Flexibility trading for aggregators of electrical vehicles within the Universal Smart Energy Framework

Graduation thesis

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TU Delft JEDLIX

Flexibility trading for aggregators of electrical vehicles within the Universal Smart Energy Framework

A research on trading flexibility in a USEF compliant market at distribution level for aggregators of electrical vehicles.

by

I.M.A. Stegmann

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Irma Stegmann
Rotterdam, November 2017

"Help users to efficiently charge their electrical vehicle through the global rollout of smart charging solution for all the electric vehicle manufacturers and flex energy connections with local utilities."

Mission of Jedlix 2017

EXECUTIVE SUMMARY

Increased use of the distribution grid due to the uptake of distributed energy resources and the expected penetrations of Electrical Vehicles (EVs) could lead to congestion problems in the distribution grid. Congestion refers to issues related to the overheating of components or voltage issues in the distribution network. Avoiding these issues is crucial to maintain a stable, economical and reliable electricity grid. By using the flexibility of aggregated EVs large investments in grid reinforcement can be avoided. However, a holistic approach is necessary to manage the procurement of flexibility services for all stakeholders involved. One approach is the Universal Smart Energy Framework (USEF), a framework that integrates the existing electricity market with a market for flexibility services from the aggregator to the Distribution System Operator (DSO). This master thesis presents a study on the flexibility market as described by USEF from the perspective of a commercial aggregator of EVs. USEF presents a framework in which flexibility potentially provides financial opportunities for aggregators of EVs. However, it is not clear what the financial impact on the charging costs of an aggregator of EVs is and in what way an aggregator has to adapt its charging logic when trading with DSOs. Therefore, the aim of this thesis is to answer the following question: how can an aggregator of EVs offer flexibility services to a USEF compliant market at distribution level? This report presents an in-depth analysis on USEF, determines the impact of network constraints from USEF on the charging costs of an aggregator of EVs and improves the charging strategy under USEF constraints.

USEF lacks an appropriate price-mechanism which leads to many opportunities for gaming for aggregators of EVs. It describes how a DSO could return a financial reward to the aggregator for decreasing the load at moments when congestion is expected, resulting in aggregators receiving a fee for not charging. Yet, this financial incentive is inefficient as aggregators would be triggered to stimulate users with flexible charging demand to charge in congested areas. To reduce these negative effects we suggest that location dependent dynamic grid tariffs might reduce the negative effects imposed by a flexibility market as described by USEF. In case of a dynamic tariff all connected users would receive an incentive to alter their consumption. Thus, the flexible and inflexible loads are both incentivised to alter their consumption pattern.

However, if the aggregator would trade its flexibility to the DSO the following criteria should be included in the smart charging strategy:

- Include network constraints in the charging strategy that are able to adapt to flexibility request of the DSO.
- Limit the power of all the EVs connected to the same congestion point when flexibility services are sold.
- Formulate the optimization as mixed-integer linear program (MILP) or MIQP for global optimal results.
- Include a direct charging mode in the charging strategy.

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Keywords:
flexibility market, Electrical Vehicles, EVs, aggregator, Smart Charging, distribution grid, USEF, Jedlix

LIST OF ABBREVIATIONS

AC	Alternating Current
BRP	Balance Responsible Party
CSO	Charging System operator
DR	Demand Response
DC	Direct Current
DER	Distributed Energy Resources
DSO	Distribution System Operator
EAN	European Article Numbering
EV	Electrical Vehicle
EVSE	Electrical Vehicle Supply Equipment
G2V	Grid to vehicle
LP	Linear Program
LV	Low Voltage
MCM	Market-coordination mechanism
MILP	Mixed Integer Linear Program
MIQP	Mixed Integer Quadratic Program
MV	Medium Voltage
PTU	Program Time Unit
PV	Photovoltaic
RES	Renewable Energy Source
TSO	Transmission System Operator
USEF	Universal Smart Energy Framework
V2G	Vehicle to grid

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Chapter 1 Introduction

The first chapter provides an introduction of the relevant topics of this thesis. Section 1.1 igives an overview of essential background information and briefly discusses the Universal Smart Energy Framework (USEF) as well as the role of aggregators of electrical vehicles (EVs) in the energy market. This thesis has been conducted in collaboration with Jedlix, an aggregator of EVs. Section 1.2 therefore presents the company and its current bidding strategy. In Section 1.3 the problem description is given, followed by the main research question in Section 1.4. To answer the research question, the methodology chosen for this project will be described in Section 1.5, , including an outline of the different chapters of report.

1.1 Background

The climate is changing leading to the urgency to reduce greenhouse gasses. The European Union has set the goal to cut greenhouse gas emission with 20%, increase the share of sustainable energy up to 20% and achieve energy saving up to 10% (European Commission, 2010). European energy markets are liberalized: the transmission, the distribution and the supply of electricity are separated between different actors. At transmission level a market design for balancing supply and demand is established. Balance Responsible Parties (BRPs) are responsible to keep the balance between electricity consumption and production. In case of imbalance the BRPs are forced to resolve this, for example by increasing the generation capacity and so the production or by trading electricity on the wholesale market. However, when the BRP fails to balance its portfolio, the Transmission System Operator (TSO) activates reserves to restore the balance in the system. The BRP is then obliged to pay the TSO an imbalance price. TSOs are responsible for the operation of the transmission grid. One of their most important tasks is to maintain stability in the high and medium voltage (MV) grid.

To achieve the climate goals of the European Union the electricity system is transitioning towards a new system where electricity is increasingly produced by distributed Renewable Energy Sources (RES). Decentralized energy production is mostly coming from wind and solar, sources of electricity with an intermittent nature, that can cause production peaks of electricity. Electrification, for example the growth of all-electric houses and the adoption of EVs, are other trends emerging at distribution level (International Energy Agency, 2016; Klaassen et al., 2016). EVs are becoming increasingly popular in the mobility sector.
Not emitting carbon dioxide is one of the major advantages of EVs. Moreover, they produce little noise and can be charged with electricity produced from RES. Despite those advantages the market penetration of EVs is challenging the electricity grid. Charging EVs can cause congestion problems at distribution level in terms of voltage problems and the overheating of electrical components. Preventing these issues and accelerating the creation of smart grids can be achieved when EVs are charged in a controlled manner. Smart grids are electricity networks that utilize information and communication systems to integrate the production, consumption and distribution of electricity. This power system is able to use bidirectional power flows and is further described in Chapter 2.

Prosumers are customers that produce and consume energy themselves, i.e. households with photovoltaic (PV) systems and services related to smart home applications. In the future, the group of people that is considered to be a prosumer will grow and therefore have a significant impact on the capacity of the current distribution network (PwC, 2015). Prosumers with a connection to the distribution grid can cause high electricity production or consumption peaks. When flexibility from prosumers is exploited, for example by demand response (DR), it could help to reduce electricity peaks. Flexibility is "the capacity to increase or decrease the load in a certain time frame" (Klaassen, 2016) and demand response is the modification of the load pattern of consumers (Koliou, 2016). Using flexibility to charge an EV is called smart charging and refers to the modification of the charging pattern by an external signal. Smart charging can help to increase the use of RES, reduce distribution grid capacity issues as well as the charging costs for customers (Hu et al. , 2014; Meer et al., 2016; Movares, 2016; Sarker et al., 2016; Sundstrom & Binding, 2012). If EVs do not smart charge, they will increase the stress on the distribution grid enormously (Clement-Nyns et al., 2010). Aunedi et al. (2015) show that uncontrolled charging of EVs with penetration levels of 5% to 30% will cost around 200€/EV/year, compared to 92€/EV/year up to 156€/EV/year when the EV is charging smart

1.1.1 Aggregators

The threshold for individual parties, such as residential and small commercial customers, to exploit the value of their flexibility by entering the energy market is fairly high. The volume of flexibility of individual customers is too small to trade on the electricity market, besides it can be risky and complex. However, when this flexibility is accumulated by an external party, referred to as aggregators, monetizing flexibility becomes possible (Bessa et al., 2010; Eid et al., 2015; van den Berge et al., 2016). By collecting flexibility of several customers the volume of flexibility can become large enough to trade on the electricity market. The aggregator also shields the customer for the risks of trading on these markets. It is possible to aggregate the flexibility coming from EVs and trade this on the electricity market. By creating smart charging strategies aggregators of EVs can achieve a wide variety of objectives. For example: increasing the consumption of RES or reduce the overall charging costs. It all depends on the business model of the aggregator and the driving needs of customers that contract the aggregator. Several of these possibilities are described and discussed in more detail in Chapter 2.

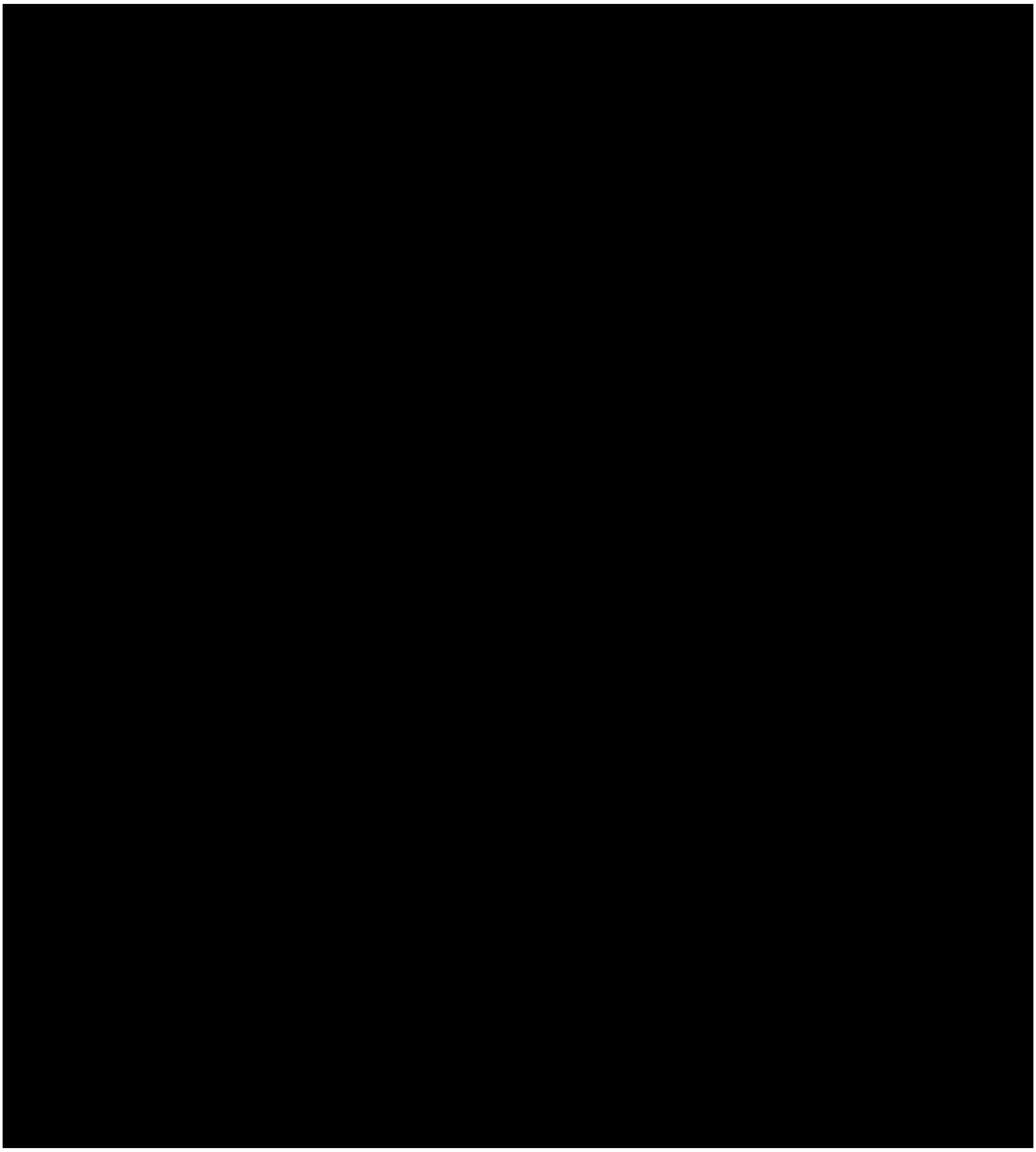
1.1.2 Universal Smart Energy Framework

One framework that integrates actors and that can be built on top of the current electricity system is the Universal Smart Energy Framework (USEF). USEF is an integral design for smart energy markets and is based upon international common standards (USEF, 2015). The framework aims to provide a market design that includes existing and upcoming actors within smart grids. It is currently under development and several pilots in the Netherlands are implementing the framework (Energie Koplopers, 2016; Maandag et al., 2016; van der Laan & de Heer, 2016). In USEF aggregators are responsible for trading flexibility from prosumers to the TSO, DSO and BRP (USEF, 2015). The framework also defines possible business models for aggregators and describes market mechanisms. One of the advantages of USEF is that it is based on open IT systems making the integration of a wide variety of new energy products possible. In addition, it aims to realize a more efficient energy system by providing an integral market design where existing and new market roles are included. USEF could therefore help to accelerate the transition from the traditional grid toward a smart grid. A standardised interaction with all relevant market stakeholders is proposed that could potentially decrease the barriers for aggregators to trade flexibility for congestion management of the DSO (USEF, 2017). Chapter 3 further elaborates on the relevant actors, market design, business cases and market mechanisms that are described in USEF.

1.2 Jedlix

[redacted]

The mission of Jedlix is to "Help users to efficiently charge their electrical vehicle through the global rollout of smart charging solution for all the electric vehicle manufacturers and flex energy connections with local utilities"(Jedlix, 2017). The aim of the company is to become an international player which is why Jedlix intends to be able to smart charge all types of EVs at any location. The services of Jedlix are linked to a free mobile application for smart phones. By entering the car model, departure time and the amount of electricity that should be directly charged (direct charging) are registered when the charging session is started by the user. EV owner's can then easily start a smart charging session that is controlled by Jedlix. [redacted]



1.3 Problem description

At first sight USEF provides a broad and detailed framework with a key role for aggregators. However, with regard to the pilot in Lombok, we can conclude that many questions arise on the implementation of the framework. The value of flexibility in terms of prices is yet unsolved: DSOs are hesitant to offer prices and the current regulation of the Netherlands does not allow the DSO to acquire flexibility services from aggregators. In the USEF pilot in Lombok the aggregator of EVs, Jedlix, delivers a prognosis on the expected charging profile of an EV. In USEF this role is fulfilled by an independent party to avoid opportunities for gaming, which could lead to manipulation of the market. In addition, the role of the independent aggregator, an aggregator without commercial interest, is unclear. The value of USEF is therefore difficult to identify for aggregators such as Jedlix. One of the major questions relates to the quantitative impact of a new market at distribution level and thus relates to on the current charging strategy of Jedlix.

Consequently, the aim of this thesis is to analyse the impact of a market at distribution level as described by USEF on the current charging strategy of Jedlix. It also proposes three adaptations of the current charging strategy to increase the amount of bids that can be made in an USEF compliant market.

1.4 Research question

To answer the problems identified in the section above the following research question have been formulated. First the main research question is presented, followed by sub-questions.

1.4.1 Main research question

RQ1	*"How can an aggregator of EVs offer flexibility services to a USEF compliant market at distribution level?"*

1.4.2 Sub-questions

SQ1	*What are possible solutions to improve USEF?*
SQ2	*What are criteria for an optimal smart charging strategy for an aggregator of EVs when trading in a USEF compliant manner?*
SQ3	*What is an optimum smart charging strategy for EVs when trading flexibility at distribution level in a USEF compliant market?*
SQ4	*What is the quantitative impact on the charging costs of an aggregator when charging in an USEF compliant market?*

1.5 Methodology and thesis outline

This section describes the methodology used and provides an overview of the research done in this thesis.

The first chapter gives an overview of relevant developments in the changing energy sector and provides background information regarding USEF and its influence on the future business development of Jedlix, focussed on emerging opportunities at distribution level.

The second chapter presents a literature study focussed on the way aggregators of EVs can trade in current markets and how this might emerge in future markets at distribution level. An extensive literature study and desk research are needed to ensure that the knowledge created in the following chapters is expanding on existing knowledge. Chapter 2 starts with an explanation on the current transition of the electricity system and the congestion issues that emerge due to new technologies entering the market. Moreover, it explains how smart grids at distribution level can benefit from aggregators. Commercial aggregators have an interest in trading flexibility, therefore, we study the evolving markets of the trade of flexibility at distribution level. The chapter concludes with an explanation of smart charging and how it can be used within a smart grid.

The third chapter elaborates on USEF. The focus lies on describing the market USEF proposes and illustrating how USEF can facilitate the role of aggregators to trade of flexibility. The aim of this chapter is to explain USEF as it is described by the USEF foundation. Furthermore, chapter 3 emphasizes the fact that the framework currently lacks an appropriate price-mechanism, which makes it difficult to analyse the quantitative impact of this market for an aggregator.

With regard to chapter 3, the next chapter explores USEF in greater detail by identifying its major weaknesses and strengths. Chapter 4 is based on desk research and discussions with experts in the field of USEF. Based on a discussion on how USEF can possibly improve, several improvements are proposed. Some of the proposed improvements are necessary to determine the quantitative impact of the model on the aggregator.

The fifth chapter presents a framework in which we include the main criteria and assumptions that are necessary to explain how an aggregator of EVs can function within USEF. The chapter starts with explaining the goals and objectives for this research. The goal is to find the quantitative impact of USEF on the current charging strategy of Jedlix and to improve the charging strategy to increase the amount of flexibility offers that can be placed when including network constraints in a smart charging strategy. It also contains findings from a stakeholder analysis that is based on interviews and discussions with experts in the energy field. Since the market design of USEF lacks an appropriate price-mechanism, we state the most important assumptions made to deal with these issues. Due to these reasons we define a way of researching the quantitative impact of the USEF market without receiving price incentives from this market. To do so, we propose an optimization problem that is able to optimize the costs of charging EVs connected to the same congestion point with and without network constraints coming from USEF. The difference between the results of these optimization problems indicates the lower boundary of the price that at least should be paid by the DSO to incentivise the aggregator to provide flexibility services. The reason for proposing an optimization problem is that optimization problems can minimize an objective, such as charging costs, while respecting constraints (Papadimitriou et al., 1998). We propose a mixed-integer linear program (MILP) and a mixed-integer quadratic program (MIQP) to ensure global optimum and to be able to include binary decision variables. In total, four optimization problems are proposed: the current charging strategy, linear penalty strategy, quadratic penalty strategy and the charge-at-least strategy. All of these strategies are able to include user preferences, V2G and network constraints from USEF: the first charging strategy is based on the current charging strategy of Jedlix and includes a direct charging mode. This direct charging mode is enabled right after the EV is connected to the EVSE and is included in the application for end-user of the Jedlix application. The other three strategies propose adaptations of the direct charging mode to improve the ability of the aggregator to include network constraints from USEF into the charging strategy. We describe the functionalities of the strategies and present design specifications that consist of a list of requirements and wishes as described by Boeijen et al. (2016). The requirements are similar to constraints in the sense that the strategies have to be able to meet those. The wishes represent statements that preferably should be met by the strategies. This list is used in Chapter 7 to evaluate the performance of the strategies.

The sixth chapter proposes a mathematical model, it starts with the explanation of a suitable optimization method and is followed by a proposal for a smart charging strategy for EVs. The most important contribution of this thesis is to present a smart charging strategy for EVs connected to the same congestion point that is able to include network constraints and user preferences. If aggregators are the key actor in USEF to trade flexibility, they should be able to perform optimum and at least be compensated for including network constraints in their current charging strategy. The mathematical model proposes an optimum charging strategy by MILP for EVs connected to the same congestion point including the network constraints from USEF. Reason to use MILP is due to the opportunity to include several binary features in the model, for example when enabling and disabling the direct charging mode. The model is programmed in General Algebraic Modelling System (GAMS) software, a software tool that contains a solver that is able to solve MILP problems. The expected outcome is a feasible optimum solution that finds the minimal charging costs for all EVs connected to the same congestion point, when trading flexibility in a USEF compliant manner. In addition, we propose adaptations of the mathematical model to increase the amount of possible flex-offers. In others words: these strategies are able to return more feasible solutions with the network constraints imposed by USEF.

The input data necessary to test the performance of the optimization model is retrieved from the USEF pilot in Lombok where USEF is implemented. In chapter seven the data is analysed and processed to create realistic input values for the experiments. The chapter concludes by explaining the experiments that can help to evaluate the performance of the optimization strategies. The first experiments examines the current charging strategy. The second experiments compares the improved formulation of the optimisation problem to check whether it outperforms the current charging strategy.

Chapter 8 presents the results from the experiments and discusses the relevant findings. Here, the quantitative impact of USEF on the proposed methods is explained and the implication for the user and the aggregator of the improved charging methods are given. Finally, in chapter 9 the most important conclusions for this research are given.

1.6 Relevance

1.6.1 Scientific relevance

Independent literature and research on the implementation of USEF is limited. This research provides an analysis on USEF from the perspective of an aggregator of EVs. While there is an abundant amount of research available on aggregators of EVs, no research was found on the implementation of USEF from the perspective of an aggregator of EVs. Recommendations on the improvement of the framework could potentially lead to the improvement of USEF.

The optimization proposed includes a novel way of smart charging by combining several user defined charging modes, such as direct charging, flexible charging and V2G, under network constraints defined by USEF.

1.6.2 Practical relevance

The proposed optimization could help to accelerate the implementation of a flexibility markets at distribution level. This could potentially result in better capacity management of DSOs and therefore lead to a more economical and safer operation of the distribution grid. This research is relevant for Jedlix since the DSO market offers potential business opportunities. EV owners could also benefit from the outcome of this thesis since Jedlix shares savings made on the electricity market with the end-user. Thus, smart charging EVs might become financially more attractive to them.

Chapter 2 Literature review

The following chapter introduces USEF, it aims to give an understanding about the need of such a framework. The chapter starts with presenting relevant literature regarding this topic. A literature review is conducted and thus ensures that the research of this thesis is building upon existing knowledge. Firstly, current changes in the electricity grid and market are presented, smart grid and flexibility are described in more detail. The following sections give a definition of congestion and shows how it can be avoided. Furthermore, USEF is briefly introduced. The last section discusses smart charging by discussing a wide variety of smart charging configurations.

2.1 Introduction to the transition of the electricity grid & market

This section introduces the existing electricity grid and its related market, followed by introducing active distribution grids: the smart grid. We explain how the electricity grids are developing towards networks in which DSOs need to adjust to a more active role by using market tools. Relevant topics such as demand response (DR) and flexibility will be discussed. The last part of this section focusses on aggregators, offering flexibility services to the grid.

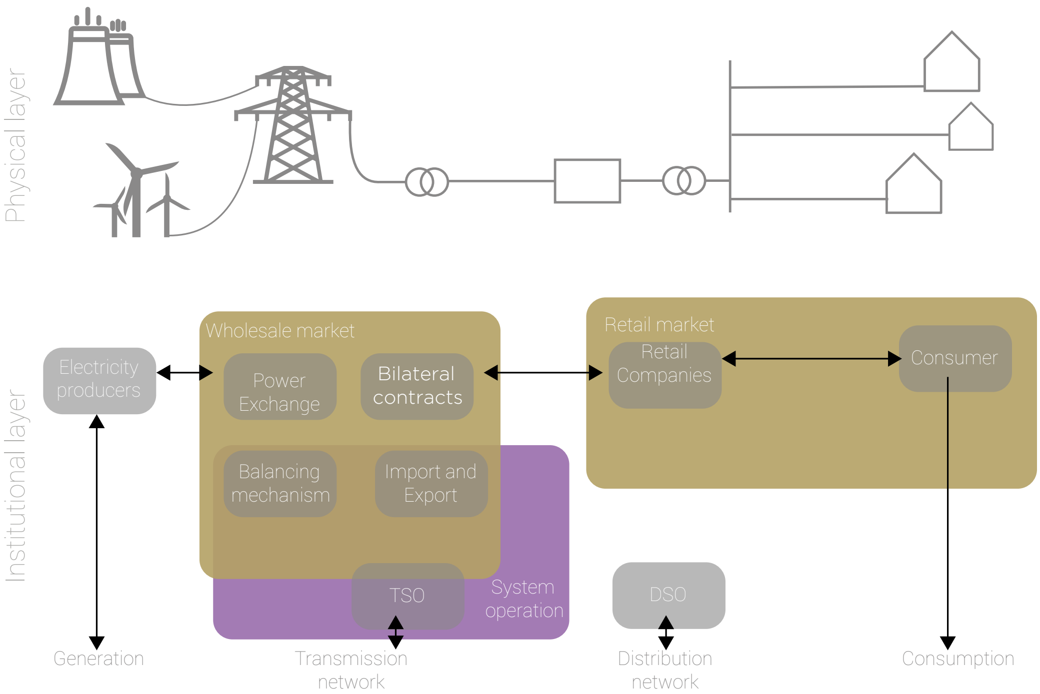
2.1.1 Liberalisation of electricity markets

The first incentives for the creation of a liberalised market in Europe for the trade of electricity came in 1996. At that time most member states had bundled actors for the transmission, distribution and supply of electricity. Reasons to liberalise the electricity market and unbundled the forces are as follows(IEA, 2005):

- To create a common market for electricity in Europe to increase overall efficiency and decrease electricity price.
- To enable customers to contract each supplier to create a competitive market with fair prices.

The traditional electricity grid was characterised by centralized generation that supplied electricity to households in a waterfall construction from the transmission grid, to the distribution grid and ultimately to consumers. Distribution grids in the traditional grid did not include production units. Yet, the market penetration of RES and the more active role of residential prosumers is changing the traditional distribution grid towards a smart grid. In the relevant literature the smart grid is a widely researched topic, however, its exact definition is difficult to trace. Most authors characterise the smart grid as a new power system where bi-directional flows of electricity and information are exchanged in a grid that is automatically able to adapt to changes with the help of ICT-based management functions (Fang et al., 2012; Rohjans et al., 2010). Figure 2 illustrates, the traditional grid ranging from TSO to small consumers, such as household, besides it shows the electricity market.

Consumers have a contract with a retail company that has a contract with a BRP or that is a BRP. BRPs can trade their electricity on the wholesale market. For further reading on trading electricity in the wholesale market see de Vries et al. (2016). The TSO operates the electricity grid. Traditionally the TSO is responsible for the transmission of electricity by means of high voltage cables and system operation. This also involves maintaining a balance in the system (Koliou et al., 2014). Market-based mechanisms for maintaining the balance on a transmission level are established as described in the European directive (2003/54/EC) and (2009/72/EC). Moreover, BRPs are in charge of delivering e-programs to the TSO. This E-program contains information on the predicted amount of electricity consumed and produced by customers and suppliers that have a contract with the BRP. The E-program needs to be balanced at all time, which means that the consumption and production have to be equal. In the case of imbalance the TSO resolves the imbalance and penalizes the BRP that is causing the imbalance.



Arrows describe information and financial flows.

Figure 2 Schematic representation of the institutional and physical layers of the electricity grid, image based on (de Vries et al., 2016).

Subsequently, if a BRP helps to restore the balance in the system, the TSO returns this party a fee for its service. This balancing mechanism is used to maintain the frequency in the electricity grid, but it does not deal with congestion issues that may arise at distribution level, e.g. in the case of high electricity consumption or production peaks in a residential area. The TSO is not able to measure power flows and voltage levels in the distribution grid, since its responsibility is limited to the high-voltage (HV) grid and the transfer to the medium-voltage (MV) grid. In addition, conventional congestion methods used by the TSO are only capable of curtailing the production of RES, which could lead to less electricity production and consumption from renewable sources (Haque et al., 2016a). Transmission grids have different physical characteristics than distribution grids. Therefore it is not possible to simply copy the policies on transmission level to the distribution grid. One of the most important differences is the topology of the network. The transmission grid has a meshed nature with many loops. The location of the load and generation are therefore not as closely related to each other as in a distribution grid, see Section 2.1.2.

2.1.2 Smart grids (active distribution grids)

It is necessary to balance the use and production of electricity while not violating the capacity constraints of the distribution grid to maintain economical operation and ensure the security of supply. The distribution grid is maintained and operated by the DSO and the main tasks are:

- to plan the adjustment of capacity of the grid
- to maintain the security of supply within the distribution system
- to manage the flow of power to meet the quality requirements and
- to keep the voltage of the distribution grid at the European standard EN50160.

The capacity of the traditional distribution network is based on the peak-demand and the consists of a low voltage (LV) network and MV network (Schavemaker et al., 2008).

The topology of the LV network is usually radial, meaning that households are connected to the electricity grid by lines and cables to one central supply substation, such as for example a transformer or a feeder. Figure 3 presents a schematic representation of multiple grid topologies.

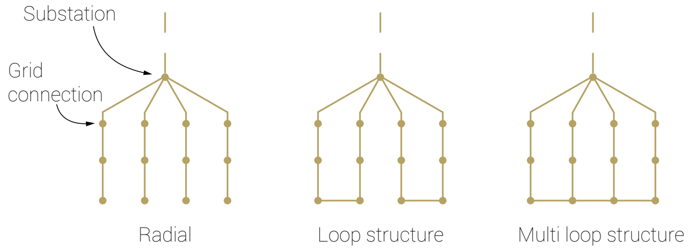


Figure 3 Grid topologies based on (Schavemaker et al., 2008).

One of the main advantage of radial networks is that they are relatively cheap to build in comparison to other LV topologies. Despite this benefit, radial networks are less reliable compared to structures with more loops between the power lines (Schavemaker et al., 2008). Figure 3 illustrates a scenario in which one of the cables can no longer be utilized due to congestion.

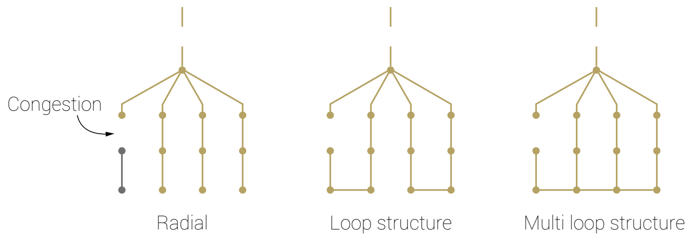


Figure 4 Functioning of grid topologies in case of faulty cable.

In the radial network some of the grid connections will be cut off from electricity, whereas the loop structured network is still capable of delivering the electricity to the connection. The more loops, the safer the network is. Furthermore, monitoring radial networks is generally low. Data from the LV grid is typically coming from aggregated measurements of substations. To ensure the privacy of consumers connected to the grid, data is available after a certain delay (Eurelectric, 2013a).

The production of electricity of distributed sources of RES, like solar and wind, is of an intermittent nature and does not have a correlation with consumption patterns, thereby leading to electricity peaks in the distribution grid. It is expected that the frequency of these peaks will continue to grow in the coming years. Active control on distribution grids by DSOs could help to effectively avoid congestion while enabling stable transport of electricity (Haque et al., 2016a). In Eurelectric (2013a) the authors define three networks in the transition of the distribution grid. The first network defines a network as it currently is a passive distribution grid, where the capacity of the grid is based on the peak load. This approach might not be future proof due to the changes in the current electricity grid. The second network described is the reactive network. The distribution network deals with peak load or peak production of DER by curtailing the production whenever there is an overflow of the grid. This results in less production of DER and in a negative business case for DER. The last grid discussed is a grid where DSOs have an active role in the planning and operation of the network and furthermore presents a grid acting as a smart grid. By actively measuring and controlling the performance of the grid the functioning of the network can be measured and improved. The role of the DSO in this grid is no longer limited to connecting customers and reinforcing the grid where needed. It is changing towards active management of the capacity of the grid e.g. by buying flexibility services from entities in the grid. In smart grids the DSOs adapt to a more active role for the methods of planning, managing and measuring the capacity of the distribution grid. In Ramos et al. (2016) the authors conclude that DSOs require market tools to accustom to this active role.

An important concept in the smart grid context is DR. In the past the traditional power system adjusted the production of conventional power plants to the electricity demand, however, with increased electricity production from uncontrollable sources of energy, such as solar and wind energy, this approach seems outdated. In addition, Schweppe et al. (1980) stated that the philosophy of supply following demand leads to inefficient use and over-dimensioning of the power system. They introduced the idea of a system where generation and load react to each other to obtain balance. This idea can be seen as the basis to what is called DR. DR is the alteration of electricity consumption patterns based on an external signal (Koliou, 2016, 2014). DR can emerge from several sources of flexibility. At transmission level TSOs have agreements with large electricity consumers to alter the consumption pattern of e.g. large industrial plants. At distribution level the DSO is able to make use of flexibility sources, such as micro-combined heat and power (CHPs) or controlled refrigeration systems (Zhang et al., 2014). From a technical perspective, flexibility is the adjustment of power at a certain moment that lasts a certain time at a specific location in a grid (Eid et al., 2016), as presented in Figure 5.

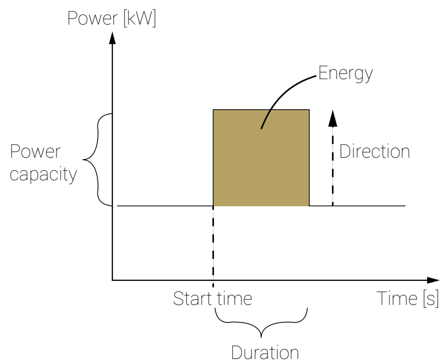


Figure 5 Technical characteristics of flexibility, based on (Eid et al., 2016).

Characteristics that Eid et al. (2016) define for flexibility are: the direction of power (for EVs this could be G2V and V2G), capacity power in [kW], starting time (e.g. for EVs the arrival time at a charging station), duration (the duration of the power) and the location of the flexibility (e.g. the location in the electricity grid).

2.1.3 The function of aggregators in smart grids

An aggregator is an actor that accumulates flexibility services from end-users. It operates as an intermediate party between the end-user and the electricity market. In liberalised markets the aggregator is able to trade the flexibility services to TSOs, DSOs and the energy market. Aggregators monetize the flexibility of the end-user by offering flexibility services to the power system and provide incentives for end-users to offer their flexibility to them (USEF, 2015). In Eurelectric (2014), aggregators are retailers or third parties that accumulate DERs and consumption from prosumers to provide electricity or services in the system to actors in need of flexibility. Both formulations are similar, but differ somewhat from the concepts (Bessa et al. 2010). The literature discussed by Bessa et al. (2010) the focus lies on the interaction between system operators and aggregators. In this context, the interaction with BRPs is not explicitly mentioned. Wang et al. (2016) state that an aggregator could be held responsible maintaining a secure and balanced electricity grid and, at the same time, fulfilling the needs of the end-users. The role of suppliers of electricity is closely related to the role of aggregators. Suppliers provide end-users electricity when there is demand for it. Aggregators define the best moment to use electricity and activate electricity consumption when that is most beneficial. The difference lies in the ability of an aggregator to alter the consumption pattern, whereas the suppliers follows the consumption of the user.

2.2 Congestion

This section firstly elaborates on what congestion at distribution level is, followed by an introduction to congestion management, which is a manner of avoiding congestion related problems. Congestion can also occur in the transmission network, however, the physical characteristics of the network differs from the distribution grid. Therefore the technical implications are different. The scope of this thesis is smart grids on distribution grids the discussion is focussed on congestion at distribution level.

2.2.1 Congestion in the distribution grid

In the distribution network congestion is used to describe voltage problems and overload issues. Voltage problems occur when the voltage exceeds around 10% of the line limit and when the thermal limits of power components are exceeded overload problems arise (Huang et al., 2014). In the netcode for distribution system operators, EN 50160, this limit should be met during 95% of the operational time (Büscher, 2016). DSOs are responsible for maintaining distribution grids and securing the distribution of electricity. Avoiding power quality related issues, such as: imbalance, harmonics and voltage profiles, power losses and overloads, are crucial to ensuring economical and secure transport of electricity (Clement-Nyns et al., 2010). Congestion issues related to the penetration of decentralised energy production and the increased use of electricity by households are becoming a challenge for DSOs. EVs that charge in an uncontrolled manner cause high power peaks and overheating problems in the LV network in residential areas (Lampropoulos I et al., 2010; Procopiou et al., 2016; Verzijlbergh et al., 2014). Typically these power peaks related to uncontrolled charging occur between 18h and 20h, when the domestic load in LV grids is already shows a consumption peak.

2.2.2 Congestion management in the distribution grid

In the traditional grid TSOs have always been responsible for congestion management. With the tradition waterfall construction of electricity transport, DSOs could rely on TSOs for the prevention of congestion. However, with the transition of the electricity system DSOs are challenged to prevent congestion due to the market penetration of decentralized electricity production and the growth of peak loads. From the perspective of the DSO, maximum utilisation of existing assets is necessary to ensure a reliable, economical and safe distribution grid (Haque et al., 2016a). Verzijlbergh et al. (2014) also found that congestion management at distribution level is necessary due to a weakening correlation between the prices in the wholesale market and the electricity consumption.

Avoiding congestion can be achieved by reinforcement of the grid, nevertheless, this is an expensive and time-consuming operation. Active control of the distribution grid is a more cost-effective way of integrating DER and utilizing the existing distribution grid (Eurelectric, 2013a). In Huang et al. (2014) congestion management methods at distribution level are divided into two control strategies: indirect control and direct control. Indirect control is a market-based approach where a price signal is used to influence the flexible demand. An example of an indirect control method is a distribution grid capacity market, where the DSO allocates the capacity of the grid to the aggregator (Verzijlbergh et al., 2014). In this market the DSO has a dynamic tariff: during high loads the DSO is able to charge the aggregator higher prices for the use of the electricity grid. The aggregator can decide to alter the consumption pattern of end-users to avoid congestion issues. There are many methods for congestion management. The following section starts by explaining what direct control implies and is followed by a description of three methods for indirect control. Section 2.2.3 ellaborates one emerging market for the trade of flexibility services for the DSO, namely USEF.

Direct control

Direct control methods are used in cases where indirect control is not sufficient to resolve congestion. This includes the alteration of the distribution grid and the control of active and reactive power, see for further reading (Huang et al., 2014). Considering that aggregators of EVs can only operate in the green and yellow regime, see Section 3.2, we consider the direct control method to be beyond the extend of the scope of this thesis.

Intra-day shadow pricing

The objective of intra-day shadow pricing, as discussed by Biegel et al. (2012), is to optimize the portfolio of a BRP to minimize the losses on the imbalance market and to divide the local capacity of the distribution among the BRPs active in that area. The DSO proposes a price based upon the summation of all loads. If the grid is congested, the price of the distribution grid will increase. The opposite will happen, if the grid is underloaded. This process is iterated until the price of the use of the distribution line reflects the marginal price, BRPs would be willing to pay for the use of the distribution grid. The outcome of the iteration is a price called the shadow price. This process is represented by an optimization problem so that global optimum is reached and no information is shared between BRPs. In this context, DSOs only receive payments for the grid tariffs and BRPs can trade capacity between each other by implementing shadow prices. Biegel et. al (2016) show that there is an interaction between the DSO and the BRP. The BRP uses the flexibility of prosumers to trade on the proposed market, which includes trading on the day-ahead spotmarket.

Flexibility market

Another indirect method discussed by Huang et al. (2014) is a flexibility market. The DSO buys flexibility from aggregators to resolve congestion issues. The market design discussed is FLECH, a Danish flexibility market design, where the DSO procures flexibility from the aggregator via a platform named FLECH. The flexibility market coexists in parallel with the existing wholesale market. However, the aggregator only trades with the DSO. The procurement of flexibility is done via a clearing house and trades can be initiated on demand by the DSO or by the aggregator (Zhang et al., 2014). The market design of FLECH limits the role of the aggregator since the only interaction described involves selling flexibility services to the DSO, whereas in reality, due to the liberalisation of the electricity market, aggregators could also sell their services to other stakeholder.

Auctions for capacity of the grid

In Philipsen et al. (2016) the authors propose a market design for congestion management at distribution level with an auction for the capacity of the grid. An optimum problem is proposed to minimize the cost of the aggregator of EVs that includes the electricity costs, grid capacity costs and fee for missing deadlines. In addition the model includes static and unknown charging demands. The authors conclude that the gradual release of capacity can decrease the charging cost of an aggregator slightly compared to an auction where the capacity is released instantly.

2.2.3 USEF

Haque et al. (2016b) propose an USEF compliant MILP algorithm for curtailment of load in a LV network from the perspective of the DSO. This algorithm optimizes the power that should be curtailed, which is a form of direct congestion management, in selected congestion points. Results show that this optimization leads to reduction of loads on the transformer, losses in the grid and costs related to curtailment. This approach may lead to a more optimal solution of congestion management for the DSO, but connected customers may experience curtailment of their loads.

Nguyen et al. (2016) propose a mixed-integer quadratic program (MIQP) that optimizes the day-ahead planning of the deviation between the expected and the real load. The algorithm is verified in a small scale pilot where the flexibility sources are micro-CHPs, resulting in prevention of congestion on distribution level in a USEF compliant manner. The goal is to minimize the difference between the day-ahead prognosis and the actual demand and production during the operation phase, while not violating network constraints.

USEF is modelled in Hippolyte et al. (2016) as an ontology-based multi-agent system. The authors conclude that the implementation of USEF is still an open issue, since it does not specify the functions that are required when participating in the framework. The interaction between the aggregator and the prosumer, in this research, is limited to the aggregator and the energy management system in the household. The aggregator uses the flexibility form the energy management system in the house to trade on a local market with the DSO. This model does not include the possibility to trade flexibility with the BRP or the TSO.

Eid et al. (2016) researches if one of the pilot projects of USEF, for further reading see (Energie Koplopers, 2016), is in line with the European regulation on retail competition. The authors conclude that compared to the current situation it is not beneficial for supply companies to contract consumers that have a contract with an independent aggregator, since this will affect the consumption pattern (Eurelectric, 2015). In addition, Eid et al. (2016) conclude that DSOs are currently not allowed to procure flexibility due to their monopoly position in the liberalised market. Recommendations made on how the model could be included under European regulation are: allowing DSOs to buy flexibility, include specifications on how supply companies should be compensated when an independent aggregator (aggregator without contract with BRP) controls the load of a user and define what transactions between the aggregator and DSO/BRP are allowed.

2.3 Smart charging

The concept of DR is introduced in Section 2.1.2. We elaborate on a special type of DR: smart charging of EVs. Literature on smart charging is abundant. To structure this literature review we chose to only focus on papers that used smart charging approaches for aggregated vehicles. Several formulations for aggregated vehicles are used in literature: "fleet of EVs", "aggregated EVs", "aggregator" and "fleet".

The charging process of a battery powered EV depends on a chemical reaction. This process is much slower compared to the fueling process of internal combustion engine or fuel cell cars. Smart scheduling of this process is important for the comfort of the owners of EVs. Charging EVs and congestion have a strong link: charging EVs could lead to congestion problem (Clement-Nyns et al., 2010), but could potentially also resolve congestion related problems. Smart charging is making use of flexibility to charge an EV. The charging pattern is altered as a result of an external indicator, e.g. the price or the amount of renewable energy available.

Before a thorough research in smart charging, an explanation is needed on the physical limits of the charging process. The charging speed of EVs is limited to the absorption power of the battery in the EV and the power output of the EVSE. In the Netherlands the distribution grid is powered by alternating current (AC). Despite the fact that direct current (DC) distribution network offer advantages for smart grids over AC networks (Mackay et al., 2015), DC distribution networks are beyond the extend of the scope of this research because the implementation of DC in LV and MV networks is rather unusual.

The power output of EVSEs is depending on the configuration of the connection to single phase or to three phase AC grids. Table 1 presents an overview of typical configurations for EVSE in the Netherlands with the related power outputs.

Table 1 Overview of EVSEs configurations.

Capacity of connection	Single phase	Three phase
16 A	3.7 kW	11 kW
32 A	7.4 kW	22kW

Most households that have an EVSE have a 3.7kW or 11kW EVSE. Public charging stations usually operate on 11kW or 22kW. Note that the capacity tariff of a 22kW EVSE is annually four times as expensive compared to an 11kW connection[1].

2.3.1 Smart charging methods

In Wang et al. (2016) smart charging algorithms describing the interaction between EVs and smart grids were reviewed based upon three main perspectives: smart grid focussed, customer focussed and smart charging controlled by an

1 Retrieved from https://www.liander.nl/consument/aansluitingen/tarieven2017/?ref=14635

aggregator. EVs can interact with smart grids controlled by a central system, where there is direct control of all the EVs within a specific area (decentralized control) where EV owners are in complete control of the charging of their own EV, and where there is hierarchical control, a hybrid between the aforementioned control strategies. Hierarchical control can be achieved when the flexibility of EVs is accumulated by an aggregator. In a network of smart charging EVs, there is a need for precise and real-time information exchange systems dedicated to EVs. When an aggregator is controlling a fleet of vehicles communicating with the network this should include information on availability and quality-of-service to ensure safe and stable operation of the grid. Since charging strategies are based on personal information, aggregators have to protect private information to guarantee the privacy of their customers.

In (Bessa et al., 2010) nine methods are determined to charge an EV from the perspective of an aggregator of EVs; all of them are based on other external signals:

1. Dumb charging/charge anywhere anytime/opportunity charging/uncontrolled charging: the EV is charging uncontrolled without intervention of an aggregator.
2. Dual tariff charging/charging within time window: when charging is based on a price for off/on peak hours.
3. Smart charging in microgrids and multimicrogrids: when aggregator is completely in control of the EV charging and is offering services directly to a DSO (Peças Lopes et al., 2009).
4. On/off charging is stopped manually in the case of emergency
5. Charging is limited by the location or sort of location of the EV: this limitation is based on the preferences of the EV-owner. For example the EV should only be charged at home.
6. Charging based on time: the charging of the EV is turned on and off at certain moment, for example on when electricity is cheap.
7. Charging based on availability of energy: when the EV is charged by the amount of energy produced.
8. Charging based on the price of energy: when the speed of charging is depending on the price of electricity.
9. Charging based on signal on the share of sustainable energy available: in the example of (Markel et al., 2009) the charging of EVs is defined by the availability of energy from RES.

2.3.2 Smart charging and congestion at distribution level

Uncontrolled charging can lead to congestion problems in the distribution grid (Clement-Nyns et al., 2010). It is clear that smart charging could help to improve the stability of the distribution grid. Despite the fact that smart charging could prevent congestion problems at distribution level, Section 2.3.1 shows that there is a wide variety of charging methods available. Veldman and Verzijlbergh (2015) found that smart charging strategies based on price signals result in higher peak loading of components in the distribution grid, leading to more necessary grid reinforcements which ultimately result in higher costs for the DSO as compared to the situation where EVs are charged in an uncontrolled manner on the distribution grid. Hu et al. (2014) propose a framework for a distribution grid that coordinates smart charging by taking into account the objectives of the aggregator, the DSO and the EV owner. For this framework a linear program (LP) is developed that ensures that the requirements of the EV owner, congestion constraints and operation on the market by an aggregator of EVs is possible. LP is an optimization technique which will be further explained in Section 6.3. The stages in the framework resemble the stage of USEF and the optimization presented integrates a direct control and a price-based control mechanism. In the case of congestion in the distribution grid, correct signals are necessary to ensure stable operation of the distribution grid. At this moment in time, there are also other barriers for trading flexibility at distribution level for aggregators of EVs. Consequently, there is a need for a dedicated platform for the administration and operation of the trade of flexibility, transparent information on the availability of the distribution grid and a clear definition of flexibility services (i.e. conditions for the procurement of flexibility services, contractual agreements). Moreover, it is unclear what the minimum requirements are for placing bids. The entry to trade flexibility should be open and independent. Another issue to be pointed out is a missing method for creating a common baseline. Flexibility is the difference between the initially planned load profile and the adapted load profile. Therefore, a common method to create the baseline load profile is necessary (Knezović et al., 2017). USEF offers information on the implementation of a communication system between DSOs and maretparties. In addition, it describes a method for creating a common baseline (USEF, 2015). Therefore, this framework seems to reduce the barriers that are described by Knezović et al. (2017).

2.3.3 Vehicle to grid

EVs are powered by batteries, therefore it is possible that EVs will not only consume electricity, but also deliver electricity to ensure the stability of the distribution grid. For example: if we consider the scenario of a neighbourhood, there is a surge of electricity around 18 o'clock. As a consequence, the aggregator might be requested to deliver flexibility services that provide electricity. The aggregator could decide that optimal operation might be to discharge one of the vehicles with V2G. Such bi-directional power flows can improve the economical outcomes of hierarchical control strategies. Nevertheless, social acceptance of V2G is low (García-Villalobos et al., 2014) since V2G can lead to battery degradation. Variables that determine the level of battery degradation are: the depth of discharge (DoD) of the battery, the type of loads, cycles of discharge and the type of battery with related battery characteristics. Due to these dependencies it is difficult to predict what the exact resulting degradation of the battery is. Schill (2011) performed an sensitivity analysis on the degradation prices and concluded: "Current real-world battery degradation costs may seriously diminish arbitrage opportunities and related welfare gains.". The prices for battery degradation costs in his analysis vary between 0 €/MWh to 50€/MWh. The author added that these prices could decrease when battery technology will improve in the future.

2.3.4 User preferences for smart charging

Many papers that propose smart charging algorithms undermine the importance of acceptance of smart charging technology by the owner of the EV. Therefore, it might be impractical for real world application. Research on the user acceptance of smart charging is limited. In this section we discuss the available literature on this topic.

One of the functions requested by a small focus group with experienced EV drivers was to add the feature to immediately charge a minimum amount of energy as a buffer. This energy should be charged as fast as possible to be prepared for an emergency situation (Schmalfuß et al., 2017). This argumentation is supported by the research executed by Will & Schuller (2016). The authors conducted a large scale research to determine what the relevant factors are for user acceptance of smart charging, focussed on end-users. The most requested features by users of smart charging are to be able to set a minimum range and the ability to overrule the smart charging process by directly charging the EV. In Will & Schuller (2016) the authors conclude that there is an insignificant relation between the discount price EV owners receive from smart charging, but they discover a strong significance of the integration of RES in the smart charging service. In Wang et al. (2015) the authors propose a user-friendly smart charging algorithm through an mobile application which enables users to choose their preferred charging policy based on price preferences. The authors assume that this reflects the urgency of users to charge fast. The outcome of the research is that sessions with a higher price usually reflected larger volume of charging and lower timespan. However, one of the EVs was not charged since the price never dropped below the setting of the user. This is something that needs to be avoided to minimize range anxiety among EV drivers. Range anxiety is the fear of EV drivers that the battery of the capacity of their EV is insufficient to transport them to the desired destination without having to connect the EV to a EVSE. To conclude, research on user acceptance is limited, however, it does suggest that adding a features, such as the opportunity to immediately charge a certain amount of electricity, could lead to improvement of user acceptance of smart charging (Schmalfuß et al., 2017; Will & Schuller, 2016).

2.4 Conclusion

The energy transition creates new challenges related to the electricity grid. It was found that smart grids at distribution level could help to accelerate the integration of DER and EVs without increasing the grid investments. To do so DSOs have to come up with new congestion management systems. Direct control measures seem to not be in line with the current liberal energy market. Aggregators could sell flexibility services to DSOs to relieve the grid at moments with predicted congestion. There are several indirect control methods DSOs could use to relieve the grid. However, those methods create more complexity for the aggregator (Philipsen et al., 2016; Biegel et al., 2012) or limit the trade of flexibility services from the aggregator to the DSO (Huang et al., 2014). An emerging market for the trade of flexibility in the Netherlands is USEF. Research on this topic is focussed on the direct control measures that could be taken when not having enough flexibility available (Haque et al., 2016b), minimizing the difference between the expected and realized loads of micro-CHPs (Nguyen et al., 2016) or limiting the trade of the flexibility to the DSO (Hippolyte et al., 2016). USEF is different than the market proposed in Huang et al. (2014), since the aggregator is not limited to only be able to trade with the DSO. Therefore, the current research on the implementation of USEF is limited in the sense that it does not incorporate the possibilities that are described in the framework.

Aggregators of EVs are capable of charging EVs based upon external signals. On the one hand, this special form of DR can be used for many purposes (Bessa et al., 2010), some of these charging strategies may lead to congestion issues (Veldman & Verzijlbergh, 2015). On the other hand, it is also possible to include network constraints while optimising revenues for an aggregator (Hu et al., 2014). However, there are still many barriers for aggregators of EVs to trade on a market at distribution level (Knezović et al., 2017). One of the most important barriers is that there is no dedicated platform for the administration and operation of the trade of flexibility at distribution level. This is an issue that could be resolved by USEF, since this flexibility market describes a trading platform for flexibility. Smart charging is a well researched field of study. However, the implementation of smart charging in a USEF compliant market is an untouched subject. It is unclear whether other barriers for aggregators of EVs are resolved by USEF. Thus, Chapter 3 elaborates on USEF in greater detail. Another important aspect is that most smart charging strategies do not include features requested by users, such as the ability to charge a part of the energy directly after connecting the EV, as proposed by Schmalfuß et al. (2017) and Will & Schuller (2016). From a pratical point of view, the application of Jedlix includes a feature that enables this direct charging mode. For this reason including such features is important when creating smart charging strategies.

Chapter 3 USEF

USEF is a framework that describes how flexibility services can be use by the DSO for congestion management. In this chapter we presents USEF, the information is based on articles published by the USEF foundation and scientific articles written on USEF. We start with an introduction of the framework and the related goals described by USEF, the sections after the introduction elaborate on how USEF aims to achieve these goals. It describes the operational phases of the distribution grid and the market-coordination mechanism used for the trade of flexibility at distribution level. To discuss most topic covered by USEF documentation we also describe: the baseline methodology, the stakeholders as discussed by USEF, the findings of USEF on electric mobility, the market interactions possible in the framework and we briefly address the pilot projects that currently implement USEF. The focus will be on aggregators and more specifically aggregators of EVs.

3.1 Introduction to USEF

In 2014 the USEF foundation was founded, multiple Dutch stakeholders from the energy sector identified that with the energy transition a common standard will be necessary for the rise of smart grids. This common standard should support interconnectivity between European markets. From 2015 onwards the foundation started collaborating with experts that are active in the energy industry. USEF aims to "Unlock the value of flexibility use by making it a tradable commodity and by delivering the market structure and associated rules and tools required to make it work effectively" (De Heer, 2015). The framework integrates the existing electricity market with a flexibility market at distribution level by means of active operation of the smart grid to avoid congestion without having to configure the grid. In Figure 6 the USEF market is positioned within the existing electricity market described by (de Vries et al., 2016).

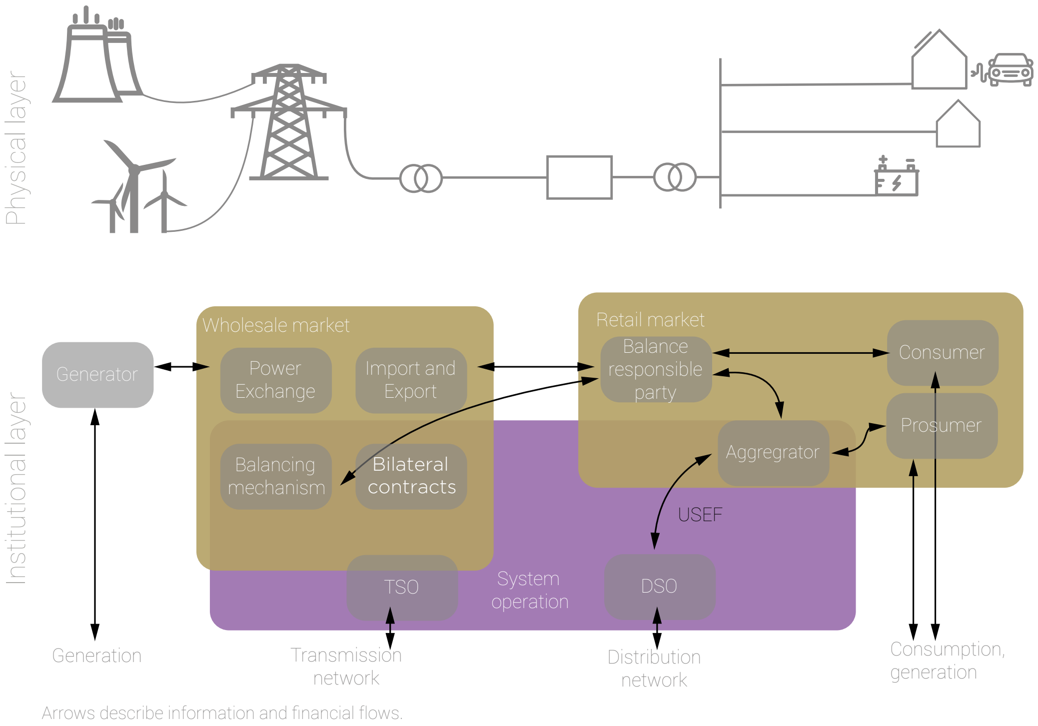


Figure 6 Image based on (de Vries et al., 2016) with the addition of a market for flexibility services at distribution level where the aggregator can trade with the DSO referred to as USEF in the figure.

The image is adjusted by adding the USEF flexibility market at distribution level. Four key goals are distinguished by USEF (USEF, 2015):

- Connect smart applications and services via open IT architecture avoiding lock-in technology.
- Increase the speed of energy transition by sharing knowledge and providing a common standard.
- Create opportunities for the smart energy market by providing a framework in which roles, interaction and the resulting values are described.
- Reduction of expenses by market-based control mechanisms to optimize the complete energy system and secure energy production, delivery and management at low cost.

Market designs for the trade flexibility at distribution level is a topic that has been widely researched, some of them are presented in Section 2.2.2, USEF aims to deliver a more top-down approach than other proposed solutions (De Heer, 2015). It describes roles of various stakeholders in the electricity system, operation regimes of the distribution grid and market-based control mechanisms (MCM) with related stages (USEF, 2015).

3.2 Operational regimes of USEF

Traditional distribution grids are either in normal operation or in outage mode (Nguyen et al., 2016), USEF on the other hand describes five operational regimes. The operational regimes describe how the distribution grid is operating and if flexibility can be traded. It describes four operation modes related to the capacity of the grid:

- **Green:** in this regime the capacity of the grid is sufficient to secure stable operation of the distribution grid without limitations from the DSO and without the need for flexibility services.
- **Yellow:** DSO will actively seek for opportunities to reduce the load within the distribution grid by requesting flexibility on a market. In this regime aggregators can offer flexibility services to the DSO.
- **Orange:** DSO limits load autonomously when there is insufficient flexibility available to resolve the congestion issues. The capacity of the network could be limited, this could mean that the capacity of households is limited and as a consequence result in sub-optimum operation of the aggregator.
- **Red:** emergency operation where protection systems will be activated within the distribution grid. During the red regime aggregators are operating in an sub-optimum manner, since the capacity of the distribution grid could be decreased and the occurrence of a blackout is possible.

During the green and yellow stages aggregators, BRPs and DSO are able to trade flexibility (USEF, 2015), whereas in the orange and red regime the DSO activates its own measures to stabilize the distribution network.

3.3 Actors in USEF

The roles and responsibilities in USEF are defined for all the actors in the electricity grid and the electric mobility sector. In the following section we discuss the relevant actors for this thesis. The definitions for prosumer, active demand and supply (ADS) and BRP are explained as described in (USEF, 2015) and the actors following those steps are defined as presented as in (van der Laan, 2015).

Prosumer: consumers who consume and produce electricity e.g. households with PV systems, but also large industries.

Active demand and supply: active demand and supply are all the systems that can provide DR related services. The systems are usually owned by prosumers and they can decide to let an aggregator be in control of the device. The owner of the ADS ultimately has control on the service and is able to limit the control that can be regulated by the aggregator.

Supplier: supply companies contract consumers and prosumers to provide them with the electricity needed. Supply companies have to contract a BRP to be able to trade electricity in the Dutch market.

BRP: To ensure the security of the electricity supply for all consumers, suppliers and producers of electricity are obliged to have a contract with a BRP. By means of an E-program the BRP provides information on electricity consumption and production within its portfolio. The portfolio of the BRP consists of all the contacted generation units and loads that contracted by the BRP.

DSO: DSOs are in charge of an efficient, economical and secure security of the supply of electricity in the distribution grid. Traditionally the distribution grid was designed to ensure the supply of electricity during peak demand. The transition of the energy system is changing the role of the DSO, USEF describes that the role of the DSO is to maintain active operation of the electricity grid.

Common Reference Operator: The common reference operator is in charge of the operation of the common reference. Information on congestion points and EANs connected to the same congestion points is published by the common reference operator, since this information is related to the distribution grid this role is related to the DSO.

CSO: CSOs are parties that manage the infrastructure and the operation of EVSEs. If the CSO has a commercial interest can also be in charge of the electricity supplied to the charging station, see Section 3.8 for more details. Another option is that the DSO is in charge of the charging infrastructure, the role of the DSO and CSO are combined in that arrangement.

Electrical mobility Service provider: Actors that provide services related to electric mobility. For example: providers of charging passes that allow EV owners to charge their EV at public EVSEs. Electric mobility service providers could also bundle the services offered, by for example offering a charging pass and smart charging services.

Aggregator: Aggregators are parties that bundle flexibility by contracting prosumers from different sources on the LV or MV grids. This party is in charge of monetizing the value of flexibility for prosumers. By offering services from the flexibility the aggregator can trade with BRPs, the TSO and the DSO, For more information on aggregators see Section 3.5.

Meter data company: This actor is only necessary in markets where the DSO is not responsible for operation of charging services. In this case the meter data company is responsible to measure the electricity consumption and to further process this data.

3.4 Market interactions in USEF

Figure 7 presents the market interactions between actors of USEF.

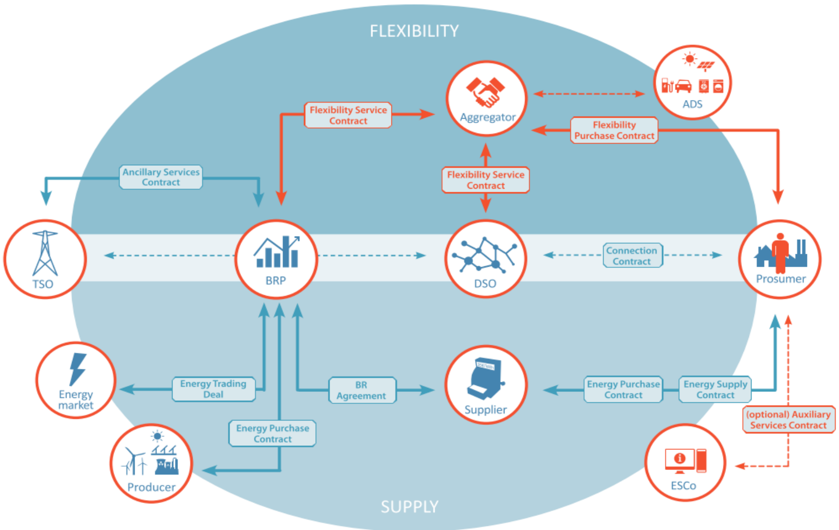


Figure 7 Interactions possible in USEF retrieved from (USEF, 2015). Orange figures describe interactions in smart grid environment. Blue figures describe traditional market interactions.

The traditional interactions of the electricity grid are incorporated with new interactions that enable the trade of flexibility at distribution level. In this figure the aggregator trades flexibility coming from ADS owned by prosumers to the BRP and the DSO. The trades of flexibility from the aggregator to the energy market are all done by via the BRP.

3.5 Aggregators in USEF

In USEF an aggregator is an actor that accumulates forces of low volumes of flexibility from prosumers for and trades flexibility services to the TSO, DSO and BRPs (USEF, 2015). Figure 8 shows the role of the aggregator as explained within USEF.

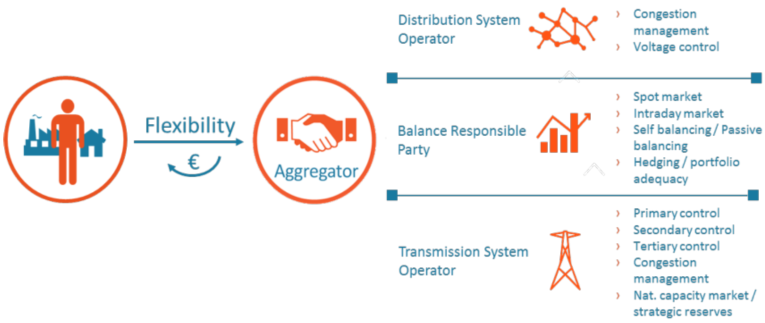


Figure 8 Role of aggregator within USEF. Figure retrieved from (De Heer et al., 2015)

For the TSO flexibility can be used to increase the stability of the transmission grid, since TSO markets are already established USEF does not further elaborate on flexibility trades with the TSO. DSO can use flexibility for grid capacity management and BRP can optimize their portfolio by using the flexibility sources of the aggregator. For the services offered by the aggregator the prosumer that is the actual source of flexibility receives a financial reward.

USEF also determines five emerging business models for aggregators in Europe (USEF, 2015):

1. **Combined Aggregator-Supplier:** The aggregator offers a combined supply and flexibility contract to the prosumer. The activation of flexibility could for example lead to an decrease of the electricity bill for the consumer or supply could be triggered by the amount of available energy from RES.
2. **Combined Aggregator-BRP:** Model that merges the task of an aggregator and a BRP. This option is rather simple because there is no need for complex contracting and the BRP does not need to be compensated for the activation of flexibility.
3. **Aggregator as service provider:** The aggregator accumulates flexibility of and offers this as a service to other parties to access and to trade this flexibility. In this model the aggregator does not trade the flexibility services itself, it is merely responsible to accumulate flexibility from users.
4. **Delegated Aggregator:** Relatively complex model where aggregators sell flexibility to clients, such as the DSO and BRP. The BRP and aggregator create an agreement on the optimum use of flexibility leading to a complex shared vision on what this optimum is. It could also imply that the aggregator needs to compensate the BRP for the activation of flexibility and might result in complex contractual agreements.
5. **Prosumer as Aggregator:** Only suitable for prosumers with enough flexibility as industrial and commercial parties, where the prosumer is enabled to trade flexibility directly on a market described by USEF.

One of the discussion points in USEF is the role of the independent aggregator, there is no clearly defined possible business model defined in USEF (De Heer, 2015). The independent aggregator is not linked to a supply company or BRP. The issue that arises in case a prosumer offers flexibility to an independent aggregator is that the aggregator influences the consumption pattern of electricity (Eurelectric, 2015), which could have a negative effect on the contracted BRP of the prosumer. Managing the balance of the energy supplied and consumed by the prosumer will become more complex and could lead to more imbalance of the portfolio of the BRP. Currently the solution for aggregators is to arrange a contract with the BRP that is in charge of maintaining the energy balance of the prosumer.

This highly limits the aggregator to contract prosumers and this situation also favours the role of the BRP over the role of the aggregator.

Another assumption made in the position paper on the independent aggregator in USEF is that only one supplier can be active per European Article Numbering (EAN) (De Heer, 2015). EAN in this context is an electricity connection, for example each household has a specific EAN and public EVSEs also have one EAN. If only one supply company can be active on a particular EAN this is forcing the aggregator to have an agreement with the BRP that is active on that specific EAN. In this agreement the aggregator and supplier make arrangements on how activation of flexibility should be aligned and in the case of alteration should be compensated. This situation could result in complex contractual arrangements, similar to the delegated aggregator model, where aggregators compensate the supply company or BRP for the imbalance caused due to the activation of flexibility (Eurelectric, 2015). Another option is that supply companies or BRPs forbid contracted customers to offer their flexibility to aggregators, which could lead to exclusion of aggregators, or customers could switch to a supplier or BRP that allows the services of the aggregator.

The topic of the independent aggregator is still under development. Two models, EG3 (Smart Grid Task Force, 2015) and virtual transfer point (VTP), seem to provide an answer in facilitating the business case of aggregators (De Heer, 2015), for further reading see (De Heer, 2015; EG3, 2013). The reason to not further elaborate on the role of the independent aggregator is that we expect that the business model of the independent aggregator will become irrelevant, due to the fact that, in the Netherlands starting from 2018, it will become possible to contract several supply companies for the same EAN (Autoriteit Consument & Markt, 2017). For owners of EVs the consequence of this legislation is that it will be possible to contract a supplier for charging their EV and another supplier for the electricity supply for domestic demand. For aggregators this is a potential chance to turn into a supply company for one specific flexibility source or for several flexibility sources. This new law reinforces the business case of the combined aggregator-supplier and the aggregator BRP, in addition It is also in line with the Virtual Transfer Point model.

3.6 Market-coordination mechanism in USEF

Next to the operational stages USEF also distinguishes five market-coordination mechanism that consists of several stages that describe the process of the procurement of flexibility services by the DSO from the aggregator. The phase defined are: contract, plan, validate, operate and settle phase (de Heer et al., 2016). Note that in documentation of USEF these steps are referred to as market-based control mechanisms (Backers et al., 2014) and as market-coordination mechanisms, both definitions are abbreviated to MCM. Rather than explaining each step, below we present an example for procurement of flexibility services of Jedlix to a DSO.

Example Jedlix in the USEF pilot in Lombok

Contract: During the contract phase EV owners can use the Jedlix application to enter their user settings (availability of the EV and the energy demand) and with that they grant permission to Jedlix to smart charge their EV. In USEF this agreement is called flexibility purchase contract. Jedlix has a contract with the supply company of the related household or public EVSE and the BRP that allows them to trade the flexibility without harming the E-program of the related BRP.

Plan/validate:

In the plan phase the first thing the aggregator needs to check is which EVSEs are connected to the same congestion point. The congestion points and related EVSEs are pre-defined in a database referred to as the common reference, which will be explained in greater detail in Section 3.3. The aggregator predicts the load during each PTU by creating a smart charging strategy of each EV and aggregates this load for all EVSEs connected to the same congestion point. When this strategy, called D-prognosis, is created it is sent to the DSO. The DSO performs a grid safety analysis. In case the DSO predicts that the capacity of the grid is insufficient capacity available for the planned activities, it can decide to acquire flexibility. This results in a flex-request by means of a signal in an IT environment in which the DSO requests to decrease or increase the electricity consumption for each PTU. In case this signal is negative this means that the DSO requests the aggregator to lower the use of electricity in that specific PTU for all the EVSEs connected to the same congestion point. If the aggregator is capable of offering enough flexibility to resolve the congestion issues it can place a flex-offer. If the DSO accepts the flex-offer of the aggregator, it places a flex-order. The aggregator updates its D-prognosis by including the accepted flex-offers. Figure 9 illustrates the plan/validate phase described in this section.

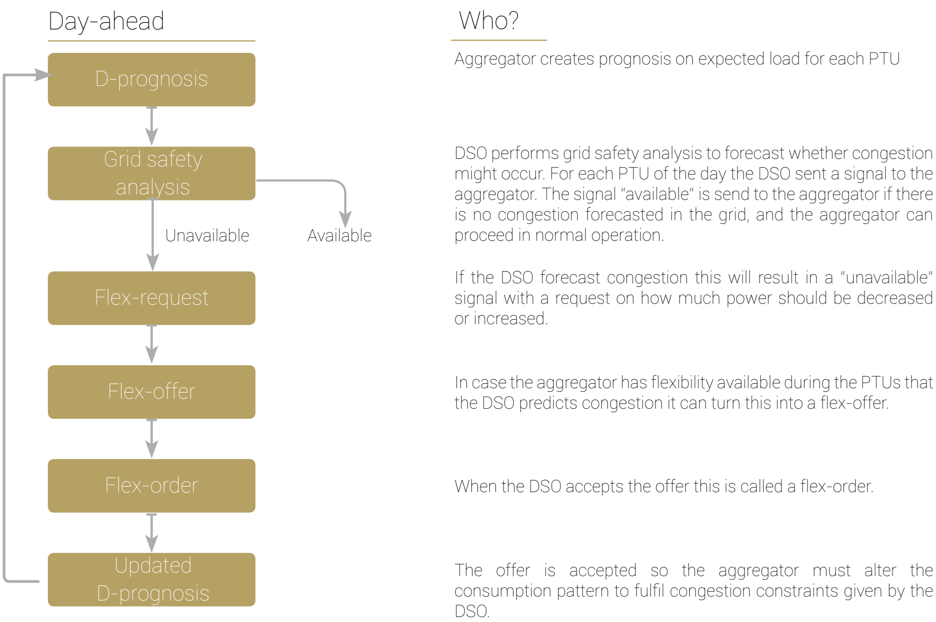


Figure 9 Steps in the plan/validate MCM phase of USEF that take place day-ahead

Operate: The operate phase describes the moment when the created plans are executed, so the day after the flex-offers are placed. This phase starts from the moment when the EV is connected to the EVSE until the charging session is finished for each EVSE connected to the same congestion point. When the charging session starts the optimum charging strategy for the EV the flex-orders are included when determining the strategy.

Settle: After the charging session Jedlix shares the profit made by smart charging the EV with the customer. Jedlix updates the savings in the application, the user can decide to be paid directly or to receive monthly payments. At this moment in time the DSO does not compensate the aggregator for the flex-order, if it would return a fee for that the settlement between the aggregtor and the DSO this would take place during this phase. In the settlement phase Jedlix also receives the income from the BRP for the flexibility services by the passive imbalance control.

Placing flex-offers for Jedlix might be risky because the plan phase is executed day-ahead while the contract with the customer starts when the EV is connected to the EVSE and the user settings are approved. Risk management is key for proper operation of the aggregator within USEF (USEF, 2015), prediction strategies on expected behaviour and electricity needs of their customers could help to improve the aggregator to understand its position in the electricity market. For DSOs USEF is also risky in the case that the market liquidity is not sufficient to provide the flex-requests (USEF, 2015). Distribution grid alterations are operations that are planned several decades a-head (Haque et al., 2016a), while USEF offers only a day-ahead security for the grid capacity management. DSOs in USEF are depending on the flexibility activation by aggregators for congestion management in the yellow operational regimes.

[redacted] The framework acknowledges the risks of gaming imposed by the MCM phases of the USEF. It describes that gaming could be discouraged by (USEF, 2015):

- Utilizing other congestion management methods e.g. alteration of the grid, investments of flexibility services owned by the DSO etc.
- Aggregators could harm their own reputation when gaming too much.
- If gaming occurs in the flexibility market too often, the DSO still have the option to reinforce the grid.
- Imposing certificates for aggregators.

USEF recommends to evaluate the accuracy of the D-prognosis created by the aggregator every month, however it lacks a specific description on how the aggregator should be evaluated.

3.7 Baseline methodology in USEF

One of the major challenges for USEF is to determine the performance of the aggregator, since the procurement of flexibility is usually the avoidance of utilisation of the grid or in other words using less electricity. *"Flexibility is simply a shift in a load profile, and it only exists because we can estimate what the load profile would have looked like if the flexibility had not been activated" (USEF, 2015)*. Since the plan and operate phase take place day-ahead, verifying whether the initial load predicted by the aggregator in reality would have taken place is impossible. USEF therefore concludes that an independent party is necessary to determine a baseline to avoid market manipulation and gaming (USEF, 2015). Until now this role seems to be left unfulfilled and it unclear what parties are interested in taking this role since there is no clear business model determined. Due to the fact that this party should be independent and should have no interest in the trade of flexibility all the roles described by of the actors USEF are unsuitable. USEF concludes that setting the baseline is heavily depending on the source of flexibility and the services related to the shift of the load.

3.8 Electric mobility in USEF

USEF published a position paper on the electric mobility market in which three possible roles for users of EVs are presented (van der Laan, 2015), since USEF is based upon common standards the communication protocol for the mobility sector is mostly based on the studies of Eurelectric (Eurelectric, 2013b). Two market models are proposed: the independent electric mobility model and integrated infrastructure model, but the report does not describe business model nor does it address charging at private locations.
The independent electric mobility model describes a market, where EVSEs are owned, built and operated independently from the DSO. The owner of the EV chooses its own energy supplier for the supply of electricity during the charging sessions. Interactions between the smart grid and the EV are possible in two different ways: the DSO request for flexibility via an energy market or the DSO directly contracts the actor responsible for the connection. EV owners pay a fee for the charging process consisting of a fee for the electricity supplied, charging service, grid infrastructure and charging infrastructure (Eurelectric, 2013b).

In the integrated infrastructure model the DSO public EVSEs are operated by the DSO, so that access to the EVSE is regulated. Here, the DSO is operating as a CSO: the electricity supplied to the EVSE is depending on the contract of the consumer (Eurelectric, 2013b).

3.9 USEF pilot projects

Despite the fact there have been many publications on the theoretical side of USEF, literature on the implementation of the framework is rather limited. Section 1.2.3 introduces the USEF pilot project in Lombok, at this moment in time there is no documentation published on this pilot project. The same holds for Hoog Dalem, an all-electric neighbourhood which is another pilot project for the implementation of USEF started in June 2016[1]. One pilot project that did publish a document is the USEF project in Heerhugowaard. It concludes that USEF can help to avoid congestion, however there were problems in the delivery of the flexibility which led to high electricity peaks in the distribution network. The cases that flexibility could not be resolved where failures in the IT systems and cases where the flexibility was already solved to the DSO (Energie Koplopers, 2016). USEF could be improved by adding redundancy in the system for the DSO. For example in the Netherlands the TSO contracts several reserves to ensure stable operation. The DSO responsible for an area subjected to congestion it might be wise to look into similar solutions. In addition, the prices offered by the DSO should be compatible with market prices that the BRP receives on the wholesale market. By making the prices interesting enough for aggregator they might delay their sales to the BRP and remain the opportunity to trade with the BRP. Another way of resolving the issue to create long term contracts. The benefit of this solution is that this will provide the DSO with more security on the long term for the necessary grid capacity.

3.10 Conclusions

USEF describes operational regimes of grid operation, market roles, interaction between actors and MCM phases in a smart grid environment. The framework proposes a new flexibility market at distribution level that can support the DSO to actively operate the grid for congestion management purposes. The market design is based on indirect grid capacity management, however USEF lacks an explanation on a price-mechanism to support the actual procurement of flexibility. It would be naïve to assume that aggregators with a commercial interest would be willing to resolve congestion without receiving a reward for their services. Therefore, it is of crucial importance that the signal provided by the DSO appeals to commercial aggregators to alter the control of charging EVs to meet the grid constraints of the DSO.

In USEF an independent party is described that creates a baseline for the procurement of flexibility, since the described roles in USEF all have an interest in flexibility these actor are unsuitable to fulfil this role. To improve USEF it is necessary to describe what the role and responsibilities of this party could be. However, we must take into careful consideration that a commercial aggregator might be reluctant to share information with this independent party. In addition USEF could be improved by finding an appropriate incentive to set the baseline for the trade of flexibility of EVs.

In USEF an aggregator is a market party that contracts owners of flexibility to monetize this flexibility. The aggregator can trade its flexibility services via a BRP to the TSO and the wholesale market, in USEF a new market design for the trade of flexibility on distribution level is proposed where the aggregator is enabled to trade flexibility directly to the DSO. In Section 3.5 several business cases for aggregators are proposed. With what is described in (Autoriteit Consument & Markt, 2017) new opportunities for the business case that combines the role of aggregators and supplier arises in the Netherlands. By enabling consumers to contract several supply companies the described process in USEF on the compensation from aggregators to supply companies for changing the electricity consumption pattern of contracted consumers might become irrelevant. This process seems complex and therefore aggregators might find the combined business case of aggregator-supplier most interesting. The aggregator should consider careful risk management when selling flexibility on the day-ahead USEF market of USEF. In case the real load is higher the aggregator might operate in a non-optimum manner. For an aggregator of EVs this might result in a situation where the fleet of EVs is not able to meet the charging requirements of the end-user. Subsequently this might result in a decline of user acceptance of smart charging technology at consumer level. It is therefore important that the aggregator determines a manner of including flex-requests into the charging strategy while remaining able to fulfil

1 Information retrieved from https://www.stedin.net/over-stedin/pers-en-media/persberichten/stedin-test-slim-energiesysteem-in-proeftuin-hoog-dalem

the preference of the end-user and finding most profitable charging strategies.

For the DSO another risk exists in USEF: grid planning is a process that happens years ahead. In USEF the procurement of flexibility, in other words grid capacity management, happens on a day-ahead basis. In case the liquidity of the flexibility market is insufficient this long term versus short term planning might fail (USEF, 2015). To improve USEF it long term contracts between the DSO and the aggregator could used to ensure that flexibility remain available within a longer time span. The most harmful risk that lies in USEF is the gaming that is made possible for the aggregator in the current framework, this topic is discussed in greater detail in Chapter 4.

Chapter 4 Analysis USEF

After describing USEF in Chapter 3, we analyse the framework in greater detail in this chapter. The first section identifies the strengths and weaknesses of USEF. The following sections describes the weaknesses in greater details and discusses possible solutions. Chapter 4 ends with other remarks that have to be taken into consideration for the development of USEF.

4.1 Introduction

To determine the strengths and weaknesses of USEF the research of Chapter 3 is used. In addition the analysis of this chapter, is conducted after intensive collaboration with Jedlix (aggregator of EVs) and multiple conversations with Milo Broekmans (USEF expert) from Stedin (DSO). Furthermore, the author has visited meetings of the consortium of Smart Solar driving, a knowledge session organised by the USEF Foundation on the development of a flexibility market from the aggregator workstream (Dynamo) and a meeting organised by Enexis (DSO) where the design of another flexibility market, Interflex, was discussed.

4.2 Strengths and weaknesses

To identify appropriate improvements for the USEF we first propose the main strengths and weaknesses of the framework.

4.2.1 Strengths of USEF

- Elaborate description of the implementation of an information exchange system for the procurement of flexibility at distribution level.
- USEF is based upon common standards in Europe which could ultimately lead to a European platform for the procurement of flexibility at distribution level.
- USEF can be built upon the existing energy market, the established market needs no alteration to incorporate USEF.

4.2.2 Weaknesses of USEF

Weaknesses of USEF related to a commercial aggregator of EVs:

- Opportunities for gaming due to the lack of an appropriate price-mechanism, which could ultimately lead to inefficient use of the electricity network.
- No proper incentive to execute the baseline methodology as described by USEF.
- Flex-requests are only created in one direction, the request consists of a signal for decreasing or increasing the load, which could lead to a situation of overshot of load created by the activation of flexibility.
- Distrust among stakeholder due to the unresolved opportunities for gaming.

4.3 Discussion of possible improvements of USEF

The following section discusses the weaknesses that are identified in the previous section. We explain each weakness in greater detail and discuss possible improvements. In some case we discuss the possible implications of solutions by an example.

4.3.1 Price mechanisms

One of the major weaknesses is the lack of an appropriate price-mechanism. USEF states that the DSO returns a financial incentive for the procurement of flexibility services, which creates an opportunity for aggregators to sell their flexibility services to this new market.

Aggregators of EVs build their current business case (or smart charging strategy) around the existing electricity market by trading with the TSO, on the day ahead and intraday markets and are only willing to trade on a different market in the case the requirements or profits there are improving their business case or the way they operate. Exact requirements for placing bids and price-mechanisms are not described by USEF. Therefore, it is unclear for an aggregator what the potential value is for trading flexibility to the DSO in a USEF compliant market. This means that at this moment in time, there is no incentive to trade with the DSO. If the DSO wants to buy flexibility services the prices for flexibility have to be competitive with the other markets. To create a competitive price-mechanism all prices signals of the established electricity market have to be taken into consideration. Although creating a price-mechanism that includes all the price signals of and requirements of other markets could be a possible solution, it also seems rather complex. This thesis only provides an answer to what the price for flexibility at least has to be when placing a flex-offer from the perspective of an aggregator of EVs that is active in the imbalance market. To find the "real" competitive price of flexibility the same research should be repeated for other bidding strategies.

Another issue is the inefficient allocation of cost related to the location of the connection. USEF suggests that aggregators receive a fee in return for offering flexibility services to the DSO. Connections in networks that are subjected to more congestion than others are likely to be compensated more for providing flexibility services: this creates an incentive to charge EVs in areas where congestion is predicted. For example: consider a neighbourhood with two congestion points that are with two public EVSEs. The end-user decides where to charge their EV and has enough flexibility available to charge up to the required preferences even if flexibility request are accepted. If the DSO is transparent about the expected congestion and returns a fee for flexibility services the owner has a financial incentive to charge at the congested location. One recommendation could be to return a low fee, low enough to prevent this incentive. However, this could also leads to a situation where there is not enough flexibility offered.

One of the assumptions made in USEF is that there is a separation between inflexible loads and flexible loads, while in reality, both loads create congestion issues. In the description of USEF only aggregators and DR systems can alter their consumption pattern in return for a fee, although in reality each connected EAN could create congestion or relieve the network from congestion. Flexibility services are simply better capable of altering the consumption pattern. The price incentives that the DSO can offer are limited if we consider that connections (EANs) pay a capacity tariff for the distribution services. A completely different market mechanism could resolve the issues presented above: a time-of-use grid tariff that is location dependent. These tariff are dynamic which means that the grid tariff will vary over the day and reflect the availability of the grid at the time that electricity is consumed, e.g. if an EVs owner wants to charge its EV during a peak electricity, the tariff will be high and subsequently the grid tariff. Time-of-use grid tariffs could incentivize all users of the local grid to alter their consumption pattern during low availability of the local grid. End-users might not be able to alternate their total consumptions pattern, but if the prices are attractive enough smart energy services, such as smart charging, become interesting for end-users. In this case, the plan and validate phase of the MCM described by USEF become irrelevant, however the system described to exchange information on the availability of the grid by USEF could become the standard to exchange the information on the availability the local grid tariff.

Another method that the DSO could implement is to decrease the grid tariff for end-users that are willing to decrease the capacity of their connection during peak hours. For households this might not be an interesting option, since it could be difficult to alter the peak-load of the whole household during peak hours. For connections such as EVSEs, this could be an interesting option. Aggregators are able to adapt these price signals into their charging strategy and by sending these signals to the connected EV or EVSE this adaptation could be implemented without having to physically alter the connection.

4.3.2 Baseline methodology

USEF presents a method for baseline methodology, nevertheless there is no incentive described for the aggregators to make correct D-prognosis. To improve USEF this baseline methodology should include an appropriate penalty system for making incorrect D-prognosis. In the current energy market BRPs have to predict the energy use day-ahead by handing in an E-program to the TSO. In case the prediction is off the TSO restores the imbalance by activating one of its reserves. The BRP causing the imbalance is penalized by the TSO for making incorrect predictions. A penalty, such as the imbalance price, is effective since there is a financial incentive for the BRP to make correct predictions. In USEF such (financial) incentive to improve the D-prognosis is missing and this creates many opportunities for gaming. Consider the following example: an EV has to be charged during one PTU and the aggregator expects congestion during one PTU. The price signals from the energy market during the connected time of the EV are flat: during each PTU has the imbalance price is the same. If the aggregator wants to optimize its profit, it should send a D-prognosis with a charging strategy of the EV to the PTU with the expected congestion. In that case the DSO returns flex-request to the aggregator for not charging this PTU: in reality the aggregator could have picked any PTU to charge the EV. Congestion in distribution grids is related to seasonal differences and the behaviour of end-users, therefore it is relatively straightforward for commercial parties to predict the moments in which congestion might occur. Commercial parties could use this principle to increase their income from the DSO. USEF acknowledges the risk of gaming and in Section 3.6 describes the methods USEF aims to reduce gaming with. If we take a closer look at the methods that are described to reduce the risk of gaming these impose that an effective method to reduce gaming is reinforcement of the grid. If the DSO decides to increase the capacity of the grid a flexibility market might no longer be necessary and therefore we conclude that this is not improving the implementation of USEF just making USEF unnecessary since congestion problems will no longer occur. Therefore, we propose a different solution: remove the D-prognosis from the MCM phases and let the DSO decide the moments when congestion issues are expected. If congestion is predicted the DSO places a flex-request and aggregators active in the area can place flex-offers. Congestion is not only related to the flexible demand within a distribution grid and the opportunities for gaming can be reduced by removing this phase from the mechanism. For the DSO this could mean that creating the predictions on the expected congestion might become more complex, however we expected that this outweighs the complexity of having to reduce the opportunities of gaming by the aggregator when a D-prognosis is included in the MCM phases.

Even if we consider the case of an aggregator that creates honest predictions of the D-prognosis, it might still be complex to predict the exact electricity demand of EVs connected to the same congestion point. BRPs base the prediction of consumptions of households on the average consumption per customer from an aggregated amount of consumers. This is more stable compared to the individual load of a consumer since the aggregated load consists of individual loads that have an imperfect correlation (Chao et al., 2008). By contracting a large variety of consumers, such as households, small industrial parties and large industrial parties, the BRP diversifies its portfolio to better manage the risk of deviation of individual consumers from the average consumption profile. Liquidity issues arise in USEF, since the amount of EVs connected to the congestion point is low compared to the whole portfolio of the related BRP. In the pilot of Lombok nine EVSEs are attached to the same congestion point, whereas the whole portfolio of Eneco Energy Trade consists of in the ranges of millions of consumers. Predicting the behaviour of a low amount of EVs may lead to a large discrepancy between the predicted and actual load. On the other hand: if incentives for making correct predictions are high enough aggregators can always improve their prediction, for example by making use of connected car data on the expected energy demand of the EV. One solution could be to let the aggregator decide what the price should be for making incorrect predictions. For example: an aggregator of EV has to include more insecurities when making flex-offers compared to an aggregator that controls heat pumps. The use of EVs is less predictable than the energy demand of a heat pump. Therefore, the aggregator that can make better predictions can raise the penalty for making incorrect prediction, however the price that it wants in return for correct predictions/ availability is also higher compared to the aggregator with less certainty on availability of the flexibility.

Another option to reduce gaming opportunities created by the baseline methodology is to make long term agreements between the DSO and the aggregators active in an area. The DSO offers a price for a longer period of time: the aggregator has to accept all flex-offers made during the contracted time. If the aggregator is not capable of placing a flex-offer when a flex-request is made, the DSO could activate a reserve to restore the balance and penalize the contracted aggregator. This reserve could be a back-up system such as a direct load control measure or another contracted flexibility service. If such long term contracts are established it is necessary to include specific requirements for the amount of flexibility necessary during the contracted time. The described method is comparable to the balancing mechanism that is established by the TSO, however the difference is that it might be difficult to find enough resources of flexibility connected to the same congestion point. Again, if the DSO creates the correct incentives this might be possible. For aggregators of EVs long term contracts might not be appealing since the behaviour of end-users highly affects the availability of the flexibility and it is difficult to predict the behaviour of consumers connected to the same congestion point. On the positive side: the contracted aggregator is inherently incentivized to make correct predictions of the expected load and available flexibility, since the responsibility of the balance is now depending on the functioning of the aggregator.

4.3.3 Flex-requests

In the current market design of USEF the flex-requests are created in one direction: either increase or decrease the consumption of energy. To prevent an overshoot the trades are iterated until the grid is safe and necessary flexibility services are settled. In the smart charging strategies that will be proposed in Chapter 6 of this thesis we include a maximum and minimum request to remain within the network constraints of the system. The advantages of including a lower and upper bound to the flex-request is that this could decrease the amount of iterations in the trading process and could help avoid situation were an overshot due to a flex-request occurs. In addition, USEF considers V2G services out of the scope of the framework, although the implementation of V2G is recognized in USEF (van der Laan, 2015). Providing a lower and upper bound is essential for the implementation of V2G, otherwise there is will not be an incentive to provide V2G services in the case the grid is experiences a high demand of electricity.

4.3.4 Attitude of the DSO towards commercial parties

Another issue is the attitude of the DSO towards commercial parties in the light of market at distribution level. During the research done the author addressed the issue of a lacking price-mechanism during a discussion session for aggregators for USEF. The reply of the responsible person of the DSO, was that if market parties want to receive a fee for the services delivered they should call a price. The issue with this remark is that at this moment in time there is no financial incentive for the aggregator to trade on this market, however that there are incentives on others markets to trade flexibility. Aggregators have to develop a platform to trade with the DSO in a USEF compliant manner. It is difficult for commercial parties to make a comparative assessment whether to invest in a dedicated trading platform for the trade of flexibility at distribution level if the price mechanism of this market remains unclear. In addition, one of the solutions described by USEF to reduce the opportunities for gaming in USEF is to reinforce the grid, which leads to a situation where a flexibility market at distribution level could longer be necessary. If the responsible DSO decides to alter the grid, the value of flexibility decreases for the aggregator active within the area connected to the congestion point. Again, this leads to an unstable market and could ultimately lead to distrust between aggregators and DSOs.

4.3.5 Requirements for operational phases of the grid

If the DSO switches frequently into the red and orange operational phase of USEF we could conclude that the congestion management of the DSO fails. In USEF there is no requirement for the amount of time that the DSO has to operate in the green and yellow phase and subsequently in the orange and red phase. One of the direct control measures a DSO could take is to decrease the capacity of the EVSEs in a certain location. The results of Chapter 8 will show that there is a difference in price for charging at lower power. Decreasing the power feed into the EVSE can increase the charging costs of an aggregator of EVs and increase the charging time for EV owners. Unclear requirements on the performance of the DSO could lead to distrust from the aggregators and could result in a decreased willingness to trade with DSOs. Therefore, DSOs have to be transparent about the amount of flexibility necessary for congestion management to establish a reliable market. USEF could be improved by describing requirements for the amount of time the distribution grid needs to be in the green and yellow operational phase of the grid.

4.4 Other remarks

4.4.1 Collaboration between TSO and DSO

TSOs send price signals to the whole electricity market and are researching whether balancing services can be provided in a distributed manner. This forces the DSO to relate the price for flexibility on a local level to the price that are paid by the TSO for balancing services. More collaboration between the TSO and DSO could also help to reduce congestion issues on local level. One possible solution could be that the DSO limits the TSO to buy flexibility services from an area that is expected to be congested. For aggregators this limitation could have a negative impact on the business case. To reduce this negative effect the DSO could announce in advance, before the aggregator starts its business in a specific area, that an area is subjected to congestion and that trades with the TSO are limited within this area. EVs are special sources of flexibility, since EVs are mobile and the location of the flexibility is determined by the location of the charging session of the EV. The location of the EV determines the location of the flexibility of the aggregator of EVs, rather than the aggregator deciding the location of the flexibility. For other sources of flexibility, such as grid connected batteries, this is different since their location is less mobile compared to EVs. This approach should therefore include a method of compensating aggregators and the TSO when trades are limited. Another limitation of this approach is that the aggregator could still trade its flexibility services to the electricity market. The DSO is not allowed to limit these trades, since the electricity market is liberalized.

Another way the DSO and TSO could collaborate is to use the E-programs of the TSO to verify whether the D-prognosis send to the DSO are realistic. The content of the E-programs shows day-ahead what the related BRP expects to produce and consume. However, BRPs make assumptions on the use and production over the whole portfolio. In theory this is related to the electricity consumption and production of each EAN: in reality the E-programs do not include the behaviour of individual consumers or small areas, as is described in Section 4.3.2. Therefore, we conclude that it is necessary to create a different prediction at distribution level, such as described by the D-prognosis in USEF. The complexity is that predicting the individual behaviour of EV-drivers is difficult. If USEF defines congestion points on a feeder level that contains just a few EVSEs, it might be close to impossible to create realistic predictions until the moment the EV is connected and the smart charging session is enabled by the end-user.

4.4.2 Development of flexibility markets in the Netherlands

If the flexibility market at distribution level will emerge, it is important that DSOs operate with the same tools to avoid even more diversity of price signals and trading platforms in the energy market. At this moment in time this is not the case in the Netherlands. There are three DSOs working on the design of a flexibility market at distribution level: Liander, Stedin and Enexis. Liander works on a flex-market at distribution level in the workgroup Dynamo, which implements USEF. Stedin is active in the pilot of Lombok and is also researching USEF. However, Enexis is working on their own design of a flexibility market at distribution level. One of the strengths of USEF is that it proposes a common standard. However, if DSOs are not implementing the same standard it could ultimately lead to different trading platforms for the areas controlled by different DSOs. Instead of developing their own tools DSOs should collaborate with each other instead of finding solutions for their own area. In the case each DSO develops their own platform to exchange information on the status of the grid this could lead to barriers for aggregators to implement different platforms for each DSO. Ultimately this could lead to a situation where the amount of flexibility services in an area is being not high enough to meet the demand of the DSO necessary for congestion management.

4.4.3 Focus of USEF

Literature on USEF describes market roles, interactions between actors and how the communication of grid availability should be implemented. The focus of USEF is too much on explaining the roles and business cases of aggregators, rather than on describing proper financial incentives or policies that create this market. If the market is established commercial parties will find themselves methods to make the most out of the opportunities on this new market.

Chapter 5 Design framework

This chapter presents the functionalities necessary for an aggregator to trade within USEF. The first section presents conclusions from a stakeholder analysis. The next section describes the manner the USEF requirements are operationalized in this research to be able to use the requirements imposed by USEF. Section 5.4 describes the smart charging strategies that are proposed to determine the quantitative impact of USEF and that could improve the amount of flex-offers places by the aggregator. It also includes a list of design specifications, which will be used to evaluate the charging strategy. The last section states relevant assumptions to deal with uncertainties when translating a real world problem into a mathematical model.

5.1 Stakeholder analysis

To determine what functionalities have to be included in the smart charging strategy, we have conducted a stakeholder analysis for the trade of flexibility from an aggregator to the DSO, the full analysis is presented in Appendix 1. Here, we present the most important findings and an overview of the relevant stakeholders and interaction in Figure 10.

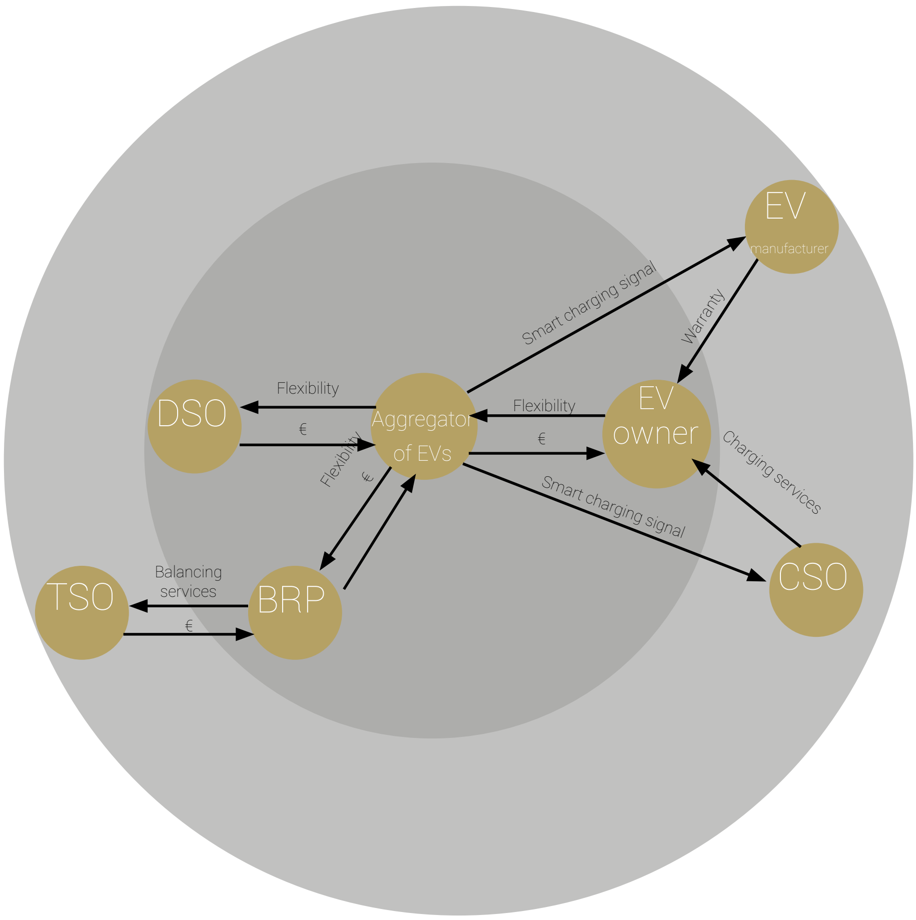


Figure 10 Overview of stakeholder with relevant interactions.

The most important stakeholder of this thesis is the aggregator of EVs, therefore the objective in the smart charging strategy has to minimize the charging costs. Users are crucial when trading flexibility, therefore it is necessary to include features requested by them in the smart charging strategy, such as giving them a certain level of control in the smart charging strategy by a direct charging mode. DSOs are willing to buy flexibility when this improves their economical operation and an aggregator can facilitate this when decreasing or increasing the load during specific PTUs by means of a flex-offer. The aggregator should only place flex-offers if user requests can be met and the price paid by the DSO for the flexibility services are at least the difference between the charging strategy without constraints and with network constraints from flex-requests of USEF. It is also important that the alteration of load pattern is in line with the balance of the BRP or reduces the imbalance. To execute the charging strategy the aggregator has to be able to send signals to the EVSE or to an EV, therefore might be restricted to the requirements set by these stakeholders.

5.2 Design

We propose a design goal and objective to clarify what the purpose of the smart charging strategies are in this thesis.

5.2.1 Design goal

The design goal of this thesis is two-fold. The first design goal is to obtain quantitative data on the impact of implementation of USEF on the current charging strategy of Jedlix. Since USEF lacks an appropriate price-mechanism therefore this is valuable information for the aggregator in the case it has to decide whether to place a flex-offer and at what price the bid should be placed. To measure the impact of USEF on the current bidding strategy of Jedlix, we define the current charging strategy as an optimization problem and modify the charging strategy to be USEF compliant. The strategy is USEF compliant when the EVs connected to a congestion point can be limited to a certain power use during a specified PTU when a flex-offer is placed by the aggregator. The reason to define the current charging strategy as an optimization problem is that these problems are capable of resulting in an optimum set of configurations to achieve a minimizing or maximizing objective. The second goal of this research is to improve the quantity of flex-offers that Jedlix can place, to achieve this three new charging strategies will be described and evaluated. These smart charging strategies should be improve the capability to cope with the network constraints imposed by flex-requests while remaining an attractive smart charging service for users.

5.2.2 Design objective

While many objectives in the stakeholder analysis can be discovered this research focusses on the perspective of an aggregator of EVs. The design objective is therefore to minimize charging cost for charging sessions of EVs connected to the same congestion point. The aggregator shares the reduction of cost with the owner of EV that is offering the flexibility. Furthermore, to be USEF compliant it is necessary to be able to adjust the charging strategy of EVs to the flex-request.

5.3 Operalization of USEF

To achieve the design goal, to determine the quantitative impact of USEF, we need to make some assumptions regarding USEF and the bidding strategy. From the analysis in Chapter 3 we found that there is no price-mechanism described by the framework, for this reason we cannot include the price signals from USEF in the smart charging strategies. From the research in the stakeholder analysis we found that it remains unclear what the DSO is willing to offer in return for flexibility, therefore, we need to operationalize the requirements from USEF to determine the quantitative impact of USEF.

We assume that the DSO is willing to pay the price as bid by the aggregator, to find the minimum price of the bid we develop a smart charging strategy that includes the opportunity to accept flex-request. These flex-request in reality are a signal given by the DSO that requests the aggregator to decrease or increase the load during a specific PTU. However, having the signal of the flex-request in only one direction, in other words to either increase or decrease the load, could lead to a system that might lead to an overshoot of loads or multiple iterations of the MCM stages which means that the optimisation problem has to be executed multiple times. This argument is explained in greater detail in the discussion in Section 4.3.3, where we also highlight the importance of having a lower and an upper limit when trading flexibility. For now we assume that the flex-requests are given as the maximum and minimum power that can be exchanged with the grid during a PTU for all the EVSEs connected to the same congestion point, in other words network constraints. If the aggregator is capable of including these network constraints for each PTU in the charging strategy, we assume that it is USEF compliant.

In the section above, we assumed that the DSO accepts the price bid by the aggregator. [redacted]

5.4 Smart charging strategies

Since the assumption is made that the DSO accepts the bid from the aggregator, we need to find the difference between the charging costs for charging EVs connected to the same congestion point with and without network constraints. The goal of this section is to describe the functionalities that should be included in the charging strategy. It is based upon the operational requirement of USEF described in the previous section and the needs of the involved stakeholders based on the stakeholder analysis. The first section describes the functionalities that the smart charging strategies should include and is followed by the design specification that consists of a list of requirements and wishes.

5.4.1 Description

By using an application on a smart phone, EV owner's have the option to smart charge their EV. [redacted] For users it is possible to charge a part of the electricity directly after connecting the EV to the EVSE starting the charging session. Figure 11 presents a schematic representation of different charging modes that can be defined by the preferences of the EV owner.

[redacted]

For the comfort of users of the smart charging application three charging modes are proposed in the optimization model:

1. *Direct charging mode*: during the direct charging mode the user of the application has the option to enter a desired energy content that should be charged as soon as possible, therefore V2G is disabled and the charging power should operate at full power. This mode is implemented so that it can help increase the user acceptance of smart charging as discussed in Section 2.3.4. For example: in the case of an emergency, where the charging session is stopped before the departure time, the user of the EV would like to have a part of the total demand. This feature is currently integrated in the application of [redacted] We introduce four configurations of this charging mode: the current charging strategy, the linear penalty strategy, the quadratic penalty and the charge-at-least strategy. The current charging strategy reflects how Jedlix charges at this moment in time, however we expect that the behaviour of EV drivers could interfere with the moments of congestion of the grid, so that the direct charging mode is enabled when flex-request are expected. For this reason, we propose three adaptations of the current charging strategy that could include more network constraints in the charging strategy.
    a. [redacted]
    b. [redacted]
    c. [redacted]
    d. [redacted].
2. *Flexible charging mode*: during the flexible charging mode the capacity of the battery is charged at least up to the total energy demand as defined by the user before the time of departure. T[redacted] The optimization model determines what PTUs are most convenient to charge the EV. [redacted]
3. V2*G mode:* is only enabled when the capacity of the battery is at a certain level to maintain battery life, as discussed by (Sánchez-martín et al., 2012). In addition the smart charging strategy should be able to exclude this function from the optimization problem. [redacted]

[redacted]

To better understand what each penalty does to the direct charging mode strategy Figure 12, displayed on the next page, represents a schematic example of what the different penalties imply. T simplify the illustration, V2G mode is not included in the example. In addition it states the most relevant advantages and disadvantages of the proposed penalization methods.

Each of the proposed charging strategies include the direct charging mode, the flexible charging mode and V2G mode, but the manner the direct charging mode is executed is depending on the strategy. The most important improvement of the optimization model is to be USEF compliant, so to be able to include network constraints coming from the flex-requests of the DSO. Battery degradation is also modelled to prevent significant losses in battery lifetime due the use of V2G and V2V discharges. This optimization is useful for the green and yellow operation phase defined by USEF and could be used to create D-prognosis.

5.4.2 Design specifications

Here, the design specification are presented which serve as the performance indicators of the proposed smart charging strategies. The purpose of this list is to create an evaluation tool for the smart charging strategy that is created to smart charge the EVs connected to the same congestion point. The requirements need to be met by all the smart charging strategies, in other words the constraints, in case one of the charging strategies violates one of the requirements the proposed model is a failure. The list of wishes is comprised of features that could be included in the strategy. To determine the best model, the strategies should be scored on their ability of meeting the wishes. The requirements and wishes are derived from the description of the charging strategies and the statements form the stakeholder analysis.

List of requirements (constraints)

1. [redacted]
2. [redacted]
3. [redacted]
4. [redacted]
5. [redacted]
6. [redacted]
7. [redacted]
8. [redacted]
9. [redacted]
10. [redacted]
11. [redacted]

List of wishes:

1. [redacted]
2. [redacted]
3. [redacted]

[redacted]

Figure 12 Schematic example of the strategies for the direct charging mode: the upper graph illustrate the current charging strategy, the middle graph illustrates what the linear and quadratic penalty imply and the lower graph illustrates the charge-at-least method.

5.5 Uncertainty and assumptions

Despite the large amount of possibilities in programming there are uncertainties that have to be simplified by assumptions to translate the real world problem into an optimisation problem.

5.5.1 Uncertainty

The mathematical model that is proposed in the following chapter contains several uncertainties.

- *Availability of EVs:* in the application of Jedlix users register their preferred leaving time and departure time and the preferred amount of directly charged electricity. For the flexibility trade in USEF the trades are executed day-ahead. In the case the user changes the settings or behaviour in between the day-ahead and the day when the trades are executed this could result in a difference of availability of the flexibility. In addition the exact energy demand to charge the EV is unknown until the charging session is started, since this depends on the current state-of-charge if the battery of the EV.
- [redacted]
- *V2G:* it is known that batteries lose capacity and that batteries degradation occurs when discharges occur. These phenomena are depending on many variables, such as exact composition of the battery, temperature, speed of discharge etc. All batteries are capable of discharging and to execute V2G, however EVSEs that are capable of including are expensive and implementation is rare.

5.5.2 Assumptions

In this section we state the assumptions made to deal with the aforementioned uncertainties. In addition the last section presents general assumptions that are necessary to create the charging strategies.

Availability of EVs

- Day-ahead the availability, preferences of the user of the applications and imbalance prices are known. This assumption is made to simplify the problem. In reality the imbalance prices are updated every 15 minutes and are volatile. Users are always enabled to change their user settings, however it is reasonable to assume that user settings are not frequently changed.

[redacted]

- [redacted]

V2G

- Degradation of the battery due to discharge of the battery depends on the amount of V2G power exchange. In reality battery degradation depends on many variables, but in many studies this is accepted as a viable assumption (Verzijlbergh et al., 2011; Meer et al., 2016; Schill, 2011).
- The EVSEs and EVs are able to perform V2G.In reality most EVSE are not equipt to perform V2G, however in the area of Lombok the first EVSE capable of receiving electricity (V2G) of the Netherlands is installed. In addition there is an increased interest in the V2G field and the subject is very relevant in the field of smart grids since these grids have bidirectional power flows.

General assumptions

- [redacted]
- The optimization problem has a static nature, as mentioned before in reality the input values for the optimization problem are updated from time to time.
- [redacted]
- In reality time is continuous, however since the charging strategy is based on the imbalance price that is released every 15 minute, we optimise the model for every PTU instead of optimising it continuously.

5.6 Conclusion

This chapter forms the basis of the smart charging strategies that are developed in the following chapter. The goal of the proposed charging strategies is to provide insight into the quantitative impact of network constraints from USEF on the charging costs of EVs connected to the same congestion point. Therefore, we assume that the DSO acts as a price taker and that the aggregator has to determine the price difference between the costs with and without network constraints from the flex-requests of the DSO. The aggregator has to operate as a middleman between the BRP, DSO and end-user, for this reason a stakeholder analysis is conducted to define functionalities that have to be included in the smart charging strategy. From the stakeholder analysis, we found that the objective of the smart charging strategy should be to minimize charging costs, however the functionalities of the model have to be appealing for end-user, therefore we propose to include a charging mode that charges a part of the energy demand directly after the EV is connected. Another important assumption that is made is that the model is static, so that the requirements of the user [redacted]

Chapter 6 Mathematical Models

6.1 Nomenclature

[redacted]

[redacted]

6.2 Introduction

This chapter contains the mathematical formulation of the optimum charging strategy to charge EVs in a USEF compliant manner. In Chapter 5, we have described the functionalities of the smart charging strategy to be satisfying for the aggregator, the user and able to include network constraints from USEF. Here, we implement these in a mathematical model. Chapter 5 also describes the insecurities that in reality exist and how to make assumptions to deals with those. The most important assumptions are that there is perfect information on the price signals and user preferences, so user settings and prices are known in advance. [redacted] The first section describes what methodology is used to create the charging strategy. Section 6.4 proposes the mathematical model. To receive flex-request the aggregator needs to create a D-prognosis. Section 6.5 on the creation of the prognosis. In the conclusion a functional flow chart of the optimization problem is given.

6.3 Optimization method

To create a strategy that is most profitable while respecting the constraints stated in Section 5.4.2 we select an optimization method. Optimization problems can be used to find the best arrangement of variables to obtain a certain goal while satisfying a set of constraints. When a problem is formulated as a linear program (LP) a mixed-integer linear program (MILP) or as a mixed-integer quadratic program (MIQP) the result found is the global optimum solution. Note that program refers to optimization and not to computer modelling. The global optimum solution is the best solution to meet the objective. If the objective function and/or the constraints are non-linear the problem cannot be formulated as an LP or an MILP. In that case other optimization problems, such as mixed integer non-linear programming and nonlinear programming, could return feasible solutions, the solution of these problems results in a local optimum. The local optimum is the best solution in the sense that there is no better solution found in the neighbourhood (Papadimitriou et al., 1998). One of the requirements of Section 5.4.2 is that the result of the optimization has to be a global optimum, therefore the optimization problem will be stated in an LP, MILP or MIQP.

All optimization problems consist of:

1. Objective function: this function is the goal that has to be maximized of minimized.
2. Decision variables: these variables are the degrees of freedom of the problem.
3. Equality and inequality constraints: these are the conditions to be satisfied in the problem.

An LP in standard form is formulated as

$$\min c'x \quad (1)$$

$$Ax = b \quad (2)$$

$$x \geq 0 \quad (3)$$

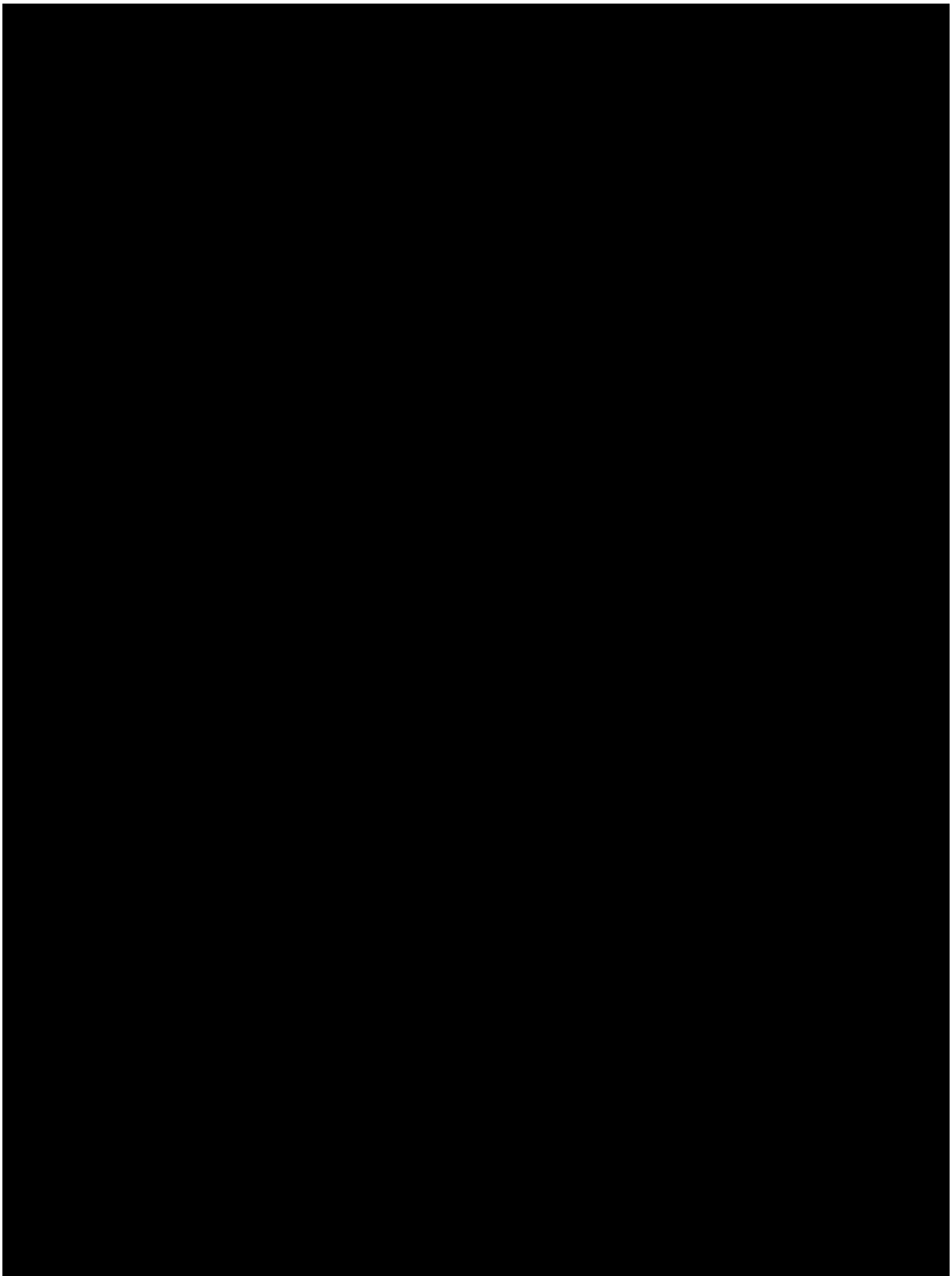
In (2) and (3) x is a vector with the decision variables, b and c are vectors with known coefficients. A is a matrix with integers. The set of points satisfying the constraints of the problem is called the feasible region. The result of (1) is the minimum optimum value of the problem and the outcome of all the decision variables is the optimum solution. The optimum solution usually lies on the intersection of constraints, these intersections are called extreme points . It is possible to have multiple optimum solutions, however if the feasible region is unbounded the result is infeasible (Lukso, 2016). The difference between a LP and a MILP/MIQP is that an LP only contains continues variables, whereas the MILP can also contain integer or binary variables. Binary variables are able to represent on and off decisions. In the description of the charging strategy presented in Section 5.4.1 is stated that the model should be able to on and off the V2G model. [redacted]

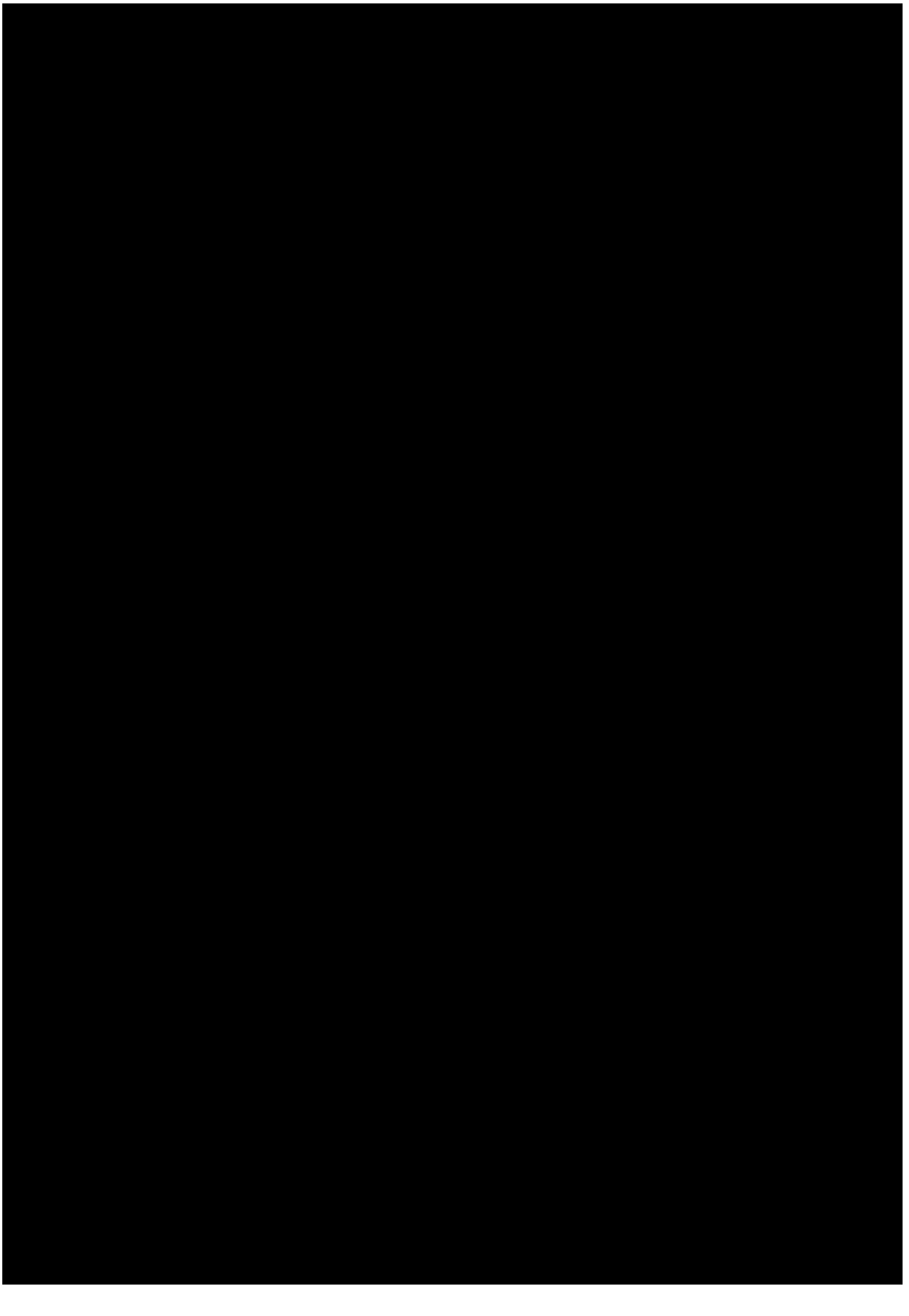
MIQP are similar to MILP , these problems also contain binary decision variable, however the problems contain a quadratic term in the objective function. The quadratic penalty strategy that will be proposed in Section 6.4.4 includes a quadratic variable in the objective function. Adding a quadratic penalty might reduce the time between the EVs with the same behaviour to reach E_i^D . To research whether this is true, we include one model that is formulated as MIQP.

When the program is properly formulated it can be solved by many different methods. One of the most efficient and widely used methods is the Simplex Method. Simplex is developed by G. Dantzing and describes a method to find the global optimum by seeking extreme points in the feasible region and searching across the edges of the region to find the following extreme point. This methods only moves to the next point if the outcome is better than the previous point. Therefore many extreme points are not evaluated, resulting in an efficient method to find the global optimum (Lukso, 2016). CPLEX is a solver of (MI)LP that was originally based on the simplex method and that has the ability to find solutions to complex (MI)LP and MIQP (GAMS, 2012). While there are many solvers available the solver that is used here is CPLEX 12. Further explanation on this topic is considered beyond the extend of the scope of this thesis.

6.4 Mathematical model

[redacted]





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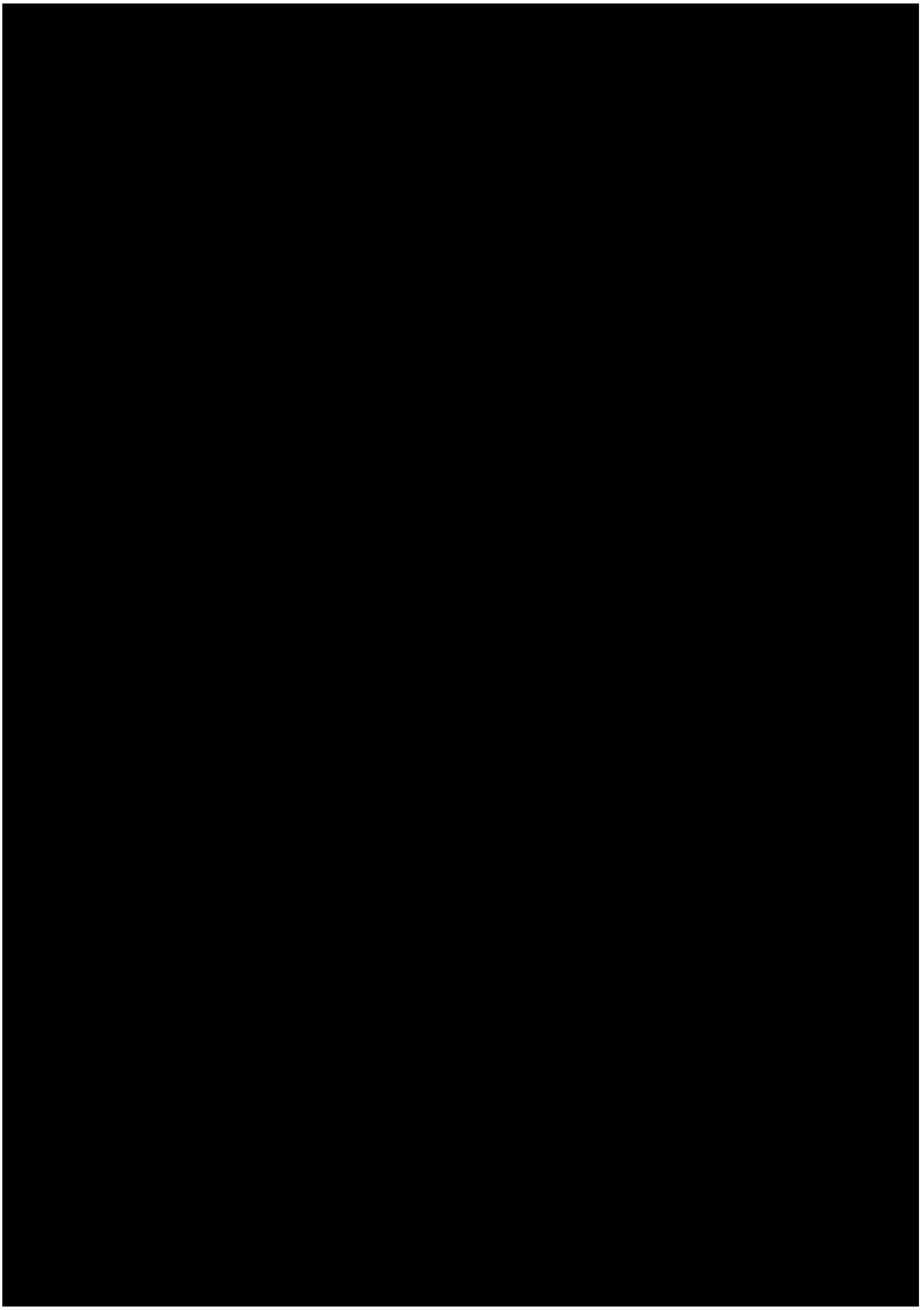

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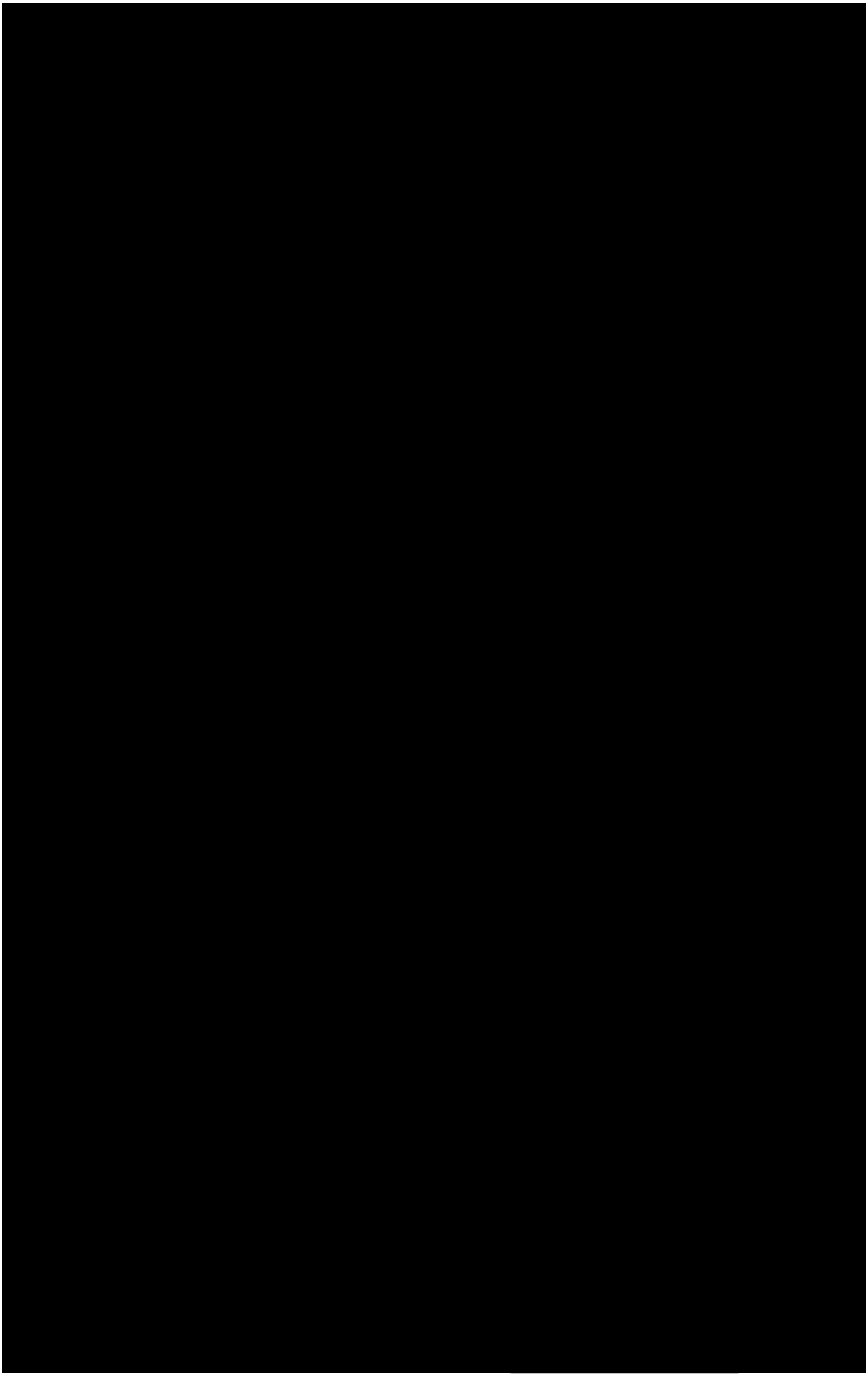


Figure 14 Functional analysis of the mathematical model in practice.

Chapter 7 Experimental set-up

This chapter presents the experiments that will assess the performance of the optimization problems of the previous chapter. Firstly, the input data that is used for the experiments will be presented, followed by a section that explains the experimental set-up. The goal of the experiments is to evaluate the performance of the charging strategies described by Chapter 6 based on the design specifications described in Section 5.4.2 and to determine the quantitative impact of USEF constraints on each of these charging strategies.

7.1 Case study Lombok

This section presents the data used in the experiments for the case study of the USEF pilot in Lombok. For each dataset we describe where the data is derived from, what the data consists of and how it is processed to use in the experiments and finally the data is presented. The input data presented in the following sections are data for:

- Flex-requests
- Imbalance price
- Charging sessions
- EVSE
- EV

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

7.1.4 Other parameters of system

To test whether V2G decreases the charging costs, the price for the degradation of the battery should be defined. Since battery technology is likely to improve in the future the authors of (Sánchez-martín et al., 2012) conducted a sensitivity analysis with different values for the battery dergadation. The research of (Schill, 2011) that uses prices ranging from 0 [Euro/MWh] and 40 [Euro/MWh], we chose to use the values that are in line with this research and thus test cases with 0,1,5,10 and 50 [Euro/MWh]. We also include one extremely high values of 100 [Euro/MWh] for $\lambda_t^{Degradation}$ .There is no information available on the charging efficiency from the EVSE to the EV, therefore we assume that for both V2G and G2V mode the efficiency is 90%, based on the round trip efficiency used by (van der Meer et al., 2016). In addition, the charging strategy allows V2G only after the battery has reached a certain DoD based on the method of (Sánchez-martín et al., 2012), and use a value of 0.90 [p.u.] for B.

Lastly, the price for the benchmark is depending on bilateral agreements between Jedlix and the DSO. The BRP returns the aggregator a reward depending on the difference between the imbalance price and the benchmark price. The benchmark price reflects the average price of the intraday and day-ahead market. Therefore, we use a value of 45 [Euro/MWh] for λ_t^{Bench} .

7.1.5 Other parameters for EV

The efficiency of the battery depends on the battery of the EV and multiple other variables including the charging speed of the EVSE and the outside temperature For the experiments in this thesis we use the characteristics of a Renault Zoe 40kWh[3]. The capacity of the battery is 41kWh and the charging speed can be up to 22kW. In Section 7.1.3 we assumed that the total demand of the EVs is 10 kWh, so to test the impact of the V2G mode the energy content at arrival is set at 30 kWh. [redacted] Most users do not change the level of this feature. However, to test the impact of the amount of direct charging for multiple settings and therefore the

3 Information retrived from https://ev-database.nl/auto/1078/Renault-Zoe-Q90.

percentage of the direct charging mode as a percentage of the total demand will be evaluated. The percentages used are 0% (no direct charging mode), 25%, 50%, 75% and 100% (comparable to no smart charging).

7.1.6 Overview of input data

This sections presents an overview of the data used for the experiments. Table 4 shows the relevant parameters of the system and Table 5 the relevant parameters for the EVs.

[redacted]

[redacted]

[redacted]

Chapter 8 Results

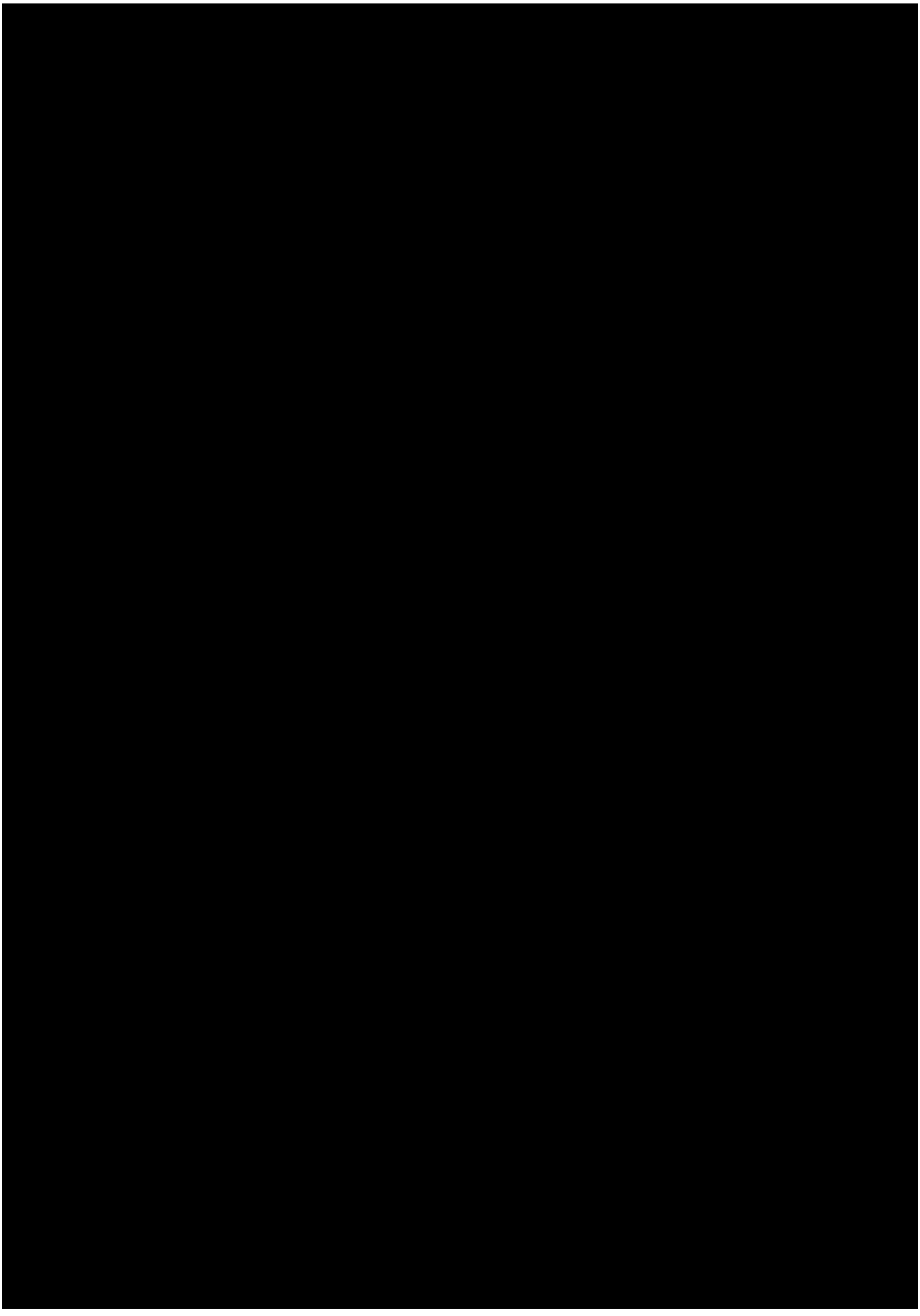
This chapter presents the results of the experiments as described in Chapter 6. Firstly an explanation on the implementation of the mathematical models of Chapter 6 will be given and we will explain more on how the results are presented. Then the results of the three experiments as described in Section 7.2 are presented. We compare the performance of the strategies in Section 8.5 and conclude with the most important findings.

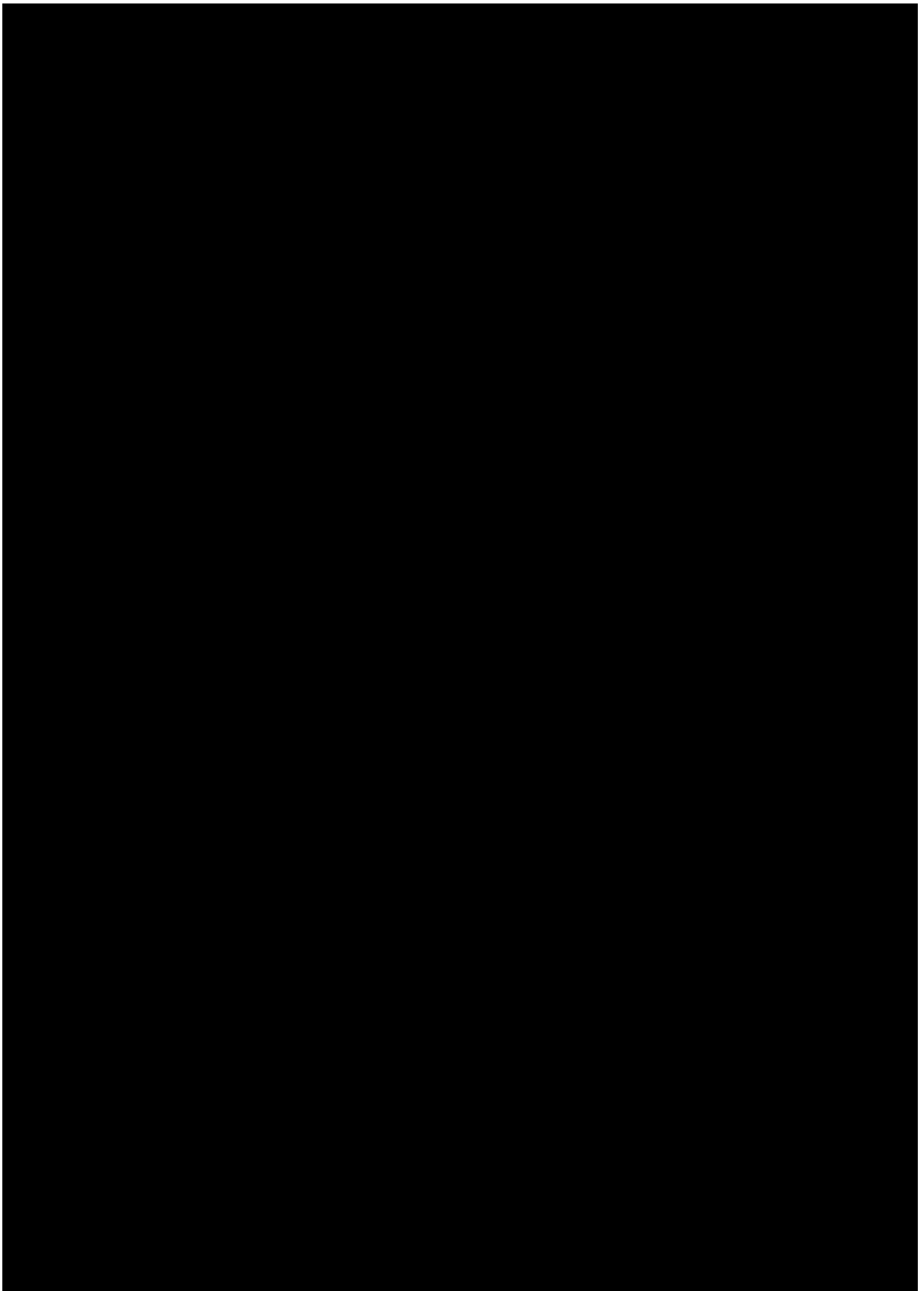
8.1 Implementation

This section explains how the MILP and MIQP mathematical models of Chapter 6 and the input data from Chapter 7 are implemented. Each model is implemented in GAMS version 24.7.4, the solver used is CPLEX version 12.6.3.0 and the optimality gap is set to 1e-5.

[redacted]

[redacted]





[redacted]

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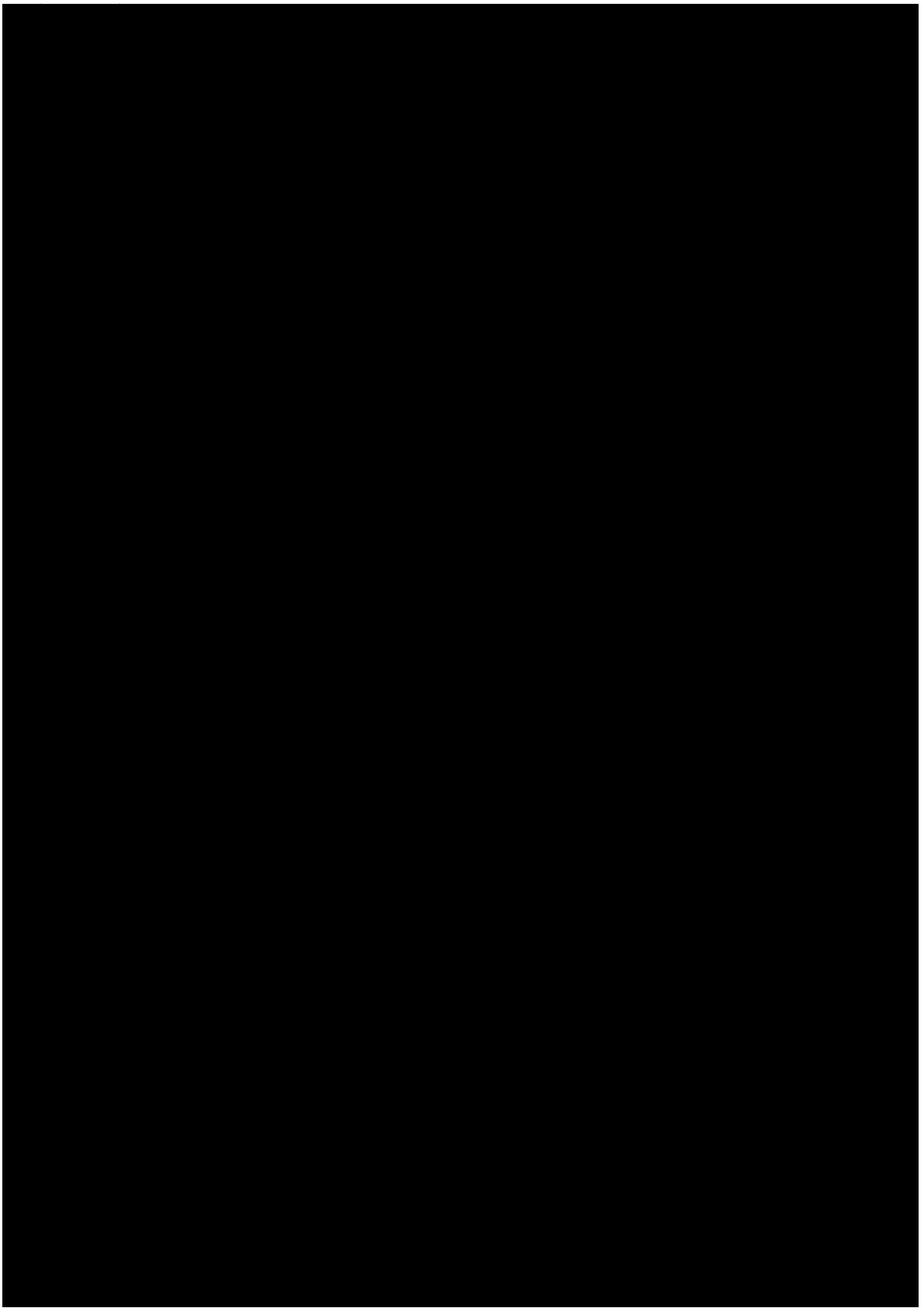
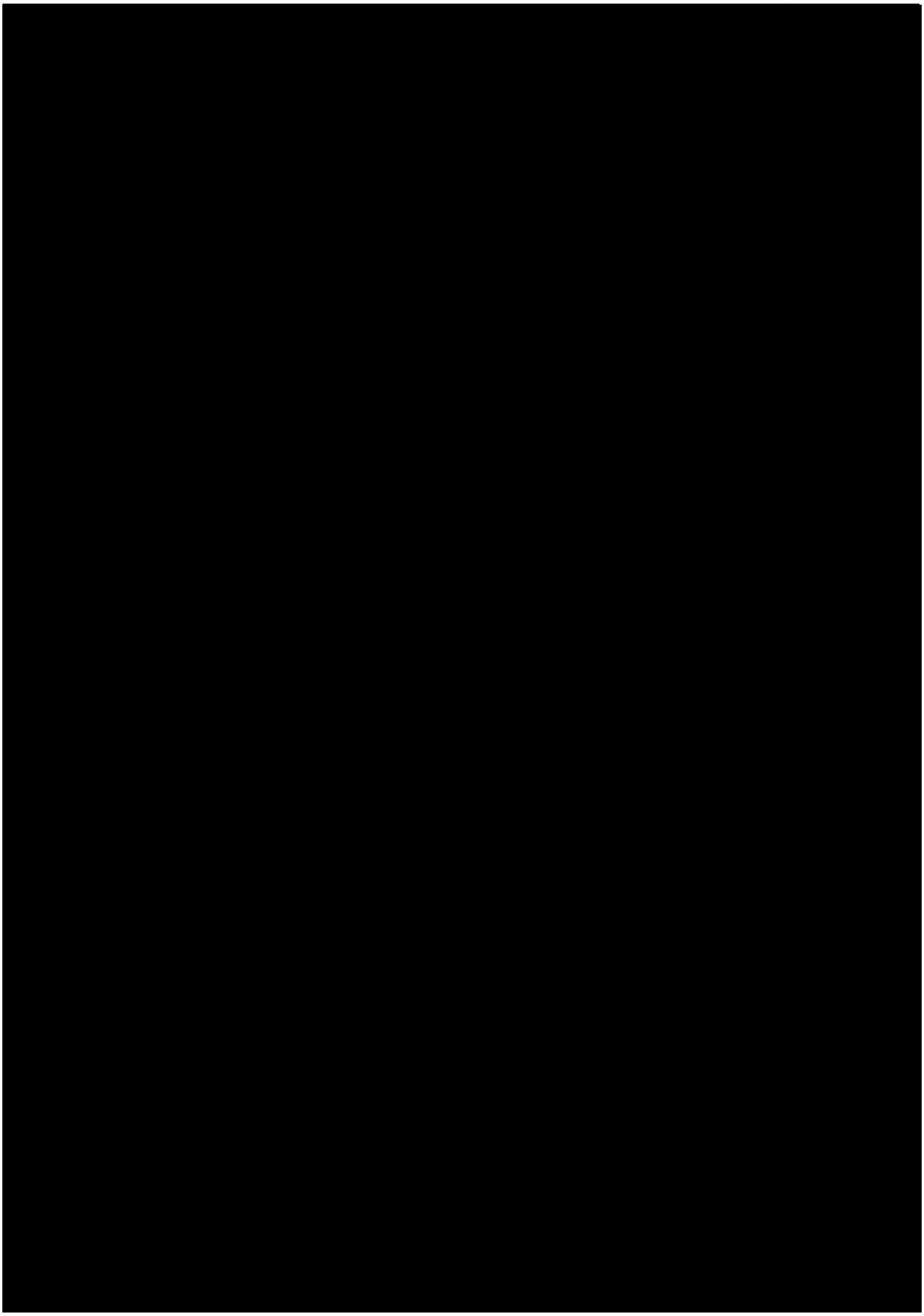


[redacted]

available in addition to a high electricity peak. Therefore, it is still possible that the DSO would accept an offer of this price.

[redacted]



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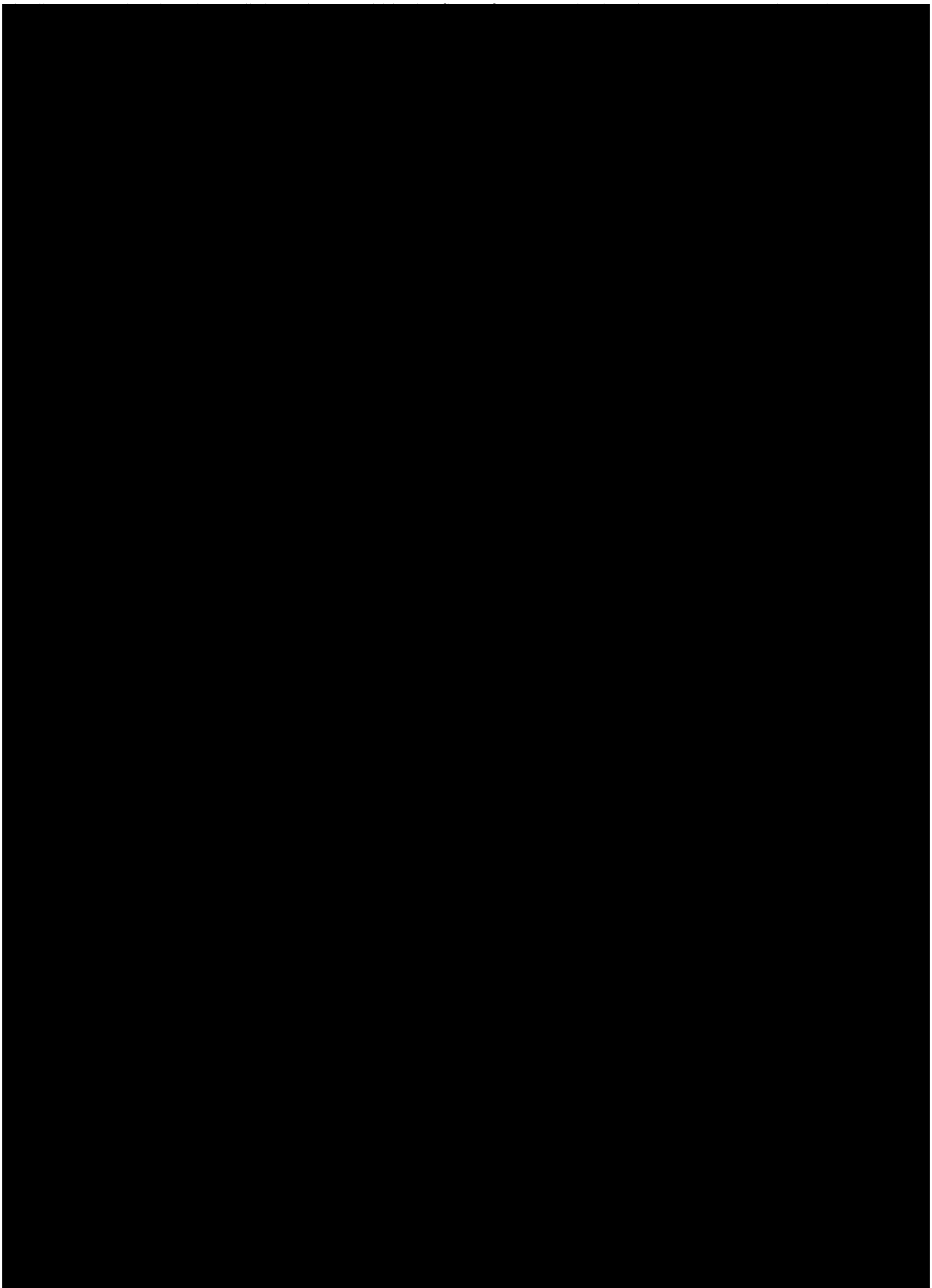

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Chapter 9 Conclusion

The last chapter of this thesis sums up the answers regarding the research questions and provides several recommendations. Advice for future research is given based on the topics: USEF, the current and improved charging strategies, quantitative costs and improvements regarding the Lombok experiments.

9.1 Main contribution

The main contributions of this thesis are:

- In-depth analysis on USEF from the perspective of an aggregator of EVs.
- Suggestions for improvements of USEF.
- Formulation of charging strategy based [redacted] as MILP with the objective to minimize the charging costs.
- Three proposals to improve the proposed optimal charging strategy as a MILP and MIQP.

9.2 Answer research questions

SQ1 *What are possible solutions to improve USEF?*

The following solutions are given to improve USEF:

- Define requirements with respect to the time the DSO is allowed to operate in the yellow and red regime. There is no consequence for the DSO to go to the red and orange operational phase, in which direct control methods could be used to decrease the capacity of the EVSEs connect to a congestion point. Decreasing the power output of EVSE by direct control by the DSO harms the income of the aggregator. It is necessary to include clear requirements on the functioning of the DSO to improve USEF. This requirement could for example be the maximum time the DSO is allowed to operate in the orange or red regime.
- Create a flex-request within a range instead of a flex-request that only asks to increase or decrease load. This will reduce the amount of iterations since an overshoot is not possible anymore.
- Remove the D-prognosis from the market-mechanism to reduce opportunities for gaming. Congestion can be predicted without the prognosis of the aggregator. Basing the need for flexibility on the party that offers the flexibility gives an incentive to create higher predictions than necessary. Therefore, removing the D-prognosis could help to reduce the opportunities for gaming.
- Increase collaboration between DSOs to work to a national flexibility market for congestion management at distribution level and prevent diversification of market mechanisms.
- Prevent locations that are congested to provide ancillary services to the TSO by collaborating between TSO and DSO at times that congestion is expected.
- Describe price-mechanisms or accept the flexibility offers imposed by the aggregator.

The fundamental issue of USEF is the inefficient allocation of costs described by the market. USEF describes that the DSO is willing to pay aggregators for decreasing or increasing the load in grid connections that are connected to the same congestion point when congestion is predicted. The location of these congestion points depends on the grid topology and might be at feeder level. This means that e.g. in a neighbourhood multiple congestion points are nearby one another. In Section 4.3.1, we provided the example of a user having enough flexibility to charge up to its demand at two EVSEs: one that is subjected to congestion and one that is not subjected to congestion. If the flex-requests are accepted by the aggregator for the congested EVSE, this creates an incentive for the aggregator to charge EV there. Consequently, this is an incentive for users to charge at the location with the expected congestion. As a result, more pressure on the already congested area might lead to a higher need to reinforce the grid. If the financial incentives are kept low, the user might not be motivated to alter its location – depending on the charging price. However, in the future, EVs might be driving autonomously, leading to more ease of use for the aggregator to control the EV to charge at a congested area.

SQ2 *What are criteria for an optimal smart charging strategy for aggregator of EVs when trading in a USEF compliant manner?*

In the following, four criteria are formulated to answer this question.

Criteria 1: Include network constraints in charging schedule of an aggregator that are able to adapt to flex-request send by the DSO. This flex-request limits the power through a congestion point during a specific PTU.

Criteria 2: Limit the power of all EVSEs connected to the same congestion point to a certain power in the case a flex-offer is placed.

Criteria 3: Create a D-prognosis that consist of of the expected electricity consumption on the next day. This is necessary to receive a flex-request from the DSO. The D-prognosis is created for all EVSEs connected to the same congestion point. However, since USEF does not include a correct financial incentive to make correct predictions, the aggregator might decide to send the prediction of uncontrolled loads to optimize its profit. Even if there is an incentive to create realistic D-prognosis it might be difficult for the aggregator to realise these, since the amount of EVSEs connected to one charging stations can be low. In the pilot project of USEF in Lombok only nine public EVSEs are connected to a congestion point.

Criteria 4: Include direct charging mode in the charging strategy. To make smart charging acceptable for users, aggregators need to include the charging requirements from their users into the charging schedule. This feature is currently implemented in the application of Jedlix. Such mode enables users to directly charge a part of their consumption right after connecting to the charging station. It is expected that a feature that provides the user more control over the charging strategy might increase the willingness to use smart charging technology.

SQ3 *What is an optimum smart charging strategy for EVs when trading flexibility on distribution level in a USEF compliant market?*

[redacted]

[redacted]

SQ4	*What is the quantitative impact on the smart charging costs of an aggregator when charging in an USEF compliant market?*

[redacted]

[redacted]tion management.

9.3 Recommendations for future research

Regarding USEF

- Explore further opportunities for implementation of location dependent dynamic grid tariffs or long-term contracts for the procurement of flexibility at distribution level. For aggregators of EVs, long term contracts are only a viable solution in the case the congested area has a high penetration of EVSEs and availability of EVs. Even if this is the case, long-term contracts are risky for aggregators of EVs. Ultimately, EVs need to be charged before the charging session is finished.
- Investigate incentives for creating correct D-prognosis or remove the D-prognosis from the market-mechanism. Without the D-prognosis, the DSO is still able to create an expectation on the congestion expected in each PTU, since this expectation is also based on the inflexible load in the grid.

Regarding the current charging strategy

- Research the practicalities of the proposed optimization strategies in a dynamic environment. In this research, we assume that the requirements of the user are known in advance and that the imbalance price is known since it is based on the historical imbalance price. The results of the quantitative impact of the USEF network constraints therefore present the minimum impact. In reality, the costs might be higher since the forecasted imbalance price might show a variance from the realized price. This risk needs to be taken into consideration by the aggregator and included in the price when including network constraints from USEF in the charging logic. Another assumption is that the user settings are known one day-ahead. In reality, the user settings of Jedlix are known at the start of the charging sessions.

- Investigate whether users are willing to accept changes in the direct charging mode by adding a fee and timespan to the direct charging mode. Research on user acceptance of smart charging is limited. Thus, it is unclear whether the direct charging mode increases the user acceptance of smart charging or how it should be implemented.

Regarding the improved charging strategies

- [redacted]
- [redacted] The current literature suggests that this feature could improve the user acceptance of smart charging. From the results, we found that the direct charging mode and the arrival time of the EVs interfere with the flex-requests. As a solution, three adaptations of the direct charging mode are presented. We assume that the user is willing to increase the time to fulfil the direct charging mode when a financial incentive is offered. Since, there is no information available for what price the user would accept the changes in the direct charging mode. Due to that reason, input values for a fee for users are suggested in this research. In the future, a user research could be executed to determine whether the direct charging mode increases the acceptance of smart charging. If this is the case, the price level and the implications for the delay in time should be tested to analyse whether users would accept the new configurations of the direct charging mode.

[redacted]

- [redacted]
- [redacted]

Regarding the experiments in Lombok

- The charging sessions are based on the arrival and the departure times of the dataset from Lombok. In addition, we assume that all EVs have the same availability. To make the situation mode realistic charging session with different user settings should be tested. This will most likely lead to a lower price for resolving congestion. Moreover, it will lead to a situation where the optimisation problem is better capable of including the network constraints into the optimization problem. Reason for this is that the EVs connected to the same congestion point also cause congestion. If less EVs are charging in the direct charging mode, less flex-requests can be expected. Note that the grid in Lombok was reinforced recently and that the likeliness of congestion therefore is low. Another solution could be to perform the same analysis with input data from an area that is more likely to be subjected to congestion.

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APPENDIX 1

A.1.1.Stakeholder analysis

This section presents an analysis on the stakeholders that are relevant for the trade of flexibility at distribution level with USEF. Each section consist of an analysis followed by the goal, objective and constraints that relevant for this stakeholder. The stakeholders analysed in the following sections in order of relevance for this research are:

- Aggregator of EVs
- EV owners
- DSO
- BRP
- Manufactures of EVs
- CSO

This stakeholder analysis is conducted after intensive collaboration with Jedlix (aggregator of EVs) and multiple conversations with Milo Broekmans (USEF expert.) from Stedin (DSO) In addition the author has visited meetings of the consortium of Smart Solar driving and a knowledge session organised by the USEF Foundation on the development of a flexibility market from the aggregator workstream (Dynamo). To gain more understanding the end-user using smart charging service the author visited an EV forum.

A.1.1.1. Aggregator of EVs

The goal of an aggregator of EVs is to monetize the flexibility of end-users by fulfilling their needs by minimizing the charging costs. Jedlix shares the savings made on the electricity market by returning a share of the profit to the owners of EVs that are offering flexibility. For aggregators of EVs this flexibility is the volume and timespan in which this volume should be charged. This reduction of charging cost leads to lower charging costs for end-users and in the case of maximisation of profits we assume that the aggregator will split cost with the EV owner. In addition the aggregator has to contract owners of EVs in a way that they adapt to smart charging technology without violating the needs of customers. It is of great importance that the aggregator makes smart charging appealing and accessible for EV owners. Therefore, Jedlix offers a feature to charge a certain amount of energy directly from the moment the EV starts charging, in other words it starts with dumb charging. With this feature the owner of EVs is ensured that the battery of the EV charges as soon as possible to a certain energy content.

Goals: offer smart charging and flexibility services to stakeholders.
Objectives: minimize charging costs for users, and create flex-offers for the DSO.
Constraints: the restrictions given by the manufacturer of the battery of the EV and physical limits of distribution grid and EV in the case the aggregator places a flex-offer.

A.1.1.2. EV owners

The goal of an EV owner here is to charge their EV with a smart charging service. The reason for using this extra service is personal and therefore defining objectives and constraints is rather difficult. However, EV owners are crucial in the trading process of flexibility, since their EV is ultimately the source of flexibility used by the aggregator. Research held in Germany among 237 EV drivers shows that features demanded by EV drivers include (Will & Schuller, 2016): a function to submit a minimum range; enable the customer to disallow smart charging and a function that enables customer to control the departure time. Further research on the user acceptance of smart charging is limited.
From feedback of users of Jedlix we found that EV owners are aware of grid tariffs and the impact that EVs have on the electricity grid. User feedback was given via personal mail contact and via an internet forum. One user of the Jedlix application mentioned “Even without financial compensation, my opinion is that we should get used to smart charging and have to help balancing the electricity”[1].This opinion is also supported by Will et. al (2016), where an analysis showed that there is a strong significance between the acceptance of smart charging and using smart charging for grid stability. Other strong significant driving factors for user acceptance of smart charging are: the

1 Retrieved from https://teslamotorsclub.com/tmc/threads/ervaringen-jedlix-slim-laden-app.85656/page-5#post-2057006

integration of RES and that smart charging fulfils the mobility needs of users. Another finding was that there was a weak significance in the customisation of the features for the individual needs of an EV owner.

Goal: charge EV with smart charging service.
Objective: related to personal preferences, possibly reduce charging costs, improve grid stability etc.
Constraints: related to personal preferences, i.e. the possibility to enable of disable smart charging/V2G/direct charging function.

A.1.1.3. DSO

The goal of the DSO is to have a distribution stable grid by efficient congestion management. In USEF this congestion management is done by buying flexibility services from aggregators. The DSO plays a significant role in determining congestion in the distribution network. By performing a grid-safety analysis one day-ahead the DSO decides whether a flex-request is necessary. By exchanging information with the aggregator flex-offers can placed and congestion can be avoided with the flexibility brought.

Goals: secure the supply of electricity.
Objectives:

- Stable operation of the distribution grid: security of supply is necessary to maintain stable operation.
- Maintain economical operation of the distribution grid: in the case the investment in flex is higher than reinforcement of the grid
- Develop appropriate planning of maintenance and operation of the distribution grid
- For USEF areas maintain in the green and yellow operational regime.

Constraints: ever since the liberation of the European Energy markets DSO are monopolies that are in charge of controlling areas of the distribution electricity grid, therefore the are obliged to facilitate market players active in those regions.

A.1.1.4. TSO

The goal of the TSO is to maintain a stable transmission grid. The TSO has a balancing mechanism in place that incentivises BRPs to balance their portfolio and create day-ahead E-programs. In the case the BRP is not in balance, the imbalance price has to be paid by the aggregator. When trading with passive imbalance control the aggregator trades with the BRP to help restore the imbalance, this means that the aggregator indirectly offers balancing services to the TSO. The price signals on the imbalance market are predicted and provided by the BRP to the aggregator, but are depending on the balancing system maintained by the TSO.

Goals: secure the supply of electricity over the transmission grid.
Objectives:

- Stable operation of the transmission grid
- Maintain economical operation of the transmission grid: by utilising the balancing mechanism, reserves and alterations of the transmission grid.

Constraints: the physical limits of the transmission grid.

A.1.1.5. BRP

The goal of the BRP is maintaining the energy balance. If loads are shifted in time i.e. by an smart charging strategy the normal prediction of the BRP are affected. Since the smart charging strategy affects the load pattern of the end-user the BRP needs to be informed or compensated for the activities of the aggregator. The BRP, in the specific case of Jedlix, is fulfilled by Eneco Energy Trade. To keep balanced the BRP and the aggregator could optimize both business case by exchanging information. The aggregator can use the flexibility services of the aggregator to restore its own imbalance. The aggregator needs a BRP to offer services to the TSO.

Goals: Balancing its portfolio.
Objectives: exchanging information on portfolio balance, electricity price predictions and scheduling of loads.
Constraints: E-programs have to be submitted before 12 p.m. day-ahead.

A.1.1.6. EV manufacturers

When smart charging an EV the battery of an EV is steered by an external signal, in this case an aggregator, the most important is to maintain the lifetime of the battery. In the case of V2G the battery of the EV will be used for a different purpose than the manufacture of EV has designed the battery for, namely discharging for driving purposes and charging for powering the battery. [redacted]

In the case of The USEF pilot in Lombok one of the partners is Renault, which is a manufacturer of EVs, has committed to develop a V2G system (Renault Press, 2016). Therefore the possibility of V2G is modelled in the smart charging strategy. However the loss of guarantee on the capacity of the battery should be carefully be considered by the party developing the smart charging strategy. V2G should be limited and in the case the owner of the EV is losing the guarantee on the lifetime of the battery, V2G should be penalized in the objective function.

Goal: guarantee the owner of EV with stable battery capacity.
Objective: limit the V2G or the amount of V2G.
Constraints: physical capacity of the battery.

A.1.1.7. CSO

The CSO maintains and operate public EVSE. For the aggregator it is possible to collaborate with the CSO, for example when creating a connection with the controller in the EVSE that can control the smart charging method. With this connection the aggregator could send a smart charging strategy signal to the EVSE to be able to smart charge an EV.

Goal: of the CSO is to maintain stable operation of the EVSE and attract customers.
Objective: guarantee the owner of EV with stable battery capacity.
Constraints: physical capacity of the battery.

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GLOSSARY

Congestion point	In USEF a congestion point is a component of the distribution grid that might be subjected to congestion, e.g. feeders or transformers.
Congestion	The over-voltage or overheating of components in the distribution grid.
Direct charging	The direct charging mode is a mode in which the charging process of the EV is executed directly after the time the EV is connected to the EVSE.
E-program	Each day, BRP are responsible to hand in a program that consists of the expected consumption and production for each PTU for the following day to the TSO.
EAN	European article numbers are the unique identifications numbers of connections to the electricity grid. There is a large variation of connection possible: households, industrial connection
EV	Electrical vehicle is a battery powered car.
EVSE	Electrical vehicle supply equipment is the same as a charging station and refers to the product that is able to charge the EV.
Flex-offer	In USEF a flex-offer is the reaction of the aggregator to the flex-request of the DSO. This offer includes the amount of load that can be altered during a specific PTU.
Flex-request	In USEF a flex-request is the request of a DSO to aggregators to alter their load during a specific PTU.
Flexible charging	The flexible charging mode is activated after the direct charging mode. It refers to the charging pattern that is based on the imbalance price, energy demand and available duration of the charging session.
Gaming	The deliberate manipulation of a market by market players to achieve certain goals which usually lead to an inefficient market design.
Imbalance	Imbalance is the situation were the production and consumption of electricity is not in equilibrium.
PTU	Program time unit refers to the quarterly time slots used in the power market.
Smart charging	The alteration of a charging schedule of EVs based upon an external signal.
V2G	Vehicle to grid (V2G) refers to the discharge of the battery of the EV.
Range anxiety	Drivers of EVs can experience a concern that the range of the EV is insufficient to reach the desired destination.

NOMENCLATURE

η_i^{V2G} Vehicle to grid discharging efficiency for each EV [p.u.]

η_i^{G2V} Grid to vehicle charging efficiency for each EV [p.u.]

λ_t^{Bench} Benchmarket price of the electricity [Euro/kWh]

$\lambda_i^{Degradation}$ Degradation cost of the battery for using V2G mode [Euro/kWh]

λ_i^{Direct} Penalty for violating user settings for direct charging mode [Euro/kWh]

λ_t^{Feed} Feed-in imbalance for electricity price during time periode t [Euro/kwh]

λ_t^{Take} Imbalance price for electricity taken from grid during time periode t [Euro/kwh]

Δ Duration of one PTU in hours [h]

$\upsilon_{i,t}$ Binary variable that enables or disables the direct charging mode, (0) disables direct charging and (1) enables direct charging {0,1}

$\omega_{i,t}$ Binary variable that enables or disables the flexible and very flexible charging mode, (0) disables flexible charging and (1) enables flexible charging {0,1}

$\delta_{i,t}$ Binary variable that prevents V2G and G2V to occur at the same time for each EV, (0) enables V2G and (1) enables G2V {0,1}

B Ratio of the battery after which V2G is allowed

$d_{i,t}$ Relaxation variable corresponding to the direct mode charging constraint [kW]

$e_{i,t}$ Energy content of EV [kWh]

$E_i^{Arrival}$ Energy content at time of arrival [kWh]

E_i^{D} Energy content of each EV desired by direct charging [kWh]

$E_i^{Dep.min}$ Minimum energy content that should be charged before departure [kWh]

E_i^{EVmax} Maximum capacity of the battery [kWh]

E_i^{EVmin} Minimum capacity of the battery [kWh]

F_t^{max} Maximum power through congestion point during t [kW]

F_t^{min} Minimum power through congestion point during t [kW]

P_i^{EV} Maximum absorption power of battery of EV [kW]

P_i^{EVSE} Maximum power output EVSE [kW]

$p_{i,t}^{G2V}$ Power from grid to vehicle [kW]

$P_{i,t}^{G2Vmax}$ Maximum G2V power [kW]

P_t^{inflex} Inflexible load [k]

$P_{i,t}^{V2Gmax}$ Maximum V2G power [kW]

$p_{i,t}^{V2G}$ Power from vehicle to grid [kW]

$^{inflex}_{t}$ Reactive power from the inflexible load [V r]

$^{EV}_{t}$ Reactive power from EVs connected [V r]

$|S|$ pparent power [kVa]

$T_i^{Arrival}$ Time of arrival

$T_i^{Depart\ re}$ Time of departure

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Lay-out I.M.A. Stegmann