) to fulfil the 2-degree goal. This can only be achieved by the development and widespread use of alternative propulsion systems, such as electric vehicles (EVs) or fuel cell electric vehicles (FCEV). At the same time, it is of great importance to account for an ecologically sustainable generation of these alternative fuels (either electric energy or hydrogen), as the well-to-wheel emission of a vehicle strongly depends on upstream emission levels.

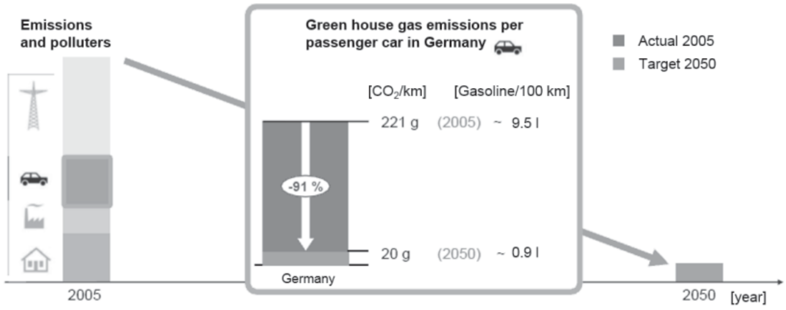

Figure A.1. Greenhouse gas emissions in Germany (Volkswagen AG, 2011)

Moreover, two further societal megatrends are the continuous urbanization of the society and increasing digitalization through the widespread use and integration of digital technologies, such as smart (online) devices and social media usage, within conventional products. The first megatrend – urbanization – leads to virulent societal problems such as increased noise emissions and severe air pollution caused in part by increased public and private transportation in urbanized regions (Panayotou, 1997). The second megatrend – digitalization – enables a whole range of new technical possibilities and empowers users through the vast amount of information available to gain a decent overview of their environmental footprint and to transform the conventional automotive industry and their products because of their increased sustainability demands. Thus, these two megatrends are major drivers for a shift towards an ecologically more sustainable – i.e., emission reduced – means of transportation.

Though several forms of sustainable transportation technology exist, this cumulative dissertation thesis focuses on electric mobility[1] as it promises relatively short-term success. All major industry countries' governments pursue the goal of supporting the development and increasing market penetration of electric vehicles by creating large-scale subsidy programs and/or research funding. As an example, Germany's government aims to have 1 million electric vehicles on the road by the year 2020. To achieve this goal, both government and industry plan to spend approximately 4 billion euro by 2020 in research programs that aim to develop or improve areas including battery technology, electric propulsion systems, light weight construction, and relevant information and communication technologies along with its infrastructure (NPE, 2012).

As a result, electric mobility is an emergent area of research in many disciplines that are closely related to the information systems (IS) discipline (e.g., computer science, computer engineering, industrial engineering). Examples of the great research potential include the recently created graduate

[1] For the further parts of this cumulative dissertation thesis, the German National Platform of Electric Mobility's (NPE) definition of electric vehicles (NPE, 2012) is followed. Thus, when speaking of electric vehicles (EVs) or electric mobility in general, battery electric vehicles (BEV), range extended electric vehicles (REEV), and plug-in hybrid electric vehicles (PHEV) are considered.

schools that focus primarily on electric mobility research, such as the graduate school "Energy Storage and Electric Mobility Lower Saxony" (Graduiertenkolleg Energiespeicher und Elektromobilität – GEENI) of the Technical University Braunschweig or the "Cooperative Graduation Program Electric Mobility" (Kooperatives Promotionsprogramm Elektromobilität – KPE) of Lower Saxony's Automotive Research Center (NFF).

To better understand why electric mobility is also a very promising domain for the information systems community, it is advisable to recap the origin of IS research, especially the German perspective on this discipline:

> " *Information Systems defines itself as sciences of the development of computer-aided information systems in corporate environments.*" (Scheer, 1978)

> " *Information Systems perceives itself as an interdisciplinary science between the disciplines of business administration and computer science and in addition also contains information- or general-technical […] objects of research. The key determinants of IS are human, task and machine.*" (Mertens et al., 2005)

Thus, the challenge of IS in the domain of electric mobility is to connect humans (users) and machines (vehicles and charging infrastructure) to sufficiently fulfill the task of enabling environmentally sustainable transportation. In this regard, IS may act both as a driver and enabler for, e.g., innovative electric mobility concepts, mobile online services that supply users with the relevant information about their mobility demands, and the successful integration of electric vehicles into the existing power grid to account for environmentally and economically sustainable charging of the vehicles.

This cumulative dissertation thesis therefore aims at supplying a sufficient insight into the domain of electric mobility research from an information systems perspective to enable IS researchers to effectively focus their future studies on problem areas within this domain that demand IS expertise.

In the next sections the central research questions that are answered throughout this thesis are introduced. Subsequently, the structure of this cumulative dissertation thesis is explained, anticipated contributions are elucidated, and an overview of the underlying research methodology is given. Furthermore, a structured literature analysis provides the reader with a decent understanding of the existing body of knowledge. Finally, challenges and potentials for the IS community in regard to future sustainable transportation are discussed and a detailed research agenda is introduced, followed by the main parts of this thesis, which develop the answers to the central research questions.

2 Research Questions

The overall aim of this thesis is to help the IS community better contribute towards sustainable electrified mobility. This goes in line with Watson et al. (2010) calling upon the IS community to contribute towards more sustainable behavior in general. Therefore, the first central research question (RQ1) of this thesis can be formulated as follows:

What is the role of IS in the development of electric mobility, and what can the information systems community do – how should it position and structurally align its research – to optimally foster sustainable electrified mobility?

In order to answer this central question, the entire thesis is going to draw upon the Interconnected Electric Mobility Framework (IEMF) presented in Chapter A.7.2.1 to structure and align the subsequent research. Nevertheless, at the beginning of each research project, "a review of prior, relevant literature is an essential feature of any academic project. An effective review creates a firm foundation for advancing knowledge. It facilitates theory development, closes areas where a plethora of research exists, and uncovers areas where research is needed" (Webster & Watson, 2002).

With the focus of Watson et al.'s new emergent subfield of energy informatics (Watson et al., 2010), the second research question aims at creating this firm foundation for the specific problem domain and tries to unearth the areas that demand the IS community's future research attention:

RQ2 What has been done by the IS community to contribute to a more sustainable behavior in the domain of energy informatics?

To successfully promote the formulated goal of optimally fostering sustainable electrified mobility, the information systems' central entities – people, function, and machines (Mertens et al., 2005) – must be optimally supported through IS's three functions of automation, information, and transformation (Schein, 1992). Hence, it is important to first gain an in-depth understanding of the problem domain to be able to precisely define the solution space. Regarding the problem domain of electrified transportation from a socio-technical systems perspective (Geels, 2004), the problem domain should be analyzed from two different perspectives. First, the problem domain should be analyzed from the functional/user side to understand the social and psychological factors of the technology's usage. In addition, to complement the understanding, the technical and process-related sides should be explored in order to provide answers about how the sustainable technology (electric vehicles) can be optimally supported through the implementation of information systems and information technology in (corporate) technology usage processes. Hence the third research question that shall be answered with this thesis is divided into two parts and can be formulated as follows:

RQ3 *Which*

> *a)* *social/psychological*
>
> *b)* *technical/process-related*

factors determine the adoption of a more sustainable behavior in terms of mobility?

As electric vehicles depend on a highly connected ecosystem to unleash their vast potential to reduce carbon emissions in the transport sector, the emergence of new and important market players in the automotive sector is irresistible. This evolution leads to the entrance of market players from the ICT and energy industry, such as IBM, Siemens, and Vattenfall. With these new players, various new IT-enabled services (e.g., charge point reservation) that are counted towards the overall electric vehicle business are created. For practitioners as for academics, this fast developing and confusing service landscape creates a fair amount of uncertainty of how to develop and position their products, services, and research to benefit from the developments around electric vehicles. Bearing in mind the overall aim of this thesis is to find ways in which information systems are able to optimally foster sustainable electrified mobility, it is essential to structure this complex service ecosystem, supporting both researchers and practitioners in aligning their research and business activities. Hence a fourth research question can be formulated as follows:

RQ4 *How can the complex service ecosystem of electric mobility be structured to reduce complexity and thus help other researchers and practitioners understand and analyze the domain?*

At last, this thesis understands itself as an inspiratory piece of work for the whole IS community in determining the community's future orientation in the field of sustainable electrified mobility research. Thus, taking a rather design-oriented perspective (Gregor & Hevner, 2013; Hevner, March, Park, & Ram, 2004; Kuechler & Vaishnavi, 2012) and closing the first identified gaps by supporting and creating practical solutions in the form of constructs, models, methods, and instantiations highlights the thesis' practical relevance. Hence, the fifth research question reads as follows:

RQ5 *How can practical solutions be supported by IS to contribute to a more sustainable mobility behavior?*

3 Structure of the Thesis

This work is a cumulative thesis encompassing eight individual publications. All but one publication are published either in leading IS conference proceedings, such as proceedings of the European Conference of Information Systems (ECIS) or the International Conference of Information Systems (ICIS), nationally renowned IS conference proceedings in Germany such as proceedings of the Multikonferenz Wirtschaftsinformatik (MWKI) or the Corporate Environmental Information Systems Days (BUIS), or as a book chapter. One piece is considered a working paper and is currently in the review process of a renowned IS journal.

Paper Contribution	Section	RQ #	Research Question	Title of the Paper Contribution	Outlet
1	A.6	2	What has been done by the IS community to contribute to a more sustainable behavior in the domain of energy informatics?	The Evolvement of Energy Informatics in the IS Community	European Conference on Information Systems 2012, Barcelona
2*	A.7	1	What is the role of IS in the development of electric mobility, and what can the information systems community do – how should it position and structurally align its research – to optimally foster sustainable electrified mobility?	Challenges and Potentials for the IS Community for Future Sustainable Transportation	W. Brenner & T. Hess (Eds.), Wirtschaftsinformatik in Wissenschaft und Praxis, 2014, Springer Gabler
3	B.1	3a	Which social/ psychological factors determine the adoption of a more sustainable behavior in terms of mobility?	Understanding the Role of Culture in Eco-Innovation Adoption	International Conference on Information Systems 2013, Milan
4	B.2	3b	Which technical/process-related factors determine the adoption of a more sustainable behavior in terms of mobility?	Exploring the Impact of IS on Economic Performance of Eco-Innovations	Working paper
5	C.1	4	How can the complex service ecosystem of electric mobility be structured to reduce complexity and thus help other researchers and practitioners understand and analyze the domain?	An Ecosystem Overview and Taxonomy of Electric Vehicle Specific Services	Multikonferenz Wirtschaftsinformatik 2014, Paderborn
6	C.2	5	How can practical solutions be supported by IS to contribute to a more sustainable mobility behavior?	The Value of IS to Ensure the Security of Energy Supply	Americas Conference on Information Systems 2013, Chicago
7*	C.3	5		Container Terminal Operations As a Pioneer of Electric Mobility	Corporate Environmental Information Systems Days (BUIS) 2013, Oldenburg
8	C.4	5		Decision Support Systems for Environmental Sustainability Technology Transformations	Multikonferenz Wirtschaftsinformatik 2014, Paderborn

* *The original version of the paper is in German language. To preserve the consistency of this cumulative dissertation thesis, the original paper is translated to English.*

Table A.1. Included paper contributions

The thesis is divided into four parts. The first part, "Blueprint," begins with the motivational introduction for this dissertation project. Furthermore, this part elaborates on the research questions that are answered throughout this work, information about the structure of the thesis, anticipated contributions, and the underlying research methodology. The blueprint section concludes with two sections comprising the first two paper contributions of this cumulative dissertation thesis. The first Section A.6 comprises a literature analysis providing the reader with a structured overview of the existing body of knowledge in the investigated field. For this, a concept matrix illustrating the methods used and investigated units of analysis is developed. The following Section A.7 provides a detailed research agenda that is used in the following parts as a guiding structural element.

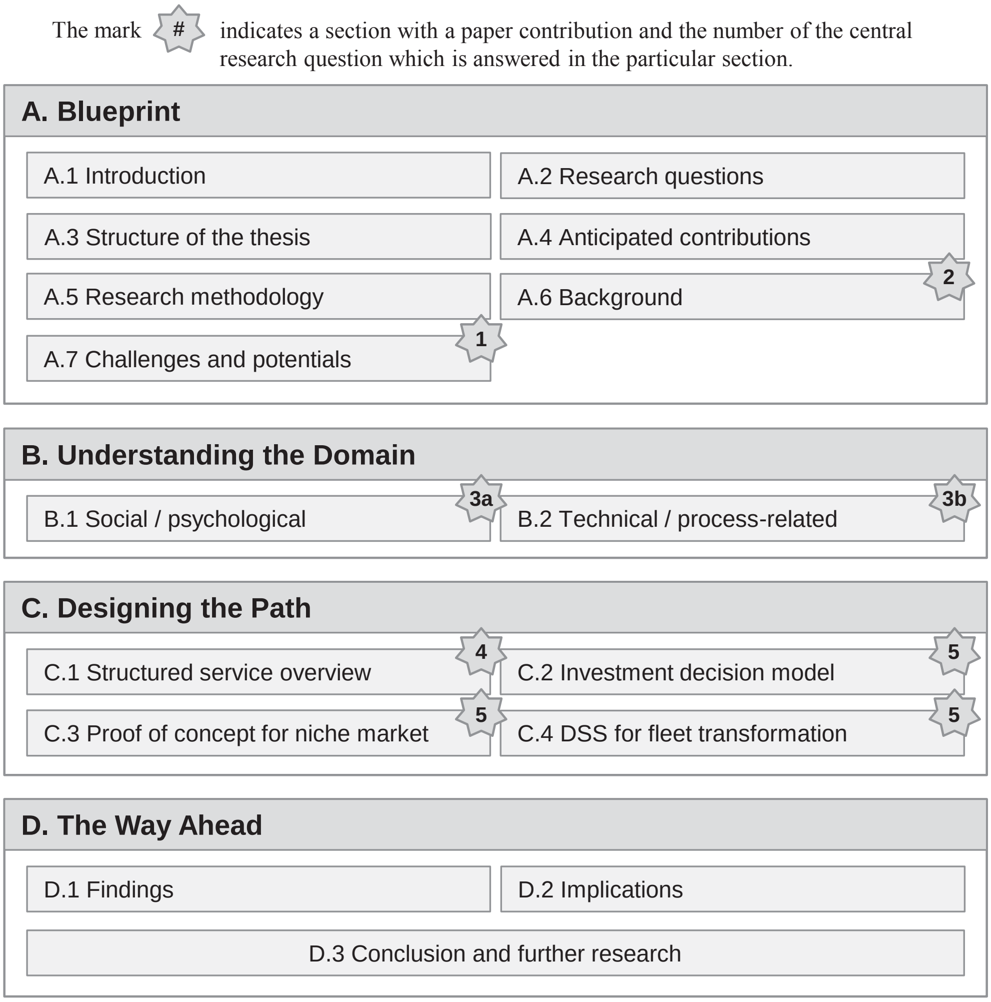

Figure A.2. Structure of the thesis

The thesis' core consists of part B, "Understanding the Domain," and part C, "Designing the Path." These two parts entail six publications in total. The first part is of a behavioristic nature and sheds light on the domain from two different perspectives: Chapter B.1 analyzes how social and psychological factors influence the adoption of electric vehicles by individuals and how IS can affect this relationship, while Chapter B.2 takes a deeper look into the role of IS in the diffusion of electric vehicles in corporate settings, analyzing how it affects technical and process-related factors influencing the technology's adoption.

Based on these insights, part C ("Designing the Path") focuses on developing and evaluating artifacts that help to close existing gaps in the current electric mobility's road to success (identified in both parts A and B). First, a model providing a structured service overview is developed and evaluated in Section C.1. It provides an overview of electric vehicle–specific service groups and interfaces that were identified by assessing current working practices and conducting expert interviews and a literature analysis. On this basis, a taxonomy that structures identified service groups within an electric-vehicle ecosystem according to certain criteria is developed.

As the market penetration of electric vehicles continuously increases in pursuing government goals, e.g., of one million EVs by the year 2020 in Germany, the question arises of whether to invest in more generation capacity or in smart grid components that account for optimal charging schedules and thus ensure grid stability and the security of energy supply. Section C.2 deals with this particular decision problem by developing a mathematical model simulating the generation as well as the usage, i.e., the charging side. The value of information systems that enable these smart-charging processes is reflected by the calculated cost-saving potentials, resulting from reduced expansion of the generation capacity.

When talking about electric mobility, most people only think of individually owned or shared passenger cars. However, many experts believe that an additional, maybe even greater, potential of electric mobility lies within niche markets or applications, such as warehouse logistics and airport movement areas. All these examples for closed transport and logistic systems bear the advantage that most processes and movements are very predictable. Hence, an optimal determination of charging schedules is possible and creates the potential to participate in smart energy markets offering energy system services, such as control power. Through this, further revenues can be generated, helping to overcome the higher acquisition costs of electric (transport) vehicles in relation to conventional power trains. As this great potential is achieved mainly through the implementation of advanced information systems, Section C.3 presents insights into a research project that tries to deliver a proof of concept for the application domain of electrified harbor logistics.

Section C.4, being the last publication contribution in this thesis, centers around the transformation decision problem of fleet operators considering when and which individual fleet vehicles should be transformed into electric vehicles. To find a solution for this problem, a general model of decision support systems for sustainability technology transformations is developed. In addition, a pilot case study was conducted to specify and evaluate the developed model for the case of the electric-mobility adoption decision of a car-sharing company.

Part D, “The Way Ahead,” first presents all findings at a glance and aggregates them to a combined result. Afterwards, implications for researchers as well as for practitioners are given. At the end, Section D3 concludes with suggestions for future research.

4 Research Context and Applied Methodologies

Once Watson, Boudreau, and Chen successfully published their paper with the title “Information Systems and Environmental Sustainable Development: Energy Informatics and New Directions for the IS Community” (Watson et al., 2010) in the *MIS Quarterly* journal back in the year 2010, they called upon the IS community to contribute to a more sustainable behavior in general, specifically focusing on measures that help to reduce energy consumption and thus greenhouse gas emissions. Subsequently, the IS community picked up on this call and responded with a multitude of paper contributions that can be allocated to this newly created field of energy informatics, e.g., Corbett (2011), Kranz & Picot (2011), and Yim (2011). In the year 2012, Kossahl, Busse & Kolbe (2012) conducted a structured literature analysis to support the emerging research field by identifying common methods and creating a theoretically grounded research framework that helps guide future work in the evolving research domain.

As this cumulative dissertation thesis understands itself as a composition of single paper contributions that all aim at contributing towards Watson et al.’s energy informatics agenda, this structured literature analysis is included in this cumulative dissertation thesis as Section A.7. It provides a comprehensive overview of the research background of this thesis in terms of the energy informatics domain.

Furthermore, it can be observed that in recent years a significant number of paper contributions have been published that can be aggregated in an even more specific subdomain underneath energy informatics that can be called “IS for Sustainable Electrified Transportation.” All contributions of this subdomain focus on understanding the influence or impact of IS on sustainable, electrified transportation – i.e., means of transportation such as electric mobility that bear emission-reduction potentials – or IS’ opportunities and challenges to support, enhance, or enable such mobility solutions. Exemplary paper contributions to this subdomain include Brandt, Feuerriegel, & Neumann (2012); Brandt, Feuerriegel, & Neumann (2013); Wagner, Brandt, & Neumann (2013); and Rickenberg, Gebhardt, & Breitner (2013).

Thus, to be even more precise than allocating this cumulative dissertation thesis to the domain of energy informatics only, this thesis should be understood as a fundamental research work exploring the role of IS for this special subdomain to effectively outline and structure the field of “IS for Sustainable Electrified Transportation” for other IS researchers.

To provide this explorative insight, the cumulative dissertation thesis follows a two-sided methodological meta-research approach: At the beginning (part B, “Understanding the Domain”), the thesis follows a behavioral-science approach to gain an in-depth understanding of the problem domain (“IS for Sustainable Electrified Transportation”) to be able to precisely define the solution space and better focus on crucial research gaps that are addressed in the second part of this thesis (part C, “Designing the Path”). In this part the thesis chooses a rather design science–oriented approach in following Owen (1998), Hevner et al. (2004), Kuechler & Vaishnavi (2012), and Gregor & Hevner (2013) by designing solutions for the problems / research gaps identified in the first behavioristic part B.

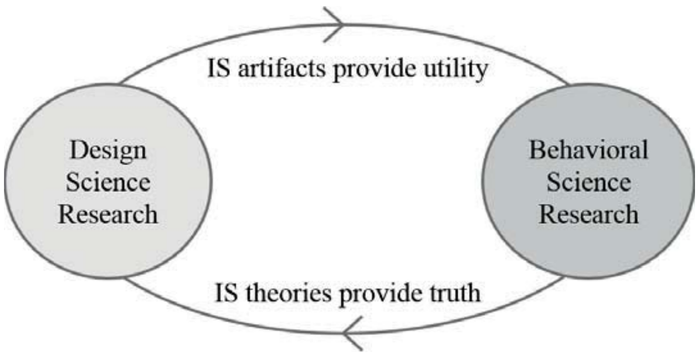

Figure A.3. Meta research paradigm (Hevner & Chatterjee, 2010)

In total, this thesis comprises eight single-paper contributions that all aim at answering the five research questions that were introduced in Section A.2. Table A.2 below provides an overview of the single-paper contributions along with their 1) core research question addressed, 2) specific research objective (design oriented or behavior oriented), 3) precise research design, 4) dominant method of data collection, 5) method of data analysis, and 6) main contribution. With regard to research objective, almost all individual paper contributions include both design science as well as behavioral science–oriented aspects. However, each individual paper’s listed research objective in Table A.2 can be seen as the dominant research paradigm within the individual work.