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Demand-Side Integration Programs for Electric Transport Vehicles

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A. Foundations

The first part of this cumulative dissertation is divided into two chapters. Chapter A.I explains the general motivation of this work and presents the research questions, structure, research context and anticipated contributions of this thesis. Afterwards, Chapter A.II provides the reader with relevant background information.

I. Introduction

The first section in this chapter highlights the relevance of the research topic, followed by a description of the research questions and the structure of the thesis. Afterwards, Section A.I.4 explains the research context and design. Finally, Section A.I.5 concludes this chapter with a description of the anticipated contributions for research and practice.

I.1 Motivation

During recent years, there has been a fundamental paradigm shift in the energy sector in many industrialized countries around the world. In this regard, several governments – including those of Germany and the USA – are aiming to establish a future energy system that includes sustainable energy generation, reduced energy intensity of demand, and a more effective and sustainable use of energy (REN 21, 2015; Harmelink et al., 2006). The main drivers for this development are the irreversible depletion of fossil fuels, the threat of climate change, and the increasing environmental pollution caused by the use of fossil fuels (Elliot, 2011; IPCC, 2007). A further push comes from the recent prioritization of environmental sustainability as a societal goal (Melville et al., 2010).

In particular, Germany's government has defined ambitious energy- and climate-related targets to shape a sustainable energy system. One of the most important of these is increasing the share of renewable energies to at least 80% of the total energy production by 2050 (BMWi and BMU, 2010). To date, wind and solar power are among the most widely installed and supported types of renewable energy, with a share of more than 55% of the total renewable electricity generation in Germany in 2014 (BMWi, 2014a). However, due to fluctuations in their energy supply and limited predictability, the integration of intermittent renewable energy resources into the energy grid poses enormous challenges (Ketterer, 2014). These challenges are expected to become even more formidable for grid operators as the discrepancy between power supply and demand widens (Pecas Lopez et al., 2007).

One possibility for realigning electricity supply and demand is provided by the concept of demand response (DR), which refers to the consumer's ability to alter his or her energy consumption pattern in response to external signals, such as time-dependent electricity prices or incentive payments (U.S. DOE, 2006). In broader terms, demand-side integration (DSI) also includes programs for increasing energy efficiency as well as power control procedures with the goal of optimizing demand independently of external signals (International Energy Agency, 2003). DSI programs are associated with several energetic benefits: in addition to supporting the increased deployment of renewable energy by smoothing out power fluctuations, system reliability can be improved by reducing electricity demand at critical load times (Bradley et al., 2013; FERC, 2008).

Electric vehicles (EVs) are a valuable resource for DR and DSI programs because they remain idle (in parking mode) for the greater part of the day (Kempton and Tomić, 2005a); the corresponding charging processes can then be shifted to periods in which overall electricity demand is low and the grid is unstressed or power generation from renewables is high, referred to as smart charging (Valentine et al., 2011). Furthermore, EVs' batteries can provide utility services by supplying power to the grid for stabilization and peak-time supply, known as the vehicle-to-grid (V2G) concept (Mullan et al., 2011). Hence, applying suitable DSI programs for EVs can contribute to ensuring the security of energy supply and promoting the development of renewables (Lund and Kempton, 2008).

At the same time, DSI programs seem compelling from the point of view of EV users due to their financial benefits; the application of DSI programs can make a valuable contribution to ensuring that EVs become economically competitive with conventional internal combustion engine vehicles (ICEVs) by significantly decreasing energy procurement costs or creating revenues by providing utility services (Kempton and Tomić, 2005b). Hence, applying DSI programs could also promote the market penetration of eco-friendly vehicles and would support the German government's objective of achieving a sustainable transport system, as about a quarter of greenhouse gas emissions in the European Union in 2011 was produced by road transport (European Environment Agency, 2012).

Most research (e.g., Mullan et al., 2011; Wang et al., 2011a; Andersson et al., 2010) has focused on (privately) used EVs for the application of DSI programs. Despite the promising potentials for the energy industry, EV users, and policymakers, there are several complications obstructing the realization of DSI programs in this application context – most notably the substantial investment required for constructing infrastructure, user acceptance problems, lack of incentives, and extensive regulatory requirements on energy markets (Geelen et al., 2013; Sovacool and Hirsh, 2009; Strbac, 2008).

A promising, emerging field of application for DSI programs in the domain of electric mobility can be found in commercial heavy-duty EV fleets operating in closed transport systems, such as aircraft tractors, forklift trucks, or container transport vehicles. Battery-powered heavy-duty vehicles represent an innovative transport technology and appear to have decisive economic, technical, and ecological advantages in closed transport systems. Furthermore, focusing on this application area is an important first step toward the implementation of DSI programs for EVs due to the following reasons:

1) Many larger commercial fleet operators have already implemented the smart grid and ICT technologies necessary for applying DSI programs;
2) Economies of scale result from the aggregation of numerous vehicle batteries, each with considerable storage capacity compared to privately used EVs;
3) EVs can be pooled on company grounds to exploit energetic and economic synergies;
4) The operation times of EVs can be adapted to optimally charge the batteries in a smart grid system; and
5) The energy consumption of EVs can be forecasted more precisely based on order confirmations, delivery dates, or arrival times.

Finally, the flexible load of EVs can be used for company-internal purposes, such as optimizing the company's load curve. Hence, companies adapting DSI programs for their EV fleets can utilize the flexible load for a broad range of DSI programs and are not limited to the established DSI programs for EVs, such as the V2G concept or smart charging. Due to the promising potentials of applying DSI programs in this field of application, this thesis focuses on quantifying the financial impacts of applying DSI programs for one special subtype of EVs: Commercial heavy-duty electric transport vehicles operating in closed transport systems, referred to in the following as an ETV fleet. To this end, data from a large-scale electric mobility project conducted in a container terminal that uses automated ETVs to transport containers on company grounds is analyzed to assess the feasibility and economic potential of several DSI programs.

This work contributes to the field of smart grid research (Sioshansi, 2011) by adding new insights regarding the value of DSI programs that reduce energy procurement costs for fleet operators and ensure the security of energy supply. In doing so, this thesis provides useful information for fleet operators about the economic value of applying DSI programs. This is important because DSI for EVs has experienced only moderate expansion in Germany, due in part to a limited understanding of the benefits of such DSI solutions as well as an uncertainty regarding the extent of DSI's economic value (Goebel et al., 2014; Aghaei and Alizadeh, 2013; Bradley, 2013; Strüker and van Dinther, 2012; Strbac, 2008). Furthermore, technical, operational, and in particular regulatory requirements for implementing DSI programs are given particular consideration in this dissertation. Based on these analyses, it also becomes possible to provide commercial fleet operators with guidelines regarding how to best participate in DSI programs. Simultaneously, valuable information can be given to policymakers regarding how to design a future energy market that also allows smaller flexible consumers to participate. This is essential because the question of how to integrate distributed energy resources such as flexible loads into existing energy markets remains unanswered (Goebel et al., 2014).

Overall, the results of this work have the potential to convince flexible consumers, such as E(T)V fleet operators, to adopt DSI solutions, which is crucial for an economically efficient and technically secure operation of a power system with a high share of intermittent generation sources.

I.2 Research Gaps and Research Questions

Applying DSI programs for EVs is important for improving system reliability and assisting in integrating renewables into the energy system. Furthermore, E(T)V users can expect financial benefits from applying DSI programs. Despite its potential, DSI for EVs has experienced only moderate expansion in most countries (see Section A.I.1). Adapting these thoughts, this thesis has two overarching goals. First, it aims to determine the extent of DSI's economic value for different actors from the demand and supply sides of an energy system, including EV fleet operators, ETV fleet operators, and energy suppliers. At the center of this work are fleet operators using heavy-duty electric transport vehicles, as this application context seems particularly suitable for DSI under current conditions. Second, this thesis investigates how to integrate flexible loads, such as ETV fleets, into existing energy markets, considering in particular the energy market design and regulatory requirements for applying DSI programs.

Based on this analysis, suggestions can be derived for policymakers on how to redesign the energy market in order to utilize flexibility options on the demand side to a greater extent.

To achieve both goals, four related main research questions should be answered in this thesis. As seen in Figure A:1 and elaborated in detail in the next section, RQ 1 provides an energy supply-side perspective on DSI programs, while RQs 2 and 3 provide a demand-side perspective on DSI programs with a focus on heavy-duty fleet operators. Finally, RQ 4 provides a governance (policymakers) perspective on DSI programs.

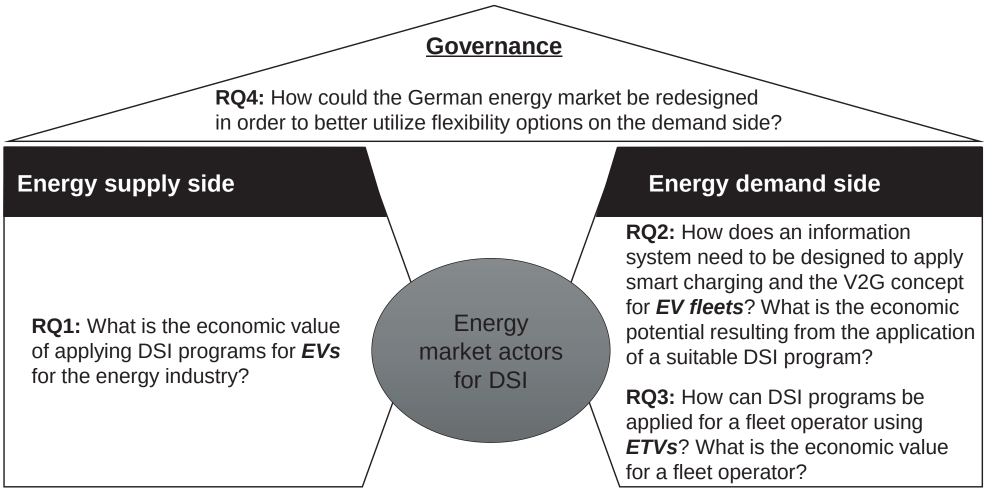

Figure A:1. Overview of all RQs included in this thesis.

From the point of view of the **supply side,** the energy industry can expect financial benefits from applying DSI programs for EVs in general. In this regard, it is assumed that charging a large number of EVs in an uncontrolled manner would create a significant load that could jeopardize the security of energy supply, in turn forcing power producers to increase power plant capacities. However, necessary power plant capacity adjustments could be reduced or even prevented by the implementation of DSI programs for EVs. To date, there is no study assessing the cost-saving potentials resulting from the application of DSI programs for EVs for the energy industry. This leads to the first research question:

1) ***What is the economic value of applying DSI programs for EVs for the energy industry?***

Aside from the supply side, this cumulative dissertation focuses on quantifying the economic potential of applying DSI programs for the **demand side**, represented by EV and in particular ETV users. In general, fleet vehicles within an existing business relationship (e.g., parcel delivery fleets) seem to be good candidates for initial DSI applications, mainly because they offer the possibility of exploit economic and energetic efficiencies through the aggregation of a large number of E(T)Vs (Williams and Kurani, 2007). There are some studies (De Los Rios et al., 2012; Han et al., 2010; Tomić and Kempton, 2007) estimating the financial profits of applying two classical DSI programs for EV fleets: smart charging and the V2G concept. To control a charging process (e.g., interruption during price peaks), however, the fleet operator must consider electricity prices beforehand and be able to predict electricity demand, allowing him to determine the margin for load shifting per charging process in advance (Geelen et al., 2013). Surprisingly, this fact has not been given much attention so far. Furthermore, hardly any study investigating the potential of DSI programs for EV fleets use real-world data and thus the results lack external validity. Therefore, the following research question is addressed:

2) ***How does an information system need to be designed to apply smart charging and the V2G concept for EV fleets? What is the economic potential resulting from the application of a suitable DSI program?***

An application context for applying DSI programs for EV fleets that has not yet been investigated but seems to hold great potential is heavy-duty electric transport vehicles operating in closed transport systems (intralogistics sector). Unlike EV fleets that are used to deliver goods outside the premises, these ETV fleets are employed exclusively within the walls of a fulfillment or distribution center. They are operated in diverse areas of application, such as in warehouses (forklifts), at airports (aircraft tractors), and at ports (container terminal vehicles). A particularly favorable characteristic for applying DSI programs in this area of application is the possibility of pooling the ETVs – each with a considerable battery storage capacity – on company grounds (see Section A.II.2.2). To ensure the practical relevance of the thesis' results, the analyses are based on a large-scale electric mobility project conducted in the largest container terminal in Germany. These issues are transformed into the following research question, which represents the focus of this thesis:

3) ***How can DSI programs be applied for a fleet operator using ETVs? What is the economic value for a fleet operator?***

From this central research question, four partial research questions are derived, answered in four corresponding articles (see Section A.I.3). The central research question is answered in Section B.II.5 by consolidating the findings from all subordinated research questions.

As mentioned above, the two most studied DSI programs for EVs are smart charging and the V2G concept. While the economic potential of these DSI programs has already been estimated for EV fleets used to deliver goods outside the premises, transferring these DSI program to the environment of closed transport systems and quantifying the economic benefits for fleet operators still appear underresearched and thus present a research gap. Hence, the following questions emerge:

3a) How can smart charging and the V2G concept be adjusted and transferred to the environment of closed transport systems? What is the economic value for a fleet operator?

To be able to realize DSI actions in practice, one must accurately forecast the ETVs' electricity demand and charging flexibility (duration an ETV is available for charging) for a certain period. Otherwise, an ETV might be unavailable due to an insufficient battery status, which could lead to enormous costs for a commercial fleet operator. This leads to the following research question:

3b) How can electricity demand and the resulting load-shifting potential from ETVs operating in closed transport systems be forecast in order to apply DSI programs?

A particular benefit that arises from the application of DSI programs to ETV fleets operating in closed transport systems is the ability to use the resulting charging flexibility for a broad range of DSI programs. For example, the flexible load can also be used for company-internal purposes, such as optimizing the load curve of the transport company. Therefore, the following research question is investigated:

3c) Which kinds of DSI programs are applicable for ETV fleets in general? What is the economic potential resulting from technically feasible DSI programs for a fleet operator?

At this stage, one can determine the most promising DSI program for making use of the charging flexibility and quantify the economic benefits for a fleet operator. However, it is also useful to evaluate the influence of the resulting cost-saving potentials on the total cost of ownership (TCO) of an ETV fleet. Moreover, some studies (e.g., Propfe et al., 2012; Thiel et al., 2010) have revealed that the economic viability of EVs is currently constrained, mainly because their acquisition costs are significantly higher than those of ICEVs. However, little is known about the economic potential of ETVs operating in container terminals. The corresponding research question can hence be formulated as follows:

3d) What is the TCO of an ETV fleet? How can DSI programs reduce the TCO for the closed transport system?

Based on this analysis, it becomes possible to measure the financial impact of applying DSI programs for ETV fleets and to evaluate the profitability of using ETVs in closed transport systems in general.

Answering the research questions above allows for both the provision of guidelines for adjusting and transferring DSI programs to the environment of closed transport systems as well as an assessment of the economic potential of applying DSI programs to this application context. On the basis of the information gained within the frame of the overall research project, it is also possible to derive important recommendations for **policymakers**. In this regard, the current energy market design in Germany seems ill-suited for smaller providers of flexible loads, such as ETV or EV fleet operators. The corresponding research question can hence be formulated as follows:

4) ***How could the German energy market be redesigned in order to better utilize flexibility options on the demand side?***

I.3 Structure of the Thesis

This work is a cumulative dissertation and contains three parts (see Figure A:2). The middle portion (Part B) covers all studies. As seen in the figure, each research question (marked with a star) presented in Section A.I.2 is answered in a particular section.

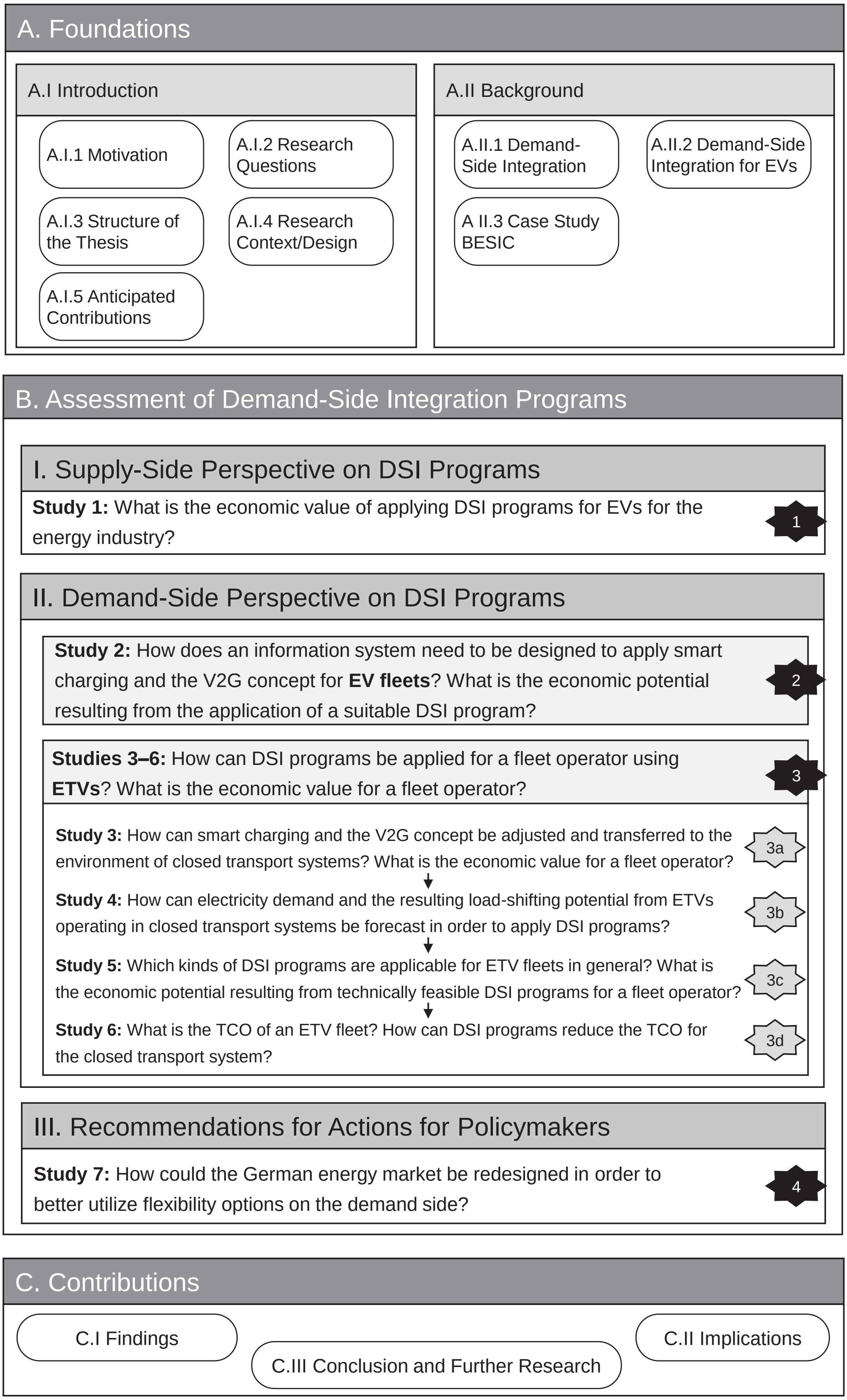

Figure A:2. Structure of the thesis (each star indicates a research question).

Part A covers the motivational introduction for this research endeavor and then details the research gaps and resulting research questions. In addition, the research context and design, thesis structure, and anticipated contributions are presented. The next subsection lays the foundation for a comprehensive understanding of DSI programs in general as well as those concerning the particular case of EVs. It also briefly addresses previous work from the context of applying DSI programs for E(T)Vs and ends with an introduction of the case study used to assess the potential of applying DSI programs for ETVs.

The following **Part B** represents the main body of this cumulative dissertation, comprising seven studies. All of the studies (see Table A-1) address the general topic of DSI programs for electric (transport) vehicles. Two of these essays have been published in leading energy journals and one has been submitted to a renowned transportation journal (Status August 2015: under review). Furthermore, two studies have been published in a leading international IS conference proceeding, and one has been published in an international energy conference proceeding. Finally, one piece has been presented at an international logistics conference.

Table A-1. Overview of studies included in the thesis.

No	Outlet	Status	Ranking (VHB)	Section	RQ	Main contribution
1	Americas Conference on Information Systems 2013	Published	D	B.I	1	Recommendations are given for the energy industry regarding whether investments in DSI programs for EVs are a suitable alternative to an expansion of power plant capacities.
2	Americas Conference on Information Systems 2015	Forth-coming	D	B.II.1	2	An IS design is developed, enabling fleet operators to apply established DSI programs for an EV fleet that operates outside the premises.
3	Energy Policy 2014	Published	B	B.II.2	3a	Suggestions are offered for applying certain DSI programs for ETV fleets, and the cost-saving potentials of applying DSI programs for ETV fleets are revealed.
4	International Conference on Logistics and Maritime Systems 2014	Presented	n.a.	B.II.3	3b	A simulation model for forecasting the logistic processes and the related electricity demand of the ETVs is developed.
5	International Journal of Energy Sector Management 2015	Forth-coming	B	B.II.4	3c	The most promising DSI programs for utilizing the charging flexibility of the ETVs under realistic conditions are identified and assessed, considering technical, regulatory, and economic aspects.
6	Research in Transportation Business & Management	Submitted (under review)	n.a.	B.II.5	3d	The commercial viability of ETVs is assessed, and two strategies that can be used to increase the profitability of an ETV fleet are developed.
7	Erasmus Energy Forum 2015	Published	n.a.	B.III	4	Several recommendations for policymakers are given for enabling smaller providers of flexible loads to participate in DSI.

Part B is divided into three chapters that represent different perspectives on DSI programs for EVs, with a particular focus on ETVs. The first **Chapter I** offers an energy supply-side perspective on DSI programs for all kind of EVs and thus provides an answer to RQ 1, regarding whether and to what extent energy suppliers can benefit economically from applying DSI programs for EVs. To answer this research question, a simulation study is conducted to determine whether the necessary power plant capacity adjustments can be reduced or even eliminated through the implementation of DSI programs for EVs.

In contrast, **Chapter II** provides a demand-side perspective on DSI programs with a predominately economic focus, representing the core of this thesis. The insights gleaned from this part contribute to answering RQs 2 and 3, which inquire how DSI programs should be applied for a fleet operator using E(T)Vs and how fleet operators can benefit economically from the application of DSI programs. This first study of this chapter focuses on applying two established DSI programs (smart charging and the V2G concept) for “normal” EV fleets that operate outside the premises and thus provides answers to RQ 2. Furthermore, it develops an IS artifact that can be used by fleet operators to apply DSI programs for their EV fleets under realistic conditions. For the economics of this DSI program, real-world data from a car-sharing operator are evaluated.

Four related studies (Studies 3–6) focus on fleet operators using ETVs to answer RQ 3: “How can DSI programs be applied for a fleet operator using ETVs, and what is the economic value for a fleet operator”? The German electric mobility project BESIC (see Section A.II.3) serves as a business case in this chapter, both to ensure the feasibility of the DSI programs presented here as well as to evaluate economic implications. The connections among these studies – which represent the main part of this thesis – are illustrated in Figure A:3.

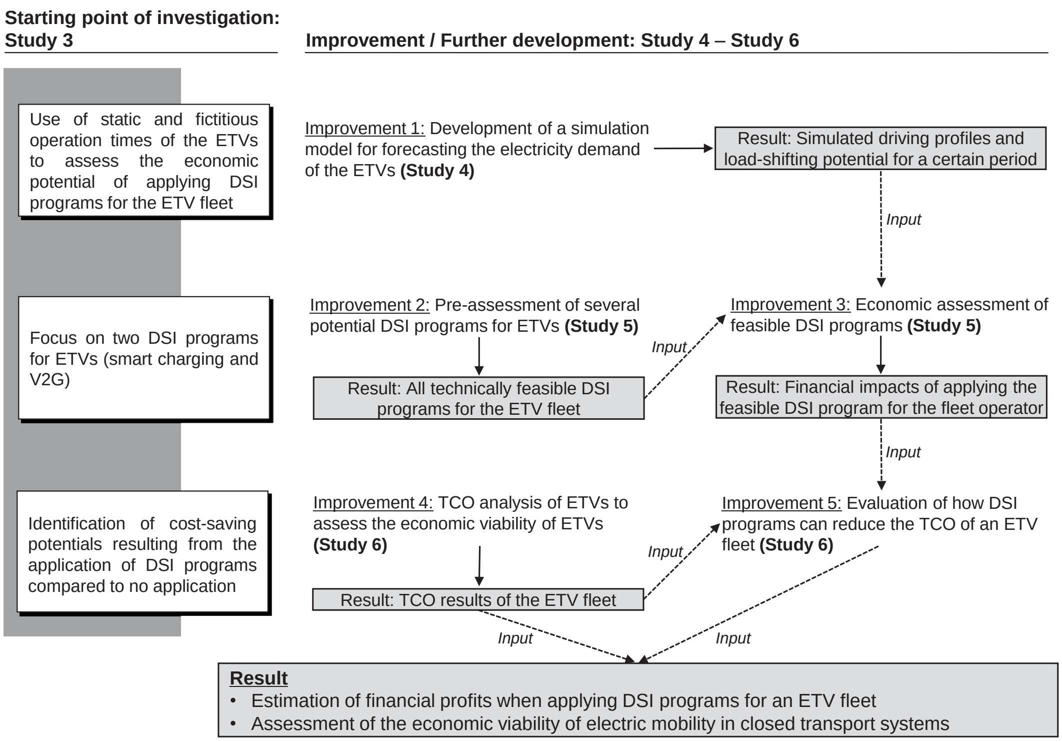

Figure A:3. Connections among the studies to answer RQ3.

The first study in this chapter, which focuses on ETV fleets (Study 3), represents the starting point of the investigation. In this study, the cost-saving potentials of applying two DSI programs are assessed using static and fictitious operation times of an ETV fleet. This work is extended and improved in the following studies, each of which builds upon the results of the previous studies. First, a fleet operator needs information about the ETV batteries’ power consumption and the time frame in which a battery is available for charging to apply DSI programs in practice. Therefore, a simulation model for forecasting the related electricity demand of the ETVs for a certain period is developed in Study 4. Furthermore, the charging flexibility of the ETV fleet can be used for a broad range of DSI programs – e.g., to optimize the load curve of the transport company – and is not limited to the two typical DSI programs for EVs investigated in Study 3. Hence, the fifth study explicitly concentrates on assessing the feasibility of several further potential DSI programs considering the technical, regulatory, and operational requirements of the fleet operator. Moreover, dynamic driving profiles on the basis of the simulation model (Study 4) are used as input data to conduct an economic assessment of feasible DSI programs. Based on this analysis, it is possible to determine the most promising DSI program for making use of the charging flexibility of the ETV fleet and to quantify the benefits for a fleet operator in economic terms. Finally, the sixth study investigates how the application of DSI programs can reduce the TCO for the ETV fleet using input data from Study 5. It also assesses whether eco-friendly (heavy-duty) transport vehicles are a viable alternative to conventional diesel-powered transport vehicles in closed transport systems on the basis of a TCO analysis. Based on these four studies, it is possible to estimate the financial profits from applying DSI programs for an ETV fleet and to evaluate the economic viability of electric mobility in closed transport systems.

The last **Chapter III** of Part B focuses on providing policy recommendations; insights from this section contribute to answering Research Question 4, i.e., how to redesign the energy market in order to encourage smaller providers of flexible loads, such as EV or ETV fleet operators, to participate in DSI programs.

Although Chapters I, II, and III of this thesis each provide a different perspective on DSI programs for E(T)Vs (see Figure A:4), all parts contribute to answering the two overarching objectives of this thesis (see Sections A.I.1 and A.I.2). A detailed discussion of each study's contribution to achieving the overarching goals of this thesis in given in Section C.I.4.

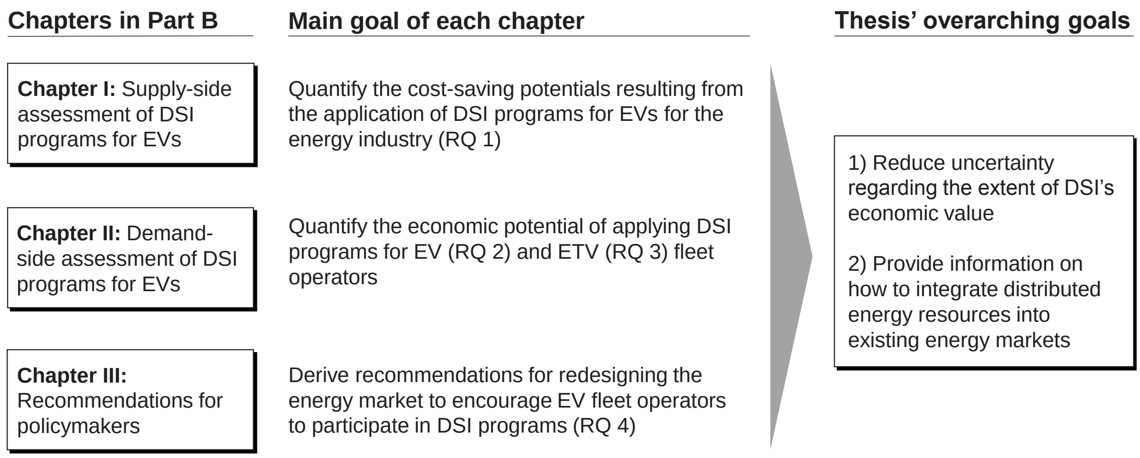

Figure A:4. Main goal of each chapter of this thesis' main Part B.

Finally, in **Part C**, the findings of this research endeavor are discussed. Afterwards, implications for researchers and practitioners are given, leading to the overall conclusions and limitations of this study. The thesis closes with suggestions for further research.

I.4 Research Context and Design

This thesis deals with energy economics-related research. A broad definition of energy economics is given by Sickles (2008), who defines this research stream as “a wide scientific topic zone that contains subjects associated to energy supply and energy demand in societies.” Energy economics is not a self-contained educational subject, as it is intertwined with several subdisciplines of economic science, such as econometrics, environmental economics, finance, macroeconomics, and resource economics. According to Bhattacharyya (2011), this interdisciplinary research field can be defined as a “branch of applied economics where tools are applied to ask the right questions and to analyze them logically and systematically to develop a well-informed understanding of the issues.” In principle, energy economics is not different from any other branch of economics; it is concerned with the basic economic issue of allocating scarce resources (in the given context, energy) in the economy (Stevens, 2000). However, the energy sector/system is complex mainly because the constituent industries tend to be highly technical in nature and each industry of the sector has its own specific feature (Bhattacharyya, 2011). Demand for energy economics research in Germany arises because the provision of an environmentally sound, reliable, and affordable energy supply is seen as one of the major challenges of the twenty-first century (BMWi, 2011). Hence, the practical relevance of this research stream is high, garnering significant attention from policymakers or practitioners.

In this thesis, the focus lies on the microeconomic field of energy economic, which is concerned with energy supply and demand (Pindyck, 1979). More precisely, this thesis concentrates on one of the main topics of energy economics: energy demand-side management (DSM). Demand-side management of energy can be defined as the “systematic utility and government activities designed to change the amount and/or timing of customer’s use for the overall benefit of the society” (CRA, 2005). Even before the liberalization of the electricity market, grid operators supported peak load avoidance and the shifting of demand into time ranges with lower prices through peak load–based tariffs and distinct day and night tariffs. DSM has evolved considerably over the last three decades due to a rapid expansion of renewable energies and steadily rising energy consumption in many countries (see Section A.II.1).

Energy economics is a complex and interdisciplinary research field; the influence of operations research, engineering sciences, business administration, and information systems research has been profound (Erdmann and Zweifel, 2010). Therefore, various methodological approaches are applied in this thesis to answer the introduced research questions (see Table A-2).

Table A-2. Overview of research design and core research questions.

No	RQ	Research design	Data collection	Method of data analysis
1	1	Techno-economic analysis	Secondary data	Simulation and economic analysis
2	2	Techno-economic analysis	Primary and secondary data	Prediction model and optimization
3	3a	Techno-economic analysis	Primary and secondary data	Optimization and economic analysis
4	3b	Mathematical model	Primary data	Simulation
5	3c	Techno-economic analysis	Primary and secondary data	Optimization and economic analysis
6	3d	Techno-economic analysis	Primary and secondary data	Optimization and economic analysis
7	4	Case study	Primary and secondary data	Interviews, field observations and analysis of documents

Regarding the applied research design, techno-economic analyses are performed in several studies; such methods are often applied in energy demand analysis, either alone or in conjunction with econometric methods. Unlike a "pure" econometric approach, techno-economic analyses can incorporate engineering and technical characteristics of energy consumption into their modeling (Bhattacharyya, 2011). Techno-economic analyses are suitable for this thesis as the focus lies on assessing several technologies, e.g., demand-side integration techniques. Furthermore, a broad range of technical characteristics (e.g., energy per vehicle, charging efficiency, or motor efficiency) is considered in this thesis.

Most studies in this thesis combine primary and secondary data sources. This is necessary because some data had to be collected specifically for this investigation (e.g., trip information and energy flows to and from the batteries [e.g., Section B.II.1]), while other data (e.g., energy prices) was already available to be used for this research endeavor. A variety of quantitative methods, such as optimization models, prediction models, and simulation studies are used to analyze the collected data. Finally, one qualitative method (case study) is applied in this thesis.

I.5 Anticipated Contributions

Although this thesis is scientific in nature, it addresses both research and practice. To ensure the practical relevance of the results, most analyses are based on a comprehensive electric mobility project conducted in a container terminal (see Section A.II.3.3). First of all, the thesis is directed to several groups in practice.

- **Transport sector**: Several suggestions – validated both practically and scientifically – should be offered to fleet operators, enabling them to apply DSI programs for their electric (transport) vehicle fleet. The methods developed in this study should also help fleet operators assess the economic potential of applying these programs to their fleets. Furthermore, valuable information should be provided regarding the economic viability of a novel transport technology in closed transport systems: heavy-duty battery electric transport vehicles in combination with a battery-swapping station.
- **Energy industry**: General information should be provided on how to integrate distributed energy resources, such as flexible loads, into existing energy markets. Furthermore, there is detailed information in this thesis about the value of applying DSI programs to ensure the security of energy supply.

- **Policymakers**: Information about the deficits of the current energy market design are revealed and suggestions can be made how to redesign the energy market in order to utilize flexibility options on the demand side to a greater extent. The need for such investigation has recently been highlighted by the publication of a Green Book “A Power Market for the Energy Reform," which is meant to promote the public debate about a new power market design (BMWi, 2014b). Finally, several policy recommendations can be given on the basis of the thesis’ investigation to promote the market penetration of ETVs.

Another key contribution of this thesis is anticipated to be providing **energy researchers** with a sound knowledge base and consolidating the scarce research efforts in the application domain of demand side management (see Section A.I.2). This study is the first to investigate a broad range of DSI programs for ETVs operating in closed transport systems. Furthermore, new techno-economic and econometric approaches investigating the economic profitability of applying DSI programs for E(T)Vs are developed in this thesis. This is significant because most prior analyses do not consider the energy market design and are thus based on unrealistic assumptions. A detailed description of this thesis’ contribution to theory and practice is given in Section C.II.

II. Background

As described in the previous chapter, this work focuses on DSI programs that can be applied for electric (transport) vehicles. Therefore, this chapter presents the fundamentals and related literature of DSI in general and DSI programs for EVs and ETVs.

II.1 Fundamentals of Demand-Side Integration

The energy system consists of both supply-side activities (generation, bulk transmission, and distribution) and demand-side activities. For many years, the focus on the energy system lay on the supply side; the objective was to arrange for an adequate energy supply so that energy demand – which was considered as given and uncontrollable – could be satisfied (Sioshansi and Vojdani, 2001).

Today, however, the energy system is developing from a centralized, constant, and fossil-based energy-generation base to a more decentralized, environmentally friendly, and intelligent electricity system, known as smart grid (Geelen et al., 2013). Many countries have been stimulating this transition of the electric power system, mainly through the promotion of renewable energies. For example, the European Union has issued a target for renewables to make up 20% of the total electricity generation by the year 2020 (European Union, 2009). For the energy industry, this trend indicates a fundamental paradigm shift; whereas in the past supply attempted to meet demand, electricity demand must now increasingly adjust to the intermittent supply from renewable energies (Pecas Lopes, 2007). Furthermore, technical innovation in the field of information and communication technology (ICT) – such as advanced metering infrastructure (AMI) or smart meters with a communication gateway – enables energy customers to play a more active role in the future energy market by adapting energy consumption according to the information received (e.g., energy prices) or incentives (Kranz, 2011; Daim and Iskin, 2010). It is thus becoming evermore apparent that the focus on the energy system will lie on demand-side activities in the future.

One possibility for balancing power supply and demand while simultaneously increasing energy efficiency and allowing customers to play a more active role in the energy system is provided by the concept of demand response. According to the U.S. DOE (2006) and the FERC (2009), DR can be defined as "changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

DR is part of the more general concept of demand-side integration, which also includes energy efficiency programs and load management programs (e.g., peak clipping) with the goal of optimizing energy demand without reacting to external price signals or incentive payments (Bradley et al., 2013; dena, 2013; York and Kushler, 2005). For example, energy customers can optimize their internal load curves to reduce the grid fees that depend on peak loads. Alternatively, energy customers can optimize their own distributed generation system that uses renewable energy by shifting energy demand in periods when power generation from renewables is high. The overall goals of DSI are hence to alter the timing, level of instantaneous demand, or total electricity consumption to ensure that demand meets available generation and the grid's power-delivery capabilities at any time (Ipakchi and Albuyeh, 2009).

In principle, energy end-users have three possibilities for adjusting their electricity usage (Mohagheghi et al., 2010; Gellings and Parmenter, 2008; Albadi and El-Saadany, 2007):

1) Reduce demand for energy during on-peak hours through load curtailment strategies (peak clipping);
2) Move energy consumption from on-peak to off-peak periods, often on the basis of pricing information (load shifting); and
3) Use onsite standby generation or energy storage systems, thus limiting customers' dependence on the main grid.

The basic principle of the two commonly used DSI options, i.e., peak clipping and load shifting, are illustrated in Figure A:5.