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Market Evaluation for the Business Model of an Electric Vehicle Aggregator

An Analysis of the Value of Flexibility in the German Power Markets

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I. Abstract

With a rising share of electric vehicles in the German market, adequate adoption of those vehicles through a smart charging approach becomes crucial for the successful integration into the grid. Market integration of electric vehicles via an electric vehicle aggregator could not only avoid demand peaks but could also turn out to be a viable business model. The following thesis will assess whether the German market is attractive for the business model of an electric vehicle aggregator. Starting with a qualitative analysis of the German energy market, the thesis will elaborate on how electric cars could participate in the wholesale and balancing markets. In a quantitative analysis, the paper will then identify patterns in the German energy markets. From this price analysis, the thesis will identify three scenarios for which a bidding optimization will be performed. Scenario A represents the participation of electric vehicles in the balancing markets, Scenario B focuses on demand shifting through smart charging, and Scenario C resembles the dumb charging approach. Thanks to the collaboration with the Nordic start-up Tibber, the optimization includes data on real driving patterns from 152 electric vehicles. While smart charging decreases the charging costs of the observed fleet by around 15%, participation in the balancing market would eliminate the charging costs completely and even lead to additional income for the aggregator. With this result, the German market appears to be more attractive for power aggregators than the Norwegian market, in which Tibber is currently active. Future developments in the German energy sector could strengthen or threaten the business model of an electric vehicle aggregator. While declining prices in the balancing markets are one of the major threats, a further increase in the market share of electric vehicles and a rising degree of intermittent renewable energy production could reinforce the business model.

II. Contents

III. List of Abbreviations

aFRR	automatic Frequency Restoration Reserve
BDEW	German Organization for Energy and Water Industry
BEV	Battery Electric Vehicle
BRP	Balancing Responsible Party
CO_2	Carbon Dioxide
DSM	Demand Side Management
DSO	Distribution System Operator
EC	European Commission
EEG	Erneuerbare Energien Gesetz (Law that includes the feed-in tariffs in Germany)
EnWG	"Energiewirtschaftsgesetz" (General law for energy economy in Germany)
EU	European Union
EV	Electric Vehicle
FCR	Frequency Containment Reserve
Hz	Hertz
kW	Kilowatt
kWh	Kilowatt hour
mFRR	manual Frequency Restoration Reserve
MW	Megawatt
MWh	Megawatt hour
NRV	"Netzregelverbund" (Cooperation of the different TSOs in Germany)

PCR	Primary Control Reserve
PHEV	Plug-in Hybrid Electric Vehicle
SCR	Secondary Control Reserve
TCR	Tertiary Control Reserve
TSO	Transmission System Operator
TWh	Terawatt hour

Note: Balancing and regulatory or regulating markets are used as synonyms in this thesis

FCR & PCR describe the same concept

SCR & aFRR describe the same concept

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1. Introduction

1.1 Relevance of the Research topic

The German energy sector is facing significant challenges. The quickly increasing share of intermittent renewable energies requires highly flexible energy management and threatens grid stability (Brunner, 2014). At the same time, a slow but constant rise of electric mobility could either be an additional threat by aggravating the peak consumption and pressuring the distribution grid or be the solution for the integration of fluctuating renewable energies and the balance of the grid frequency (Uhlig et al., 2017). An intelligent grid-integration of electric vehicles (EVs) through smart charging will be essential for the energy and the mobility transition in Germany. It could balance the intermittent renewables and, at the same time, reduce costs for EVs (Kempton & Tomic, 2005). However, this adoption will only become a reality if the right incentives for demand shifting or smart charging are in place. Due to the ineligibility of private customers to engage in wholesale markets, the business model of an electric vehicle aggregator (EV-Aggregator) might play an essential role in the establishment of smart charging for private electric car owners. This thesis is an attempt to understand the market dynamics for the flexibility provided by EVs. The thesis will analyze the German wholesale and balancing markets and investigate how an EV-Aggregator can optimally sell the charging flexibility of its fleet on the market.

Thereby, the thesis offers insights into the market potential for EVs as flexibility provider in the German electricity markets. Companies could utilize the information and findings illustrated in this paper to consider whether the establishment of the EV-Aggregator business model is strategically wise. Companies that already established the business model successfully in other markets can use this thesis to evaluate, whether a market entry in Germany seems reasonable. Likewise, regulators and policymakers can consider whether the German energy markets offer enough incentives for electric cars to perform demand-side-management (DSM). Moreover, price patterns discovered in the market price analysis can be used by traders that seek for arbitrage trading in the German energy markets.

1.2 Literature Review and Research Gap

There is a variety of articles and papers about the integration of EVs into the grid. Thereby, some authors present a rather holistic view: Kempton & Tomic (2015), for example, analyze the grid integration of EVs, concluding that integration into the electricity markets seems reasonable and beneficial for society. Other authors already focus on one market. Koliou, Eid, Chaves-Ávila, & Hakvoort (2014) investigate the German market for demand response. While they already discuss the concept of a company that aggregates small demand-response loads, they do neglect the possibilities of demand-response with EVs and focus more on household demand response.

Papadaskalopoulos and Strbac (2013) tackle the decentralized participation of flexible demand like EVs from another ankle. Their paper focuses on the electricity market design for EVs and centers around the question of how the market design would have to change to provide more incentives for micro flexibilities (Papadaskalopoulos & Strbac, 2013).

When looking at articles about the grid integration of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), one must distinguish between the bi- and the unidirectional approach. Whereas the bidirectional approach allows for grid-to-vehicle and vehicle-to-grid electricity flows (Uddin, Dubarry, & Glick, 2018) and thereby often include battery degradation analysis, the unidirectional path merely investigates the load shifting potential of EVs (grid-to-vehicle) (Schill, 2011).

Closest to this thesis are the scientific works of Anderson et al. (2010), Dalton (2018) and Kahlen & Ketter (2015). All of them analyze specific markets or case studies on the topic of EV integration. While Dallinger, Gerda, and Wietschel (2012) focus more on the enhancement of the system stability, the three earlier mentioned papers focus on the remuneration for offering the flexibility of BEVs and PHEVs at the market. Thereby, their works come close to a business case analysis. Dalton (2018) investigates in his work the optimal bidding strategy for a vehicle aggregator in Sweden and Norway, basing his methodology on the work of Vagropoulos & Bakirtzis (2013). Anderson et al. (2010) investigate the Swedish and German market within their case study. In contrary to Dalton, they utilize PHEVs and not BEVs for their calculations. Another difference is that they are not considering the driving patterns of the car owners but assume that 80% of the vehicle fleet is available for grid services any time.

Similar to the work by Anderson et al., the research by Kahlen & Ketter from the Erasmus University of Rotterdam investigates bidirectional charging in the German market. Together with the car-sharing service Car2Go, they developed an algorithm to decide whether a car in a car-sharing fleet should perform grid services or should be rentable for customers. Even though renting out cars results in higher profits, using the idle cars for grid service increased the profits by 7-12% for the sharing provider in their case study (Kahlen & Ketter, 2015).

In contrast to the case studies detected, that discuss the need for flexibility in the German electricity market, this thesis performs first a qualitative analysis on the rising share of EVs and the challenges, which arise with this growing market share. Subsequently, the thesis investigates the market design of the German energy markets to then perform a market price analysis of the German electricity markets. Next, findings of the qualitative and quantitative part are used to execute an optimization of an ideal bidding strategy for an EV-Aggregator. A major part of the thesis focuses on the detailed market price analysis, which can help EV-Aggregators to understand the price dynamics within the energy markets. This analysis enables aggregators to smartly allocate the capacity of their fleet in the wholesale markets and optimize their bidding strategy for the balancing markets.

Several institutions in the German energy sector such as the German Organization for Energy and Water Industry (BDEW), Fraunhofer or Bundesnetzagentur regularly publish data on electricity prices. While the BDEW focuses on the electricity price development for households as the basis for political recommendations, the Bundesnetzagentur also publishes data on volumes and prices in wholesale and balancing markets (Bundesnetzagentur, 2018b; Schwencke & Bantle, 2019). Fraunhofer Institute offers interactive charts where one can select price developments at specific times (Fraunhofer, 2019b). More detailed market analyses, e.g. on price volatilities, often date back more than five years and have a different focus, which makes them impractical for this thesis (Schnorrenberg, 2006). The literature research executed prior to this thesis could not find scientific analyses on recent price and volatility developments that could serve as market evaluation criteria for EV-Aggregators.

Hence, data provided by various institutions have been used to perform detailed analyses which are essential for EV-Aggregators. In combination with the optimization analysis, the results gathered from the market price analysis allow deciding whether the business model of an EV-Aggregator is attractive in the German market currently. Due to changing prices at the power exchanges and upcoming changes in market design, the results from the market price analysis and the bidding optimization are merely valid for a limited time horizon. For this reason, the qualitative analysis of the market and the assessment of the business model in chapter 7 was added to allow for an evaluation regarding the feasibility of the business model in future times.

By explaining the market design and price building mechanisms, the thesis provides insights on how the energy sector in Germany is constructed, which parts of the German market design are beneficial, and which are unfavorable for EV-Aggregators. This combination of features makes the thesis highly insightful. While most of the just mentioned authors focus their analysis on quantifying the momentary value achievable through an EV-Aggregator, this thesis tries to paint more than a transient picture. Beyond the result of the optimization, the thesis will estimate how future development might influence the business model of an EV-Aggregator.

1.3 Research Question and Outline

Research Question:

Is the German energy market lucrative for the business model of an EV-Aggregator?

In chapter 2, this thesis will depict the market share of electric cars in Germany and state certain political instruments that might foster the spread of BEVs. Moreover, the chapter reviews the issue of integration of BEVs into the grid and presents scenarios on the development of EV sales in Germany. A more detailed description of the methodology can be found in chapter 3. For the successful integration of BEVs, knowledge about the German energy market design and energy industry is integral. Hence, chapter 4 will describe the German energy sector with a focus on price developments and market design. The quantitative market price analysis follows in chapter 5. This chapter will use price information which is publicly available to identify patterns in the electricity prices and observe how specific markets correlate with each other. Price patterns are highly interesting for EV-Aggregators and will be used as a basis for the development of three scenarios. For these scenarios, chapter 6 will perform a bidding optimization based on the market price data calculated and the vehicle data given by Tibber. Paired with the insights from the qualitative analysis, the results from this bidding analysis allow an assessment of the attractiveness of the German market for an EV-Aggregator, which can be found in chapter 7. Concludingly, the thesis will summarize the results and reflect on the findings in chapter 8. Concludingly, chapter 9 suggests in which areas further research should be conducted.

1.4 Contribution

Thanks to a collaboration with the Norwegian/Swedish energy company Tibber, this thesis has had access to data on driving patterns of 152 private EVs. Tibber is a start-up that operates as an electricity retailer for private households in Norway and Sweden with 100% renewable energy. Additionally, the company offers smart home services such as optimizing comfort, control, and cost through artificial intelligence as well as acting as a reseller of hardware such as smart-thermostats. Concerning EVs, smart charging is carried out to minimize the charging cost against the Day-Ahead prices. Tibber currently supports smart charging solutions for BMW, Tesla, Volkswagen, and others. Within the thesis, the German market will be compared regularly with the Nordic energy markets. This benchmark is undertaken to simplify the evaluation of the German market for Tibber. Since the company so far is not active in the German market, the vehicle data provided by Tibber stems from the Norwegian market. The thesis assumes driving patterns in Germany and Norway to be alike to transfer the results of the car fleet to the German market.

2. Integration of electric cars in the energy sector

2.1 Development of Electric Cars in Germany

The last years have not been the most glorious period for the German car industry. Instead of catching the public's attention with new EVs, articles about "Dieselgate" were dominant in the associated press. Indeed, the sales of BEVs and PHEVs in Germany until 2016 remained lower than those of France and the Netherlands even though the potential market of Germany is larger (IEA, 2018).

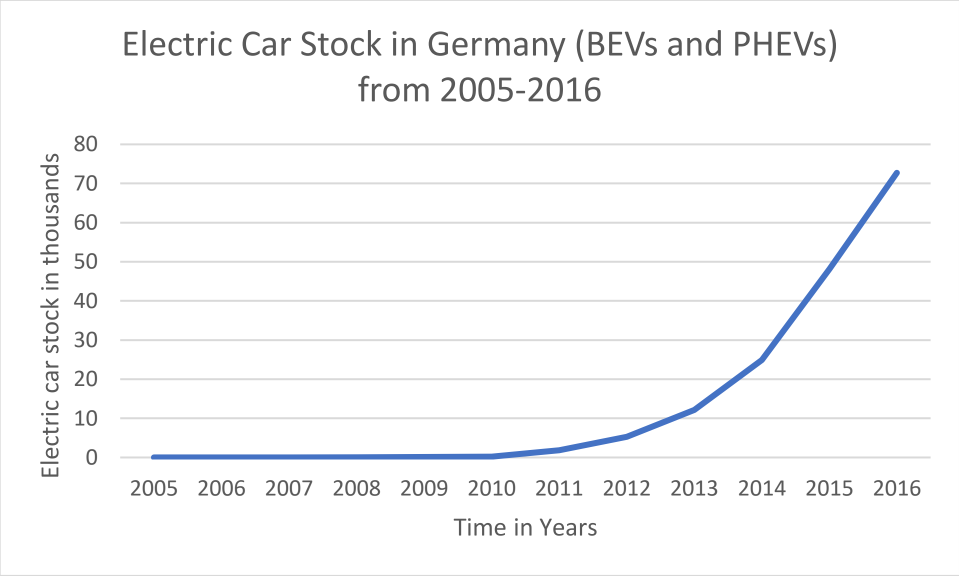


Figure 1 Development of Electric Car Stock in Germany (IEA, 2018)

The political goal to establish one million BEVs on German streets by 2020 is no longer achievable. With only 1.6% of BEVs on the street, Germany remains far from its own goals and even further from world leading countries like Norway with its 39% market share of EVs (IEA, 2018; BMWi, 2018).

However, while the image of many car manufacturers still seems shattered by Dieselgate, German car manufacturers are starting to change their strategy towards electric driving. By now, German car manufacturers offer 32 different electric models, and more BEVs are announced to hit the market in the following years. (BMWI, Elektromobilität, 2018). This does not go unnoticed by customers. Germany and Japan are the markets with the most substantial growth rate in BEV and PHEV sales in 2017 (IEA, 2018). Car sales in Germany more than doubled from 25,154 in 2016 to 54,492 in 2017 (BEV growth of 120% and PHEV growth of 114%) (BMWi, 2018). Thereby, Germany now is the country which has the fourth most EVs on the roads.

2.2 Political Incentives

2.2.1 On a European Level

The Paris Agreement aims, amongst other things, on a reduction of CO_2 emissions in the transportation sector. Starting in 2021, there will be a limit of 95 gCO_2/km for newly sold cars (Haan, Bianchetti, Rosser, & Frantz, 2018). These limits will be tightened further in the years to come. In November 2017 the European Commission (EC) proposed a target of 15 % CO_2 reduction until 2025 and 30 % reduction until 2030. Furthermore, the proposal includes a scheme to allocate emission targets to every car manufacturer – including punishments of 95 € per gCO_2/km if goals will not be met (EC, 2018).

Given that a typical PHEV emits 80 gCO_2/km, these limits will only be achieved when a certain amount of the car fleet will be electric. Together with an emission reduction aim of 60 % less CO_2 emissions in the transport sector (compared to 1990), this restriction will demand a significant degree of electric mobility in Europe (EC, 2018; IEA, 2018).

2.2.2 On a German Level

The national government transforms the European Directives into national law. To foster the acquisition and usage of EVs, the German government introduced a variety of supporting schemes in May 2016 (BMWi, 2019b). The incentive scheme includes investment incentives, incentives for the construction of additional charging infrastructure, tax cuts, and other benefits for drivers of EVs. Combined, the incentives amount to a sum of almost one billion € in governmental support for electric mobility (BMWi, 2019b). Thereby, the German government pursues its aim to develop Germany into one of the leading markets for electric mobility, including incentives like:

- A buyer´s premium that amounts to a sum of 4,000 € for the acquisition of an BEV and 3,000 € for the acquisition of a PHEV – under the condition that the price of the purchased vehicle lies beneath 60,000 € (BMWi, 2019b).

- An investment of 3,000,000 € into the charging infrastructure – 2 million for fast-charging infrastructure and one million for regular charging stations (BMWi, 2019b).
- Tax cuts, including an exemption from the Kraftfahrzeugsteuer (a tax that must be paid annually by a car owner) and tax exemption from the income tax when electric cars are charged at the workplace.
- Additional benefits that are incorporated within the "Elektromobilitätsgesetz" (electric mobility law). The law encloses benefits such as the allowance to use the bus lane and the possibility for communities to offer cheaper or free parking spots for electric cars (Bundesregierung, 2019).

2.3 Market Projections

In Germany, many BEVs still have a significant cost disadvantage compared to internal combustion engines. However, this is about to change. A significant part of the price of a BEV can be traced back to the battery of the car. Within the last years, the cost of lithium batteries has decreased significantly from year to year due to economies of scale and process innovation. From 2011 to 2018 the prices of lithium batteries fell by almost two thirds (Haan et al., 2018)

Even though this development currently dampens, economies of scale will further decrease the cost of battery packs sharply. The potential for optimization of lithium batteries still is immense and will reduce prices of electric mobility and fuel the sales of BVEs and PHEV (Maier, 2019).

At the same time, car manufacturers are determined to change their fleet towards electric mobility. Daimler is investing 42 billion € in electric driving and Volkswagen just announced that they will spend 57 billion € in the development of batteries and another 34 billion € into electric mobility in general until 2025 (Brien, 2019). This fuels phantasies of a future dominance of electric transportation in Germany.

In general, there exists a vast variety of scenarios for the development of the market share of BEVs and PHEVs in Germany. At this point, the most recent and most specific scenario analysis has been performed by Haan, et al. (2018). Considering scenarios of Shell, Fraunhofer, and PWC, they performed a microsimulation of the car market every year in the period from 2018 to 2035. The authors differentiate three scenarios:

Business As Usual Scenario (BAU): The BAU scenario takes into account the current policies and incentive schemes, but assumes no fundamental changes from the current state of the art.

Technology-Focused Mobility Scenario (TFM): The TFM scenario extrapolates the developments that will take place when the European Union (EU) introduces the planned restrictions for CO_2 emissions. Furthermore, it considers the innovativeness of car manufacturers and the changes in the mindset of private customers when buying cars.

Climate Forced Mobility Scenario (CFM): The CFM scenario acknowledges future goals for the limitation of CO_2 in the mobility sector. Also, it includes a quota scheme for sustainable mobility and the ban of internal combustion engines from German streets. (Haan et al., 2018)

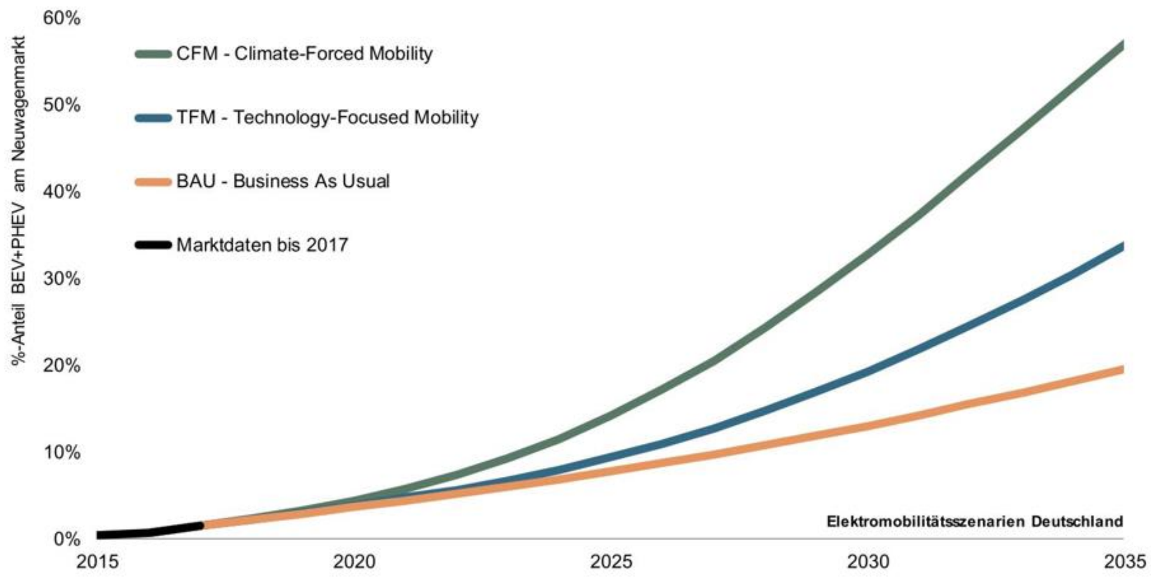


Figure 2: Electromobility Scenarios in Germany(Haan et al., p. 17)

Figure 2 depicts the relative sales of BEVs and PHEVs in the three different scenarios. In the CFM scenario, approximately 30% of the newly registered cars will be electric in 2030. In contrast, the business as usual scenario suggests a rather linear growth of electric mobility sales in Germany with only around 10% electric cars by 2030 (Haan et al., 2018). Although the share of EVs is rising, one must note that the overall market share is still significantly smaller than in one of Tibbers core markets; Norway. Even with the climate forced scenario, the relative amount of EVs in Germany in 2030 will be lower than the percentage of new-sold EVs in Norway in 2018 (Berggreen, 2019).

2.4 Short-term Effects on the Electricity Grid

Depending on the scenario, the electricity demand of EVs could reach 2-8% of the overall electricity demand in Germany 2017 by the year 2040 (Haan et al., 2018). This increase as such would not be a problem for a country like Germany that is still characterized by overcapacity. However, electric cars could aggravate the issue of the time of use of electricity by exacerbating the evening peak electricity demand. Nowadays, most cars are charged after the so-called uncontrolled or dumb charging principle. As soon as the driver comes home from work, he plugs in his EV and charges it for the next morning. Since most cars arrive at home after work at around 6 pm the uncontrolled charging principle increases the already existing demand peak at around 6 pm significantly.

Covering the demand in peak times with an energy mix made up of intermittent renewables is already a challenge today. Possible solutions can be the implementation of charging infrastructure at workplaces to benefit from solar peaks or the demand shifting through an EV-Aggregator, which this thesis will analyze intensively. The dumb charging principle, however, will exacerbate the problem of demand peaks (Dallinger et al., 2012; Schill, 2011).

Furthermore, the distribution grid in Germany is not built to deal with excessive loads within the demand peaks. A massive roll-out of EVs would require major investments in the distribution grid to avoid black-outs through uncontrolled charging (BMWi, 2018). Parts of these costs could be saved by implementing an intelligent infrastructure with smart charging and DSM principles where drivers will be incentivized to shift their charging to off-peak times, e.g. in the middle of the night where the demand for electricity and the electricity prices are low (Vallogiani, Ketter, Collins, & Zhdanov, n.d.).

2.5 Demand Side Management with Electric Vehicles

> *"The term Demand Side Management (DSM) is used to refer to a group of actions designed to efficiently manage a site's energy consumption with the aim of cutting the costs incurred for the supply of electrical energy, from grid charges and general system charges, including taxes.*
>
> *The aim of these optimisation actions is to modify features of electricity consumption with reference to the overall consumption picture, consumption time profile, contractual supply parameters (contractual power and grid connection parameters) in order to achieve savings in electricity charges."* (ENEL X, 2018, para 1-2)

While the increasing market share of electric cars could pressure the grid through dumb charging, the sheer amount of battery capacity installed in BEVs offers huge potentials for DSM. Thereby, cars could be a potential resource for the heavily needed flexibility in the grid (Ottesen et. al., 2018). The method of implementation of electric cars in the grid will decide whether the rising market share will become a nightmare for grid operators or the solution to integrate intermittent renewables to the electricity grid.

Currently, there are hardly any solutions for the smart integration of electric cars to the grid in Germany. Especially the participation of pooled EVs on the balancing market has not yet been realized. Even though DSM and the access to balancing markets should be technology neutral, the approach of using the flexibility of private households is barely touched in Germany. Due to the complicated pre-qualification of pooled generation, only a few companies are offering regulating power from batteries on the German balancing market, amongst them are Ampard and Sonnen (Ampard, n.d. ; Sonnen, 2019)

However, none of those have touched the flexibility potential of electric cars, yet. Vehicles are cheap per unit of power and utilized in only 4% of the time, which potentially makes them available to perform services for grid stability in 96% of the time (Kempton & Tomic, 2005). Even though vehicles are not plugged in the whole time they are parked, letting BEVs participate in grid regulation would create huge synergy effects by offering cheap flexibility and making EVs more affordable through new value creation.

Anderson et al. (2010) estimate in their article from 2010 that already 2.25million PHEVs (5.5% of the German car fleet) would cover the total demand for regulating power in Germany.

However, they might overestimate the power of electric cars by using improbable assumptions like:

- Vehicles are connected to 80% of the time
- The cars that have a full or empty tank are neglectable

The fleet data provided by Tibber demonstrates that these two assumptions are improbable. Still, the study by Anderson et al. shows that the potential of regulating power provided by private cars should be further investigated.

Since the balancing market requires minimum capacities from participants, individual car owners cannot participate directly in the balancing market. An EV-Aggregator, however, could combine single EVs virtually to a car fleet in order to ensure higher capacities. By aggregating the vehicles an aggregator can pave the way to a participation in the wholesale and balancing markets and share profits with individual car owners. Hence, an EV-Aggregator could make "market access possible for demand-side flexibility, by reducing transaction costs and pooling small volumes to large enough [volumes] for market participation" (Ottesen, Tomasgard, & Fleten, 2018, p. 120).

2.6 The business model of an EV-Aggregator

The following thesis will investigate the potential of the Business Model of an EV-Aggregator in the German market. Therefore, it is essential to define and explain the Business Model briefly.

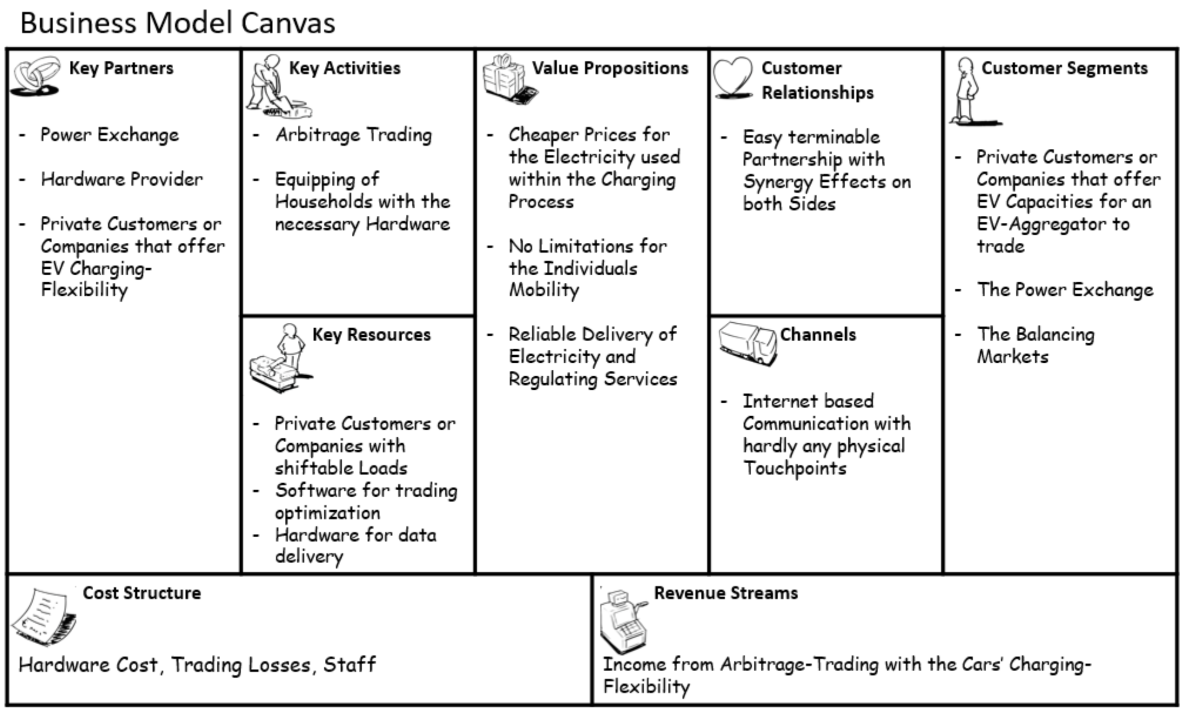


Figure 3 Business Model Canvas EV-Aggregator own Display based on (Startplatz, n.d.)

An EV-Aggregators virtually aggregates different BEVs and PHEVs. Potentially aggregators could shift electricity demand from other origins as well. Tibber, for example, shifts electricity demand for heating in Norway. Since heating is mostly not electrical in Germany, the business model analysis in this thesis will focus on EVs as shiftable demand units.

The cars can stem from companies as well as from private customers. The aggregator provides the charging management for EVs. For the private car owners, he offers a cheaper electricity price without compromising on the experienced convenience. The value creation takes place when the aggregator starts to interact with the electricity markets. Most private cars standstill in 96 % of the time (Kempton & Tomic, 2005). In the evening, private EVs tend to be connected to the individual's wall box to charge for the next day. With battery capacities between 20 kWh and 100 kWh and differences in charging power from 2 kW to 50 kW, charging times can vary significantly (The Mobility House, 2018). Since car batteries are rarely empty when the driver arrives at home, a car typically needs around 3.29 hours to recharge their batteries but is typically connected to the wall box for 8.30 hours from the evening to the following morning (calculated average from the fleet data provided by Tibber). Whether the car is charged directly at 6 pm when the owner returns home, or later in the night, usually is irrelevant for the car owner. That offers, on average, five hours during which the

EV-Aggregator can decide flexibly to buy/sell electricity for/from the car. The aggregator can use this flexibility in two different ways:

1. The aggregator shifts the charging demand to hours where the electricity prices are lower, thus, achieving cost savings.
2. The aggregator participates in the balancing market, offering the car as positive regulation (vehicle-to-grid) or negative regulation (grid-to-vehicle) for the transmission system operator (TSO) to keep the grid stable and earns money by doing so.

A necessary pre-requisite is the metering infrastructure. The business model needs a smart meter to enable the accurate measuring of electricity flows. The key activity for an aggregator is the trading with electricity and capacity at the electricity markets. By their price levels, the markets define the profits of the aggregator. Private car owners are the main resource and primary customer at the same time. The other major customer of the EV-Aggregator is the TSO or the balance responsible parties (BRPs) because the aggregator can offer its charging flexibility as regulatory power so that the TSO or the BRPs can keep the grid stable.

Besides that, distribution system operators (DSOs) could be customers, too. The operators of the distribution grid have a potentially high interest for a grid-friendly integration of electric cars. However, there is no market for providing these services on a distribution grid level in Germany, yet. Thus, this business opportunity is not focused on in this paper.

With a rising share of intermittent renewable energies in Germany, it will become more challenging to keep demand and supply in balance. To avoid grid damage and blackouts, the whole energy system must become more flexible, and demand-side-management will play an integral part in the German energy sector (Brunner, 2014). Through offering flexibility, the business model of an EV-Aggregator may become a central part of the energy system to balance the frequency and prevent the grid from damages. In the following, the thesis will investigate whether the German market offers satisfactory conditions for companies to conduct the business model of an EV-Aggregator.

3. Methodology

3.1 Qualitative Analysis

Since the business model of an EV-Aggregator highly depends on the market prices for electricity, this thesis will perform a detailed market analysis of the German market. In the first step, the German electricity market is described in detail in a qualitative market analysis.

This establishes an understanding of the market design, which is essential for EV-Aggregators, because it helps to understand how the different markets and their design influence the business model of an aggregator. During the qualitative analysis and the market price analysis in the subsequent chapter, the German market will be repeatedly compared with the Norwegian market because the contributing company. This allows Tibber, which is currently active in the Nordic market, to judge on the suitability of the German market for their business model.

The qualitative market analysis will begin with a quick overview of the German energy sector. Afterwards, it will explain the German energy market design whilst focusing on the balancing markets. This focus is due to two reasons; firstly, the substantial changes in the balancing market system in recent years and secondly, the importance of the balancing markets for the business model of an EV-Aggregator. The qualitative analysis is used as a basis for the market price analysis and the qualitative SWOT analysis, which can be found in the chapter "Assessment of the EV-Aggregator Business Model in Germany".

3.2 Market Price Analysis

3.2.1 Scope

After a first qualitative analysis of the German market, the thesis will proceed with the market price analysis. Amongst others, it will investigate average price differences, seasonal price dependencies, and the volatility of prices in the electricity markets in Germany and Norway. A market price analysis is essential for the evaluation of the business model of an EV-Aggregator because it helps to understand the underlying price dynamics.

Within the market price analysis chapter, a series of market price analyses are performed. These price analyses aim at identifying price patterns in the German wholesale and balancing markets which seem beneficial for an EV-Aggregator. These price patterns can ideally be used by the EV-Aggregator to allocate the capacity of the EVs optimally in the market. Even though it would be insightful to investigate the origin of certain price patterns, searching for explanations for every price pattern identified would be out of the scope of this master thesis. Amongst others, the chapter 6.1.5 Intermarket Spread reveals some interesting price patterns. Finding an explanation for those patterns would require lengthy analyses. Instead of devoting resources on finding reasons for those price patterns, the thesis aims at identifying as many price patterns as possible for EV-Aggregators to systematically use deviations in market prices to maximize their value creation.

3.2.2 Structure

The market price analysis is divided into two major chapters; the analyses of the wholesale markets and the analyses of the balancing markets.

Starting with the analyses of the wholesale markets, the seasonal differences of the German and Norwegian wholesale electricity market prices will be analyzed. The wholesale market analysis focuses on the analysis of the short-term electricity markets like the Day-Ahead, and Intraday market. The market for electricity futures was disregarded since this market is not characterized by high short-term price variations which could be used for arbitrage trading.

Using the data from NordPool and Fraunhofer Institute, the wholesale analysis calculates the standard deviation of the monthly average prices from the yearly average for the Day-Ahead market in 2017 & 2018. Next, the wholesale studies focus on weekly and daily price fluctuations. In a final step, the chapter calculates an intermarket spread factor which depicts the difference between the Intraday and the Day-Ahead market. Due to the different time slices in the Intraday and Day-Ahead market, a nested for-loop was used to determine the difference between the 35,040 Intraday prices and their respective Day-Ahead price. This spread factor allows judgments about the suitability of the German market for of pairs trading. A detailed description of pairs trading and its potential in the German market can be found in chapter 5.2.5.

Within the balancing market analysis, the thesis focuses on the primary containment reserve markets (PCR) and the secondary containment reserve markets (SCR). EVs have a quick response time and are qualified to provide power as a PCR, SCR or tertiary containment reserve (TCR). However, the thesis won't analyze the TCR market due to the following reasons.

In general, the price for a service provided in the balancing market rises when the capacity offered can be activated quickly. Therefore, the PCR offers a higher remuneration for the capacity provided than the SCR and the SCR offers better prices than the TCR. Due to low restrictions for providing TCR, many conventional power plants like gas turbines can bid in the TCR market, which drives down the price of TCR.

Next to offering the lowest remuneration, the volume of activated TCR declined significantly within the last years, as can be seen in figure 4.

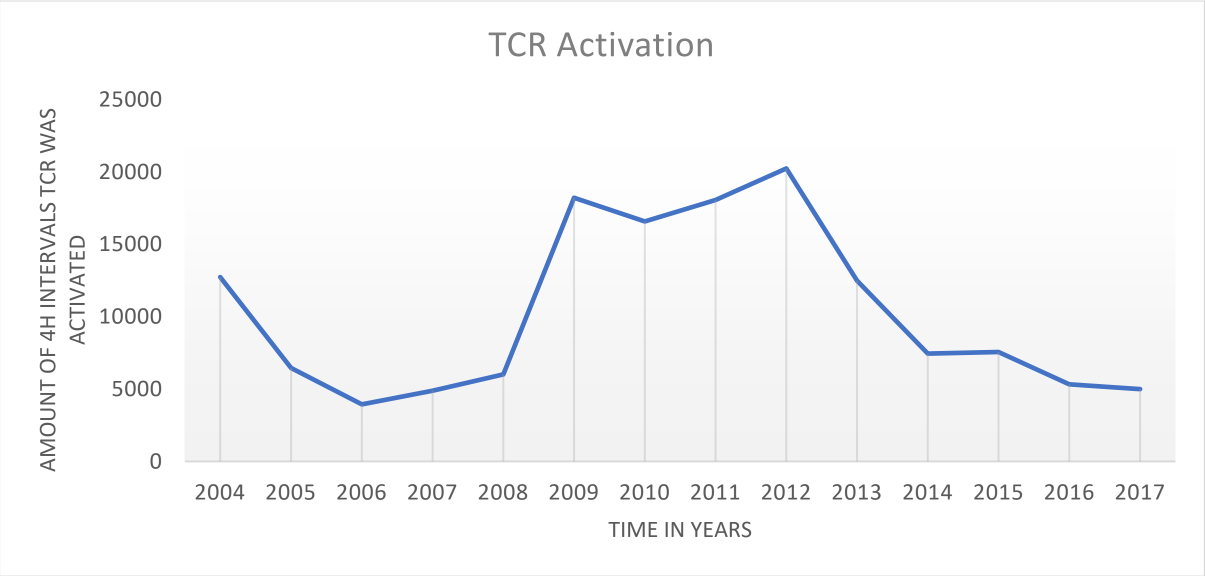


Figure 4 Activation of TCR per Year in Germany own Display based on (Bundesnetzagentur, 2018b)

Thus, the TCR market is the least attractive balancing market in Germany and the analyses of the balancing markets will focus on PCR and SCR markets.

Currently, the German PCR market is difficult to enter for Tibber, due to its long tendering periods. However, upcoming changes in the market design will lead to smaller tendering periods of 4-hour intervals starting in July 2019. This development will allow EV-Aggregators easier access to the economically attractive market. Hence, the PCR market should be monitored closely by EV-Aggregators and will be investigated in the market price analysis.

After starting the balancing market analysis with an overview of the PCR price developments in recent years, the thesis tries to identify price patterns in the balancing market. While the PCR market merely allows to display a price development over the last years, weekly and daily patterns will be observed for the SCR market.

To set the results of the market price analysis into comparison, the thesis tries to compare the German market price with the Norwegian market prices. The wholesale markets show a similar structure in both countries and can, therefore, be compared thoroughly. The balancing markets, on the contrary, show differences in the product design and the time slices in which products are tendered. This makes a market comparison hardly feasible. Hence, the thesis will not compare the Norwegian and German balancing market prices, but rather focus on identifying patterns in the German balancing markets from which EV-Aggregators could benefit.

3.2.3 Data Basis

The analyses are performed with data from 2015 to 2018 of the Day-Ahead and Intraday markets with a focus on the newest market data available. The Norwegian market data was derived from the website of Nordpool and Statnett, while the German data originates from Fraunhofer Institute, ENTSO-E, Regelleistung.net, EEX, and EXAA. Data from a variety of institutions had to be used for the German case because no single institution offers free access to all the necessary data.

Since the EPEX SPOT is the most prominent spot market in Germany, the data from EEX is used when provided. For the analysis of all Day-Ahead and Intraday prices from the year 2018, the data for the EPEX SPOT was not accessible. Therefore, the author analyzed the EXAA Spot market, which offers electricity trading in Germany and Austria. 66% of the traded volume on the EXAA is designated for the German market (Bundesnetzagentur, 2018b). Even though the EPEX data would have given the most accurate analysis, the EXAA offers a decent database due to its high correlation with the EPEX SPOT.

The following graph depicts this correlation by showing the difference between the peak and base prices of EPEX and EXAA. Although this graph merely illustrates yearly averages, one can assume that the hourly difference in prices between the two markets are small since German traders can participate in both exchanges. Large differences between the two would trigger arbitrage trading, which would lead to a convergence of the prices. Hence, even though variations occur between the EPEX and the EXAA, the markets develop similarly.

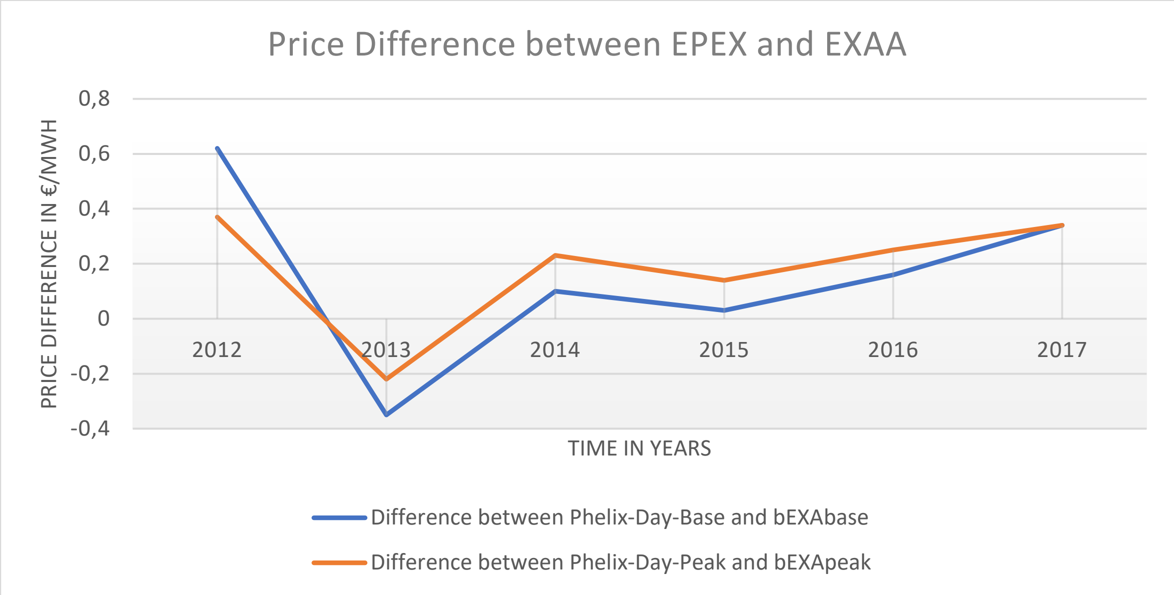


Figure 5 Price Difference between EXAA SPOT and EPEX SPOT own Display based on (Bundesnetzagentur, 2018b)

The Phelix-Day-Base is a virtual price that is build up by the sum of all 24-hour intervals of a day divided by 24. It is used as an indicator of the hourly prices during a specific day.

$$Phelix - Day - Base = \frac{Sum\ of\ hourly\ Prices\ on\ Day\ x}{Amount\ of\ hourly\ Prices\ on\ Day\ x}$$

In contrast to the Phelix-Day-Base, the Phelix-Day-Peak is the average of the prices in the time interval from 8 am to 8 pm. Thereby, the Phelix-Day-Peak indicates the price level during the peak demand hours of a day. The EXAA publishes the bEXAbase and bEXApeak accordingly. Figure 5 compares the base and peak prices from the two power exchanges by depicting the difference between the EPEX base & peak with the EXAA base & peak.

$$Difference\ between\ Phelix\ DayBase\ and\ bEXAbase = Phelix\ DayBase - bEXAbase$$

A difference of 0.29 between the Phelix-Day-Base and the bEXAbase, as can be observed in 2017, states that the mean of the prices at the EPEX in 2017 was 0.29 € higher than at the EXAA. Considering an average price of 34.2 €/MWh in 2017 (see figure 10), the differences between the average prices on the two exchanges amount to 0.85%, only. Due to this small price difference between the two exchanges, one can utilize the data of the EXAA – which in contrary to the EPEX data is publicly available - to analyze the value of the German market for EV-Aggregators.

For the balancing markets, the data provided by Regelleistung.net and ENTSO-E has been assessed to analyze the German market while the Norwegian data on balancing market prices stems from the website of Statnett.

3.3 Bidding Optimization

Next to useful insights about price patterns on the German market, the market price analysis provides the basis for a quantitative bidding optimization. Thanks to the qualitative market analysis, the valuable markets for EV-Aggregators could be identified. Furthermore, price patterns identified in the market price analysis can be utilized in the bidding optimization.

The bidding optimization can be distinguished into three different scenarios:

- **Scenario A**: Optimized Charging with participation in the SCR market
- **Scenario B**: Optimized Charging without participation in the balancing markets
- **Scenario C**: Uncontrolled/Dumb charging

All three scenarios will analyze a summer case and a winter case, meaning that the bidding behavior will be optimized for a typical summer & winter day. The main difference between the summer and the winter scenario is the different prices on the wholesale and balancing markets. To achieve one daily price development that resembles the summer prices, the averages of all Day-Ahead prices for every hourly interval from April to September have been computed. The wholesale prices for the winter cases in the optimization are the averages from all hourly intervals of the Day-Ahead market prices from the months January to March and October to December. This results in a set of 24 distinct hourly prices for the summer case and 24 distinct hourly prices in the winter case.

Due to issues regarding data availability for the balancing markets, average prices could not be computed for the SCR market in Germany. Instead, the prices of two days that most closely resemble the typical price level in summer and winter have been collected. Those two sets of prices represent the SCR prices for the winter and the summer case respectively. For the winter values of the SCR market, the prices from the 17th of November have been used, while for the summer scenario, the SCR prices of the 4th of April have been gathered to optimize bidding behavior.

Tibber shared the driving patterns of their vehicle fleet from the 1st of November 2018 with the author of this thesis. Since the driving behavior, according to Tibber, hardly varies during weekdays, the fleet data of 1st of November has been used to optimize the bidding behavior for the summer and the winter scenario. The optimization is performed ex-post, meaning that an algorithm in Python was fed with the market data for the respective days. Considering the market prices and the driving patterns of 152 BEVs, the optimization derives the optimal charging time for the vehicles and the optimal bidding time and bidding volume for the balancing markets.

In **Scenario A,** the charging of the vehicle fleet is optimized through smart charging and participation of the EVs in the balancing markets. For smart charging, the algorithm will optimize electricity acquisition in the Day-Ahead market. The qualitative analysis identified the optimal balancing market for an EV-Aggregator. While the current market design of the PCR market is not suitable for an EV-Aggregator with a low number of cars in its portfolio, the SCR market offers appropriate time intervals for EV-Aggregators. Hence, an optimization for the participation of EVs in the balancing markets focuses on the SCR market.

Scenario B considers smart charging without participation in the balancing markets. The charging capacity is shifted optimally to cheap off-peak hours without active involvement in regulatory markets.

Scenario C is the uncontrolled or dumb charging case. The EVs of the customers will be charged as soon as the owner plugs them onto the charging station. This scenario is used as a reference case to compare the value achieved through intelligent energy management through an EV-Aggregator.

The thesis uses the algorithm developed by Dalton (2018) to optimize the outcome for an EV-Aggregator. However, several parameters have been altered to fit the German market.

The optimization algorithm for Scenario A is depicted in the following chapter. The overall objective is to maximize the expected profit (see page 34, 3.1), which is made up from the revenues made in the balancing markets (3.2) minus the cost of electricity bought in the wholesale markets (3.3). A series of restrictions limits this maximization. (3.2) and (3.3) show how the revenues from the regulating markets and the costs of the Day-Ahead market form. (3.4) states that the maximum power of the fleet equals to the sum of the power of charge of the number of vehicles that are at home. (3.5) explains that the state of charge at point t+1 is equal to the state of charge at point t plus the electricity charged within this hour. The restriction shows how the state of charge in the battery of the EV increases. (3.6) defines the state of charge as a binary parameter. If the state of charge equals to 1, the car is fully charged. If the state of charge equals to 0, the car is empty. Hence, the state of charge must be between 0 and 1. (3.7 & 3.8) state that the state of charge at the time of the arrival/departure is equal to the parameter "State of Charge Arrival/Departure". This is an important constraint for the optimization model. (3.9) defines that the SCR bid cannot be higher than the real-time energy consumption of the fleet. Finally, (3.10) limits the scope to which the fleet can provide down-regulation by defining that the SCR bid has to be smaller or equal to the maximum fleet power – the actual real-time consumption of the fleet.

For Scenario B, the same optimization algorithm is taken except for the part of the revenues from the balancing market because Scenario B focuses on smart charging without the integration of the vehicle fleet in the balancing markets. We merely optimize the following:

$$\max E(\Pi^{N}) = - \Pi^{DA}$$

Hence, we minimize the costs from the Day-Ahead market by allocating the charging power smartly.

For the uncontrolled charging scenario, the electricity costs are computed as soon as the car arrives at the charger until it is fully charged.

3.3.1 Explanation of the Formulas and Parameters

Sets:

$i(I)$ Index (set) of electric vehicles

$t(T)$ Index (set) of hourly time intervals

$k(K)$ Index (set) of Block intervals (4h blocks used in SCR market)

Parameters:

$\lambda^{DA,E}_t$ Day-Ahead electricity price, in €/kWh.

λ^{SCR}_k SCR regulation price, in €/Block-bid

ΔT *H*ourly time interval in hours

η_i Efficiency of charger = 0.9

$u_{t,i}$ Binary parameter equal to 1 when *i*th veh is home.

E^{batmax}_i Battery capacity of *i*th vehicle, in kWh.

P^{chrg}_i Power of charge of *i*th vehicle, in kW.

$T^{arr/dep}_i$ Arrival/departure time of *i*th vehicle.

SOC^{dep}_i State of charge at departure of *i*th vehicle, [0,1].

SOC^{arri}_i State of charge at arrival of *i*th vehicle, [0,1].

Variables:

$E(\Pi^A)$ Expected Profit, in €.

E^{DA}_t Day-Ahead energy bid, in kWh.

E^{SCR}_t SCR regulation bid, in kWh.

E^{RT}_t Total real-time energy consumption, in kWh

$P^{RTmax}_{t,i}$ Maximum real-time power consumption of *i*th vehicle, in kW.

$SOC_{t,i}$ State of Charge of *i*th vehicle, [0,1].

The aim of an EV-Aggregator is to maximize the expected profit.

(3.1) $\max E(\Pi^N) = \Pi^R - \Pi^{DA}$

This is subject to the following conditions:

(3.2) *Regulation Return,* $\Pi^R = \Sigma\ [\lambda^{SCR}_k \cdot E^{SCR}_t]$ $\quad \forall k, t$

(3.3) $Day\text{-}Ahead\ Cost,\ \Pi^{DA} = \Sigma\ [\lambda_t^{DA,E} \cdot E^{DA}{}_t]$ $\forall t$

(3.4) $P^{max}{}_{t,i} \leq u_{t,i} \cdot P^{chrg}{}_i$ $\forall t$

(3.5) $SOC_{t+1,i} = SOC_{t,i} + \frac{\eta i}{E\ batmaxi} E^{DA}{}_{t,i}$ $\forall t$

(3.6) $0 \leq SOC_{t,i} \leq 1$ $\forall t$

(3.7) $SOC_{T^{dep}{}_i} = SOC^{dep}{}_i$ $\forall t$

(3.8) $SOC_{T^{arr}{}_i} = SOC^{arr}{}_i$ $\forall t$

(3.9) $E^{SCR}{}_t \leq E^{RT}{}_t$ $\forall t$

(3.10) $E^{SCR}{}_t \leq \Sigma\ [u_{t,i} \cdot P^{chrg}{}_i] - E^{RT}{}_t$ $\forall t$

3.3.2 Assumptions & Restrictions

Due to the limitations of a master thesis, certain assumptions/restrictions had to be made to execute the bidding optimization:

- Car driving patterns in Germany and Norway are alike

  The optimization is based on actual driving patterns of the customers from Tibber. These driving patterns have been recorded for the 1st of November 2018. One can assume that the driving patterns during weekdays are similar. For this optimization, a further assumption regarding the driving patterns is made. The thesis assumes that driving behavior in Germany and Norway are alike.

- The EV-Aggregator will always get the bid in the balancing market at the average bid price

  Tenders in the balancing markets in Germany are pay-as-bid auctions. Hence, two companies that offer balancing power at the same time can get remunerated differently for their service depending on the price for which they offered their power. In the optimization, we assume that an EV-Aggregator will receive the average of all bid prices in the balancing markets.

- The energy payment in the SCR bids will always be activated

As will be explained in the chapter of the balancing markets, a provider in the SCR market will receive a capacity payment. If the balancing power gets activated, the provider will get an additional energy payment. The thesis assumes that the energy payment will always get activated.

- Taxes and tariffs for end consumers are not considered

When calculating the charging fees for the whole fleet of 152 cars, the thesis will focus on the costs of electricity purchased in the wholesale and balancing markets. The real costs for customers are higher due to several taxes and tariffs that will increase the price of electricity. These taxes and tariffs will be ignored for the sake of simplicity and comparability.

- Battery degradation is not considered

When the car fleet provides up-regulation in the SCR positive market, this can lead to an increase of loading cycles for the batteries. In the long term, this might lead to quicker battery degradation. This possible faster degradation will not be discussed or taken into account in this thesis.

- Imbalance prices are not considered

Imbalance prices are penalties/payments for balance responsible parties that did not keep their connecting point balanced and destabilize the grid (detailed description in chapter 5.5). Since this optimization is ex-post analysis, there are no imbalances. Hence, imbalance payments have been ignored in the optimization.

- Capability of dynamic load control

The EV-Aggregator can remotely switch the charging process of single EVs in his fleet on or off on the condition that the vehicles are connected to the charger.

4. Qualitative Market Analysis

4.1 Overview of the German Electricity Market

With 653 TWh, Germany is the country with the highest electricity generation in the European Union (EU) (Enerdata, 2018). Historically, Germany relied on lignite and hard coal as its main sources of energy since the country lacks any oil or gas resources and does not feature the same topographical natural advantage as Norway.

In the context of the Europe-wide deregulation of energy markets in the early 1990ies, Germany liberalized its electricity market in 1998 (Bayer, 2015). The German electricity grid is administered by four transmission system operators (TSOs): 50Hertz in the North-East, Amprion in the Western area of the Rhineland, TransnetBW predominantly in the state of Baden-Württemberg and TenneT from the Alpine regions of Bavaria up to the Danish border.

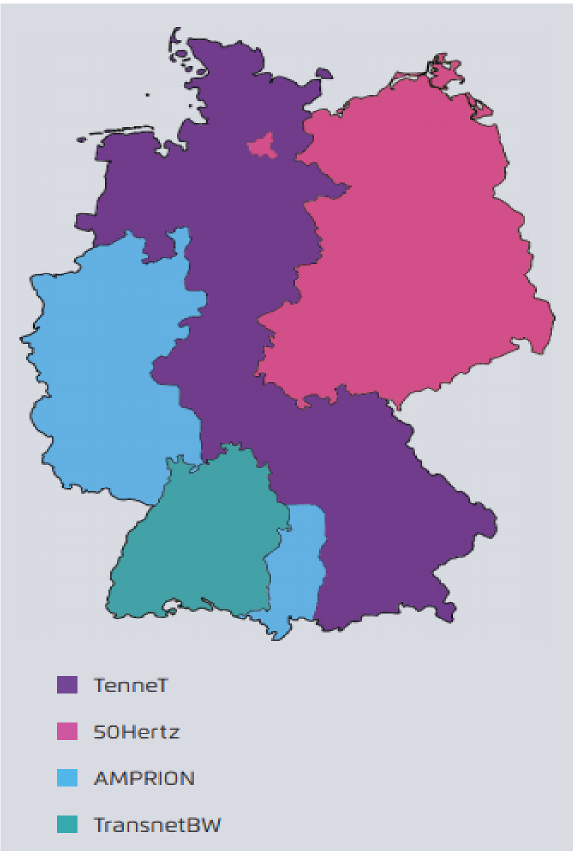


Figure 6 German TSOs (Bayer, 2015)

The TSOs were initially unbundled legally, however, in recent years some of them sold part of their ownership rights. In contrast to Norway, with its five different pricing regions, Germany applies a uniform pricing mechanism with one single energy price for the entire country.

With its central location on the European continent, Germany can make use of the transmission capacities with its neighbors. In the case of low or negative prices in Germany, neighboring countries will import electricity until the cross-border capacity is fully used or prices converge. In windy and sunny hours, Germany exports electricity up to the transmission capacities. During the so-called "Dunkelflaute" – a German word for cloudy weather with low windspeeds – Germany imports electricity from its neighbors.

For cheap baseload electricity, the French nuclear power plants can offer support. Austria and Switzerland feature similar topographic natural advantages as Norway. Thus, the exchange with those two countries utilizes their pumped hydro storage for balancing fluctuations during the day.

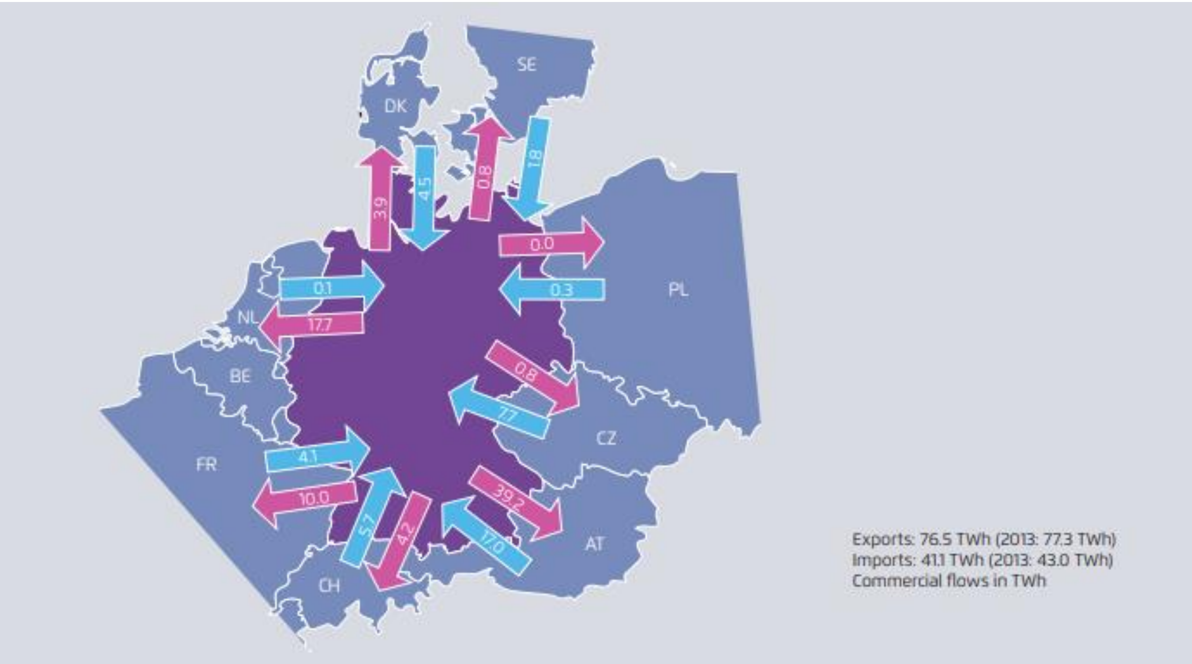


Figure 7 Imports and Exports in 2014 in TWh (Bayer, 2015)

4.2 Market Design

The German wholesale market is split into three elements: the forward/futures market, the Day-Ahead market, and the Intraday market. In addition, the balancing market system and the imbalance settlements adjust supply and demand to keep them balanced. Thereby, the German market is similarly structured like the Norwegian market. On the Financial market, called EEX futures market, trading energy is possible up to 7 years ahead. The Phelix functions, like the Nord Pool system price, as a basic value for futures.

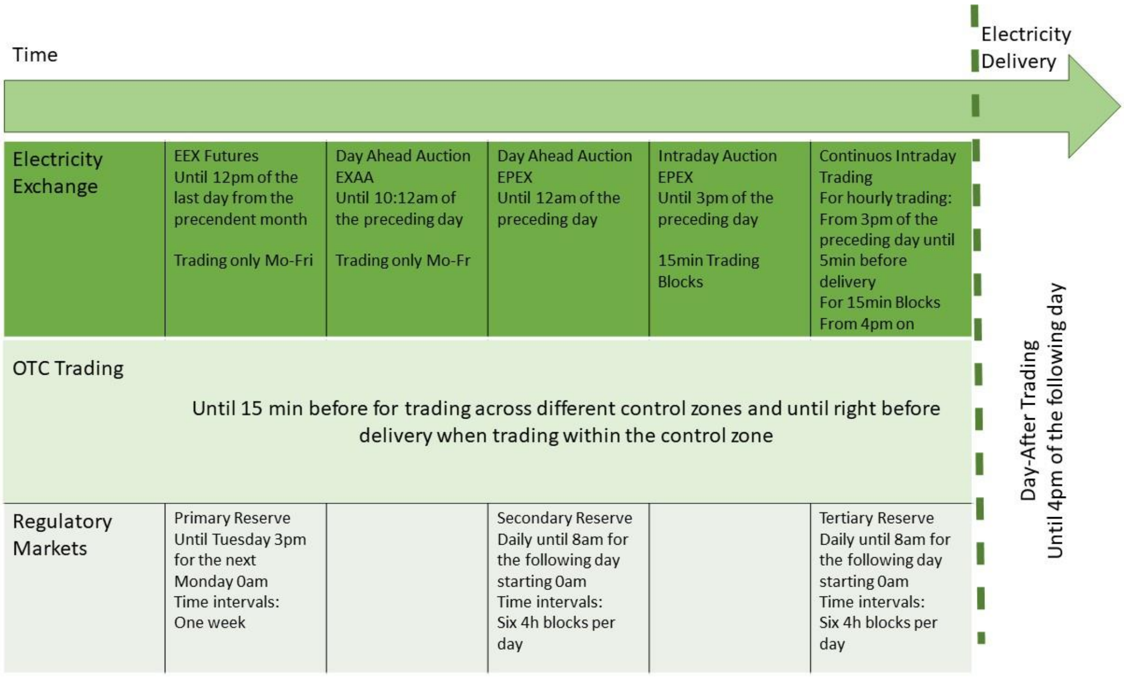


Figure 8 Market Design Overview Germany own Display based on (Next-Kraftwerke, 2019)

4.3 The Wholesale Market

Although most of the trade in Germany occurs "over the counter", stock exchanges are gaining in share. Most trading takes place either on the EEX in Leipzig, the EPEX SPOT in Paris or the EXAA in Vienna (Bundesnetzagentur, 2014). In contrary to Norway, there are several spot markets where a company could buy or sell electricity. The most prominent exchange is the EPEX SPOT in Paris that allows trading from Germany, France, Great Britain, the Netherlands, Belgium, Austria, Switzerland, and Luxembourg. It offers standard contracts for the physical delivery of electricity within the respective transmission systems, where auction as well as continuous trading, are both possible.

While the forward market focuses on the financial trading of futures contracts, the Day-Ahead and Intraday are trading physical delivered energy. The Forward market has by far the highest trading volume. However, the German market for futures experienced a sharp decline of 46%

in trading volume from 1,466 TWh (in 2016) to 786 TWh (in 2017) (Bundesnetzagentur, 2018).

In contrast to the decline of the forward market, the spot markets gain momentum. The trading volumes of the Day-Ahead market are still significantly higher than in the Intraday market. However, the Intraday market experiences steady growth in trading volume. For renewable energies which are difficult to forecast precisely, the Intraday market is of great importance, because it allows to trade power shortly before the actual delivery.

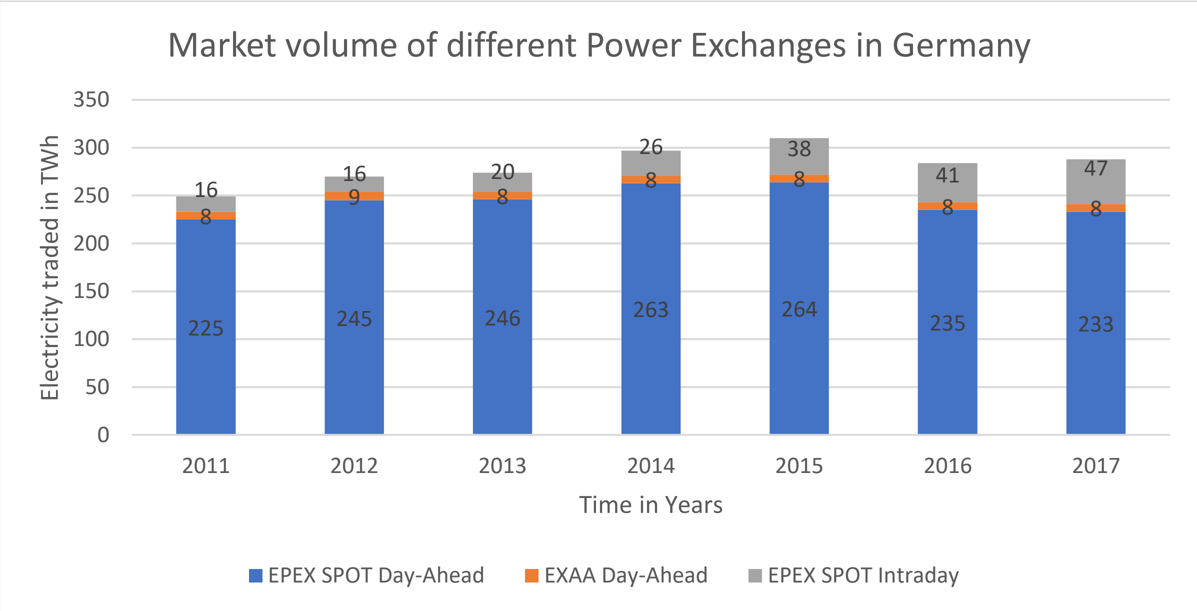


Figure 9 Trading Volume in various German Power Exchanges own Display based on (Bundesnetzagentur, 2018)

While the Day-Ahead market is characterized by an auction-based system, the Intraday market offers auctions until 3 pm of the preceding day as well as continuous trading. Continuous trading allows traders to place their bids up to 5 minutes before the actual electricity delivery and offers thereby high flexibility for trading. Another significant difference is the formation of prices. While the price is formed over a merit-order scheme in the Day-Ahead market, the Intraday market is characterized by Pay-as-bid scheme.

The typically used benchmark price for Germany and Austria is the Phelix. The Phelix-Day-Base describes the average of all 24-hour prices during a day, whereas the Phelix-Day-Peak depicts the average of the hourly prices from 8 am – 8 pm.

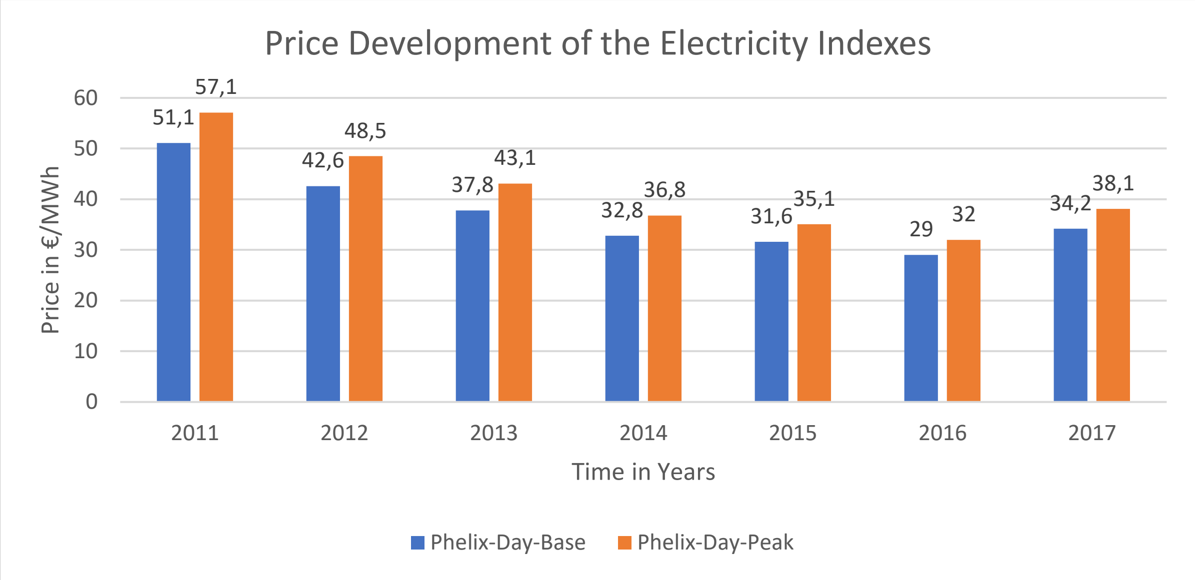


Figure 10 Price Development over the last Years own Display based on (Bundesnetzagentur, 2018)

As can be seen in figure 10, the prices for one MWh at the EPEX SPOT did increase for the first time within the last years in 2017. The development of the Phelix-Day-Base in the Day-Ahead market is illustrated in figure 11. While the overall variance in prices decreased from 2016 to 2017, one can still identify the high volatility of market prices in figure 11. Highly volatile market prices are mainly induced by unpredicted weather patterns. The German market, which is characterized by inflexible baseload production from nuclear, lignite and coal power plants paired with highly intermitted input from wind and solar power, can experience high volatility. Hence, extreme daily price averages of 101.92 €/MWh and -52.11 €/MWh mark notable differences (Bundesnetzagentur, 2018).

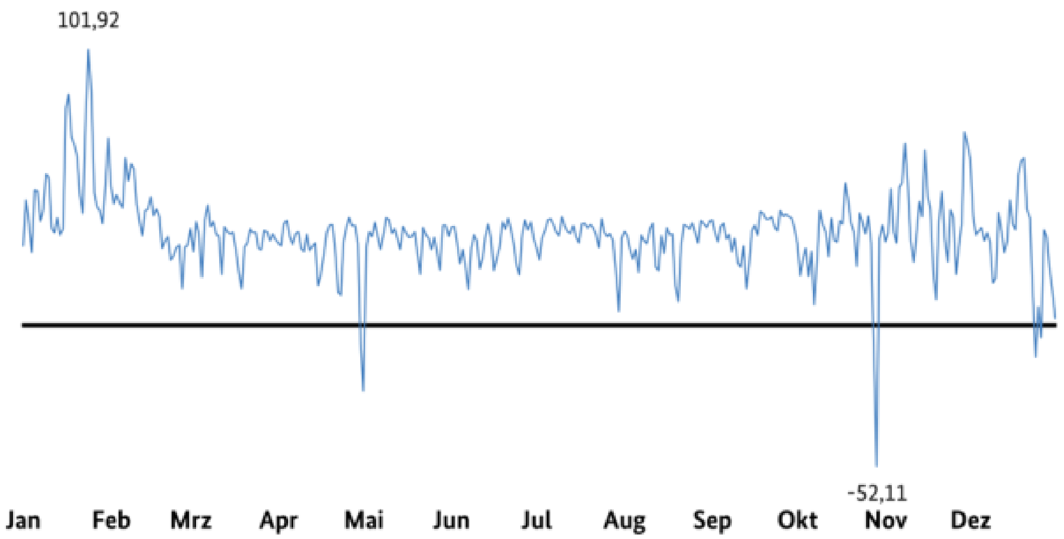


Figure 11 Price Development of the Phelix-Day-Base in €/MWh (Bundesnetzagentur, 2018, p. 234)

4.4 The Balancing market

4.4.1 Overview

The following chapters will focus on introducing the functionalities of the balancing markets in Germany. For an EV-Aggregator, who creates most of its value through the balancing markets, it is necessary to gain a profound understanding of the German balancing markets.

The balancing markets aim to keep the frequency in the grid stable. Even after the trading in the Intraday market, demand and supply tend not to be equal. In general, the frequency in the grid drops (when demand is higher than supply) or rises above 50 Hertz (Hz) (when demand is lower than supply). To keep the frequency stable, the TSO deploys the PCR, SCR or TCR.

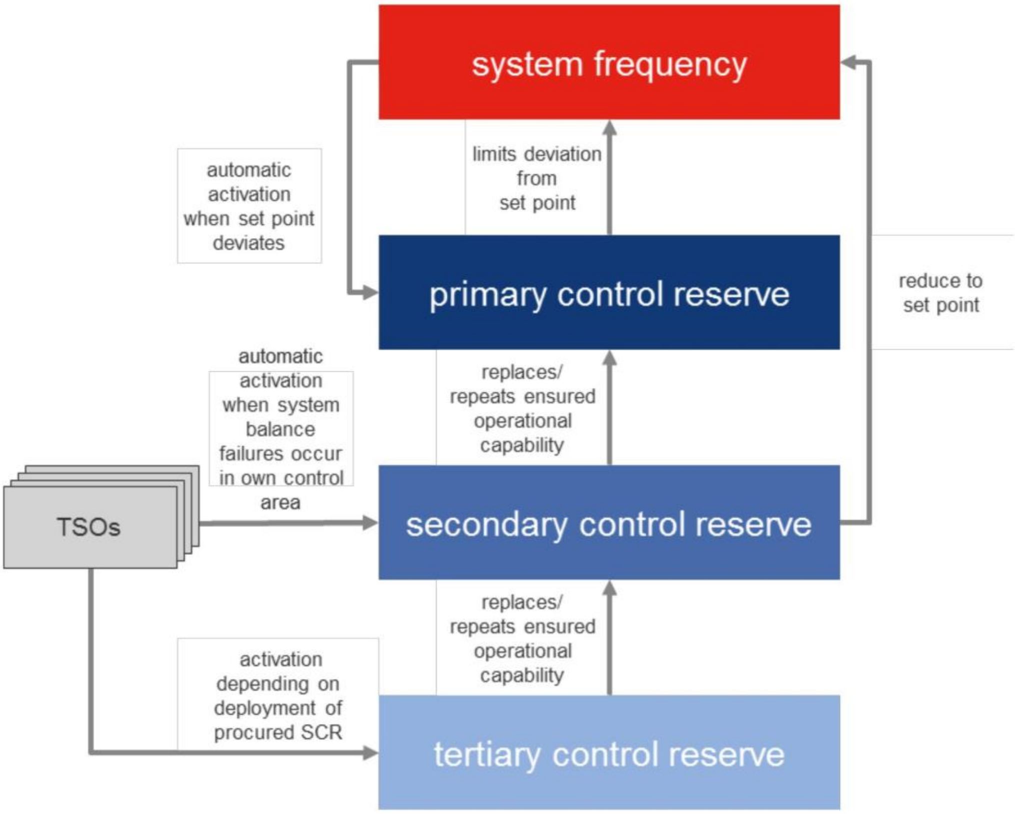


Figure 12: Different Types of Frequency Control (Consentec, 2014, p.10)

The PCR gets activated automatically as soon as the frequency starts to deviate from 50Hz. This reserve has to be activated fully within 30 seconds and is not applied longer than 15 minutes (Regelleistung, 2019). The SCR gets activated to help the PCR stabilize the grid. Due to the impossibility of perfect demand and supply forecasting, SCR is active almost all the time. One requirement for providing SCR is a full activation within 5 minutes (Regelleistung, 2019). The TCR gets activated manually by the TSO and is typically used to replace the more expensive SCR. When activated, the TCR is applied from 15 minutes to several hours (Regelleistung, 2019). However, this happens comparably seldom, because the TCR is only activated when there are large and long-lasting deviations in the grid.

4.4.2 The Pre-qualification

Alongside building and maintaining the grid, keeping the frequency stable is one of the main duties of a TSO. To ensure that the quality of a service from a balancing responsible party (BRP) is adequate, the BRP has to go through a pre-qualification process. All control reserves are pre-qualified by the responsible TSO in the specific area. The process of pre-qualification usually lasts about two months (Consentec, 2014). A detailed description on pre-qualification criteria can be found in the Transmission code of the German TSOs and over the pre-qualification portal (50Hertz; Ampirion; TenneT; TransnetBW, 2019). Within the pre-qualification, the TSO checks the deployable power, the connections of control and communication facilities, and other organizational requisites.

While some years ago, conventional power plants and pumped hydro were responsible for regulating power, today the pooling of capacities is eligible for providing power in the regulating markets, too. In general, pooling is only possible within a control area. Hence, an EV-Aggregator would need to decide whether he wants to offer regulating power in the TenneT, the Ampirion, the TransnetBW, or the 50 Hertz control zone. Merely when the pooling is used to reach a minimum supply offer, it is permissible across control zones (Regelleistung, as cited in Koliou et al., 2014).

Furthermore, achieving a pre-qualification for pooled DR technology can take longer than for conventional power regulators and BRPs must pre-qualify for every control zone where their power originates. In addition to the pre-qualification, a grid connection contract ("Netzanschlussvertrag") with the responsible DSO is essential because the electric cars are connected at the distribution level (Seidl, Schenuit, & Teichmann, 2016).

4.4.3 The Tender System

When the pre-qualified power exceeds minimum limits and standards, the responsible TSO signs a framework contract with the BRP, allowing them to participate in the tenders of the balancing market. Since 2008 the German TSOs have formed the "Netzregelverbund" (NRV) (Regelleistung, 2019). Through this cooperation, the TSOs can balance each other through the interconnectors between the different control zones, avoiding the activation of additional balance power. Moreover, the TSOs organize a joint, nationwide tender for balancing power that is administered over the website "regelleistung.net". Here, tenders for PCR take place weekly and for SCR and TCR daily. In April 2018, 24 entities were qualified to provide PCR, 38 to provide SCR and 46 to provide TCR (Bundesnetzagentur, 2018). Those are tremendously more participants than four years ago (in 2014: PCR;14, SCR; 20, TCR; 36) (Consentec, 2014). An updated list of all the companies prequalified for balancing power can be assessed at Regelleistung.net in the section "Prequalified Providers".

After the TSO publishes the needed capacity, the capacity gets tendered in nation-wide pay-as-bid auctions.

Table 1 The Balancing Markets in Germany (Consentec, 2014; ENTSO-E, 2019a; Mayr, 2017)

	PCR	SCR	TCR
Tender period	Weekly	Daily	Daily
Activation time (reserve has to be 100% activated in)	30sec	5min	15min
Product differentiation	No differentiation A BRP bidding for PCR must be able to provide up- and down-regulation	Positive & negative SCR	Positive & negative TCR
Bid volume	1 week	4-hour blocks	4-hour blocks
Minimum bid amount	1MW	5MW (However, 1MW is admitted, if the bidder supplies only one bid per SCR product, time slice, and control area)	5MW
Lowest possible increment of bid	1MW	1MW	1MW
Remuneration	Pay-as-bid (capacity payment)	Pay-as-bid (capacity and energy payment)	Pay-as-bid (capacity and energy payment)

Table 1 depicts the different criteria for the tenders of PCR, SCR, and TCR. While positive and negative SCR and TCR get tendered separately, PCR is tendered as a symmetric product. Providers of PCR must be able to provide up- or down-regulation. The tenders for SCR and TCR distinguish between the provision of control reserve capacity and the actual deployed energy. Hence, the bid of a supplier must specify a capacity bid price and an energy bid price for the deployed reserve. Then, a merit order system identifies the eligible suppliers. When selected, BRPs get the capacity bid as secure payment. The energy payment will only be activated if the balancing power provided by the BRP will be activated. In the case of regulation up, the energy price is paid to the BRP that offers electricity. For regulation down, the BRP has to pay the energy price. Typically, the prices at the balancing markets are more favorable for power providers than if they would sell electricity within the Spot market (Anderson, et al., 2010). This reflects the additional value of flexibility the companies provide with their reserve.

Since October 2018, suppliers are chosen through the mixed price method ("Mischpreisverfahren"). While in recent years the merit order system in the balancing market was based on the capacity prices only, now a combination of both prices is considered. From 2018 on bid-acceptance-price ("Zuschlagspreis"), which is an aggregation of the capacity price and the energy price, decides whether a technical unit can perform regulation. In addition, a probability factor was included in the pricing mechanism. The probability factor addresses the probability of the activation of a bid. If there is a low probability that the regulating power will get activated, a low probability factor is addressed to the bid. The factor is then multiplied with the energy price component. Thereby, it lowers the importance of the energy price component for the tendering process. Hence, this factor can display the importance of the energy price with respect to the capacity price.

The new regulation aims to avoid disproportionally high energy prices that have been activated before because the old merit order system was based on capacity prices only (Bundesnetzagentur, 2018). Regardless of its success in lowering the energy prices, the mixed price tendering method faces criticism from the cleantech industry, because it lowers the energy price component and creates an environment that favors conventional power plants over DSM and cleantech solutions in the balancing market (Plazzo, 2019). For an EV-Aggregator, who provides DSM in the balancing market, this is a troubling development.

4.4.4 The Balancing Paradox

From 2008 until 2014, the combined capacity of solar and wind production has tripled (Hirth & Ziegenhagen, 2013). A higher degree of highly fluctuating renewables typically leads to a higher demand for balancing services. Yet, the demand for balancing reserves has decreased by 20% in the same time horizon (Hirth & Ziegenhagen, 2013). From 2012 to 2017, the volume of positive SCR deployed decreased by 40%, and the volume of negative SCR dropped by 60% (Regelleistung-online, 2018). The volume of TCR activated even dropped by 75% in the same time frame (Bundesnetzagentur, 2018b). This phenomenon, which is called the German Balancing Paradox, can be explained by multiple developments in the sector:

- Improvements in the wind and solar forecasts
- Improvements of load forecasts
- Reduced Frequency of plant outages
- The TSO cooperation DRV
- Improved Intraday market liquidity
- Overcapacity in electricity production (see figure 13)

(Hirth & Ziegenhagen, 2013)

The decrease of activated balancing power through the balancing paradox is again a distressing development for EV-Aggregators. A decreasing volume of balancing power that is shared amongst a rising number of participants in the balancing markets raises the concern that prices in the balancing markets might have fallen in recent times. This concern will be investigated in the chapter “Market Price Analysis”.

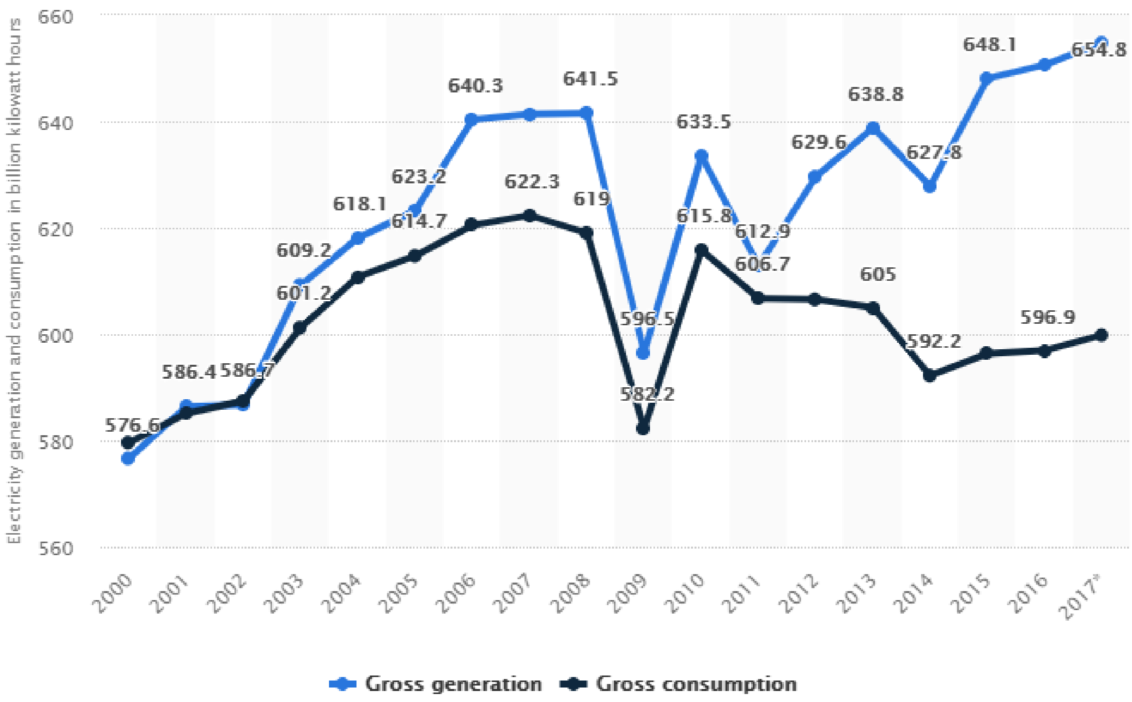


Figure 13 Balance between Generation and Consumption in Germany (Statista, 2018a)

4.4.5 Future Market Development

Due to the transformation of the energy sector, the market design of the balancing markets in Germany is characterized by frequent changes lately. Describing the details of possible future market developments would be out of the scope of this master thesis. Hence, the thesis merely states the most essential market changes for an EV-Aggregator briefly.

PCR is currently tendered on a weekly basis. According to the FCR Proposal Article from October 2018, this will change soon. Article 5 of the proposal states that the PCR product will be changed to a daily tender in July 2019 (ENTSO-E, 2019a). In July 2020, PCR will even be tendered in 4h blocks, like it is the case for SCR and TCR currently (ENTSO-E, 2019a). This will enable EV-Aggregators to participate in the PCR auction with smaller car fleets and is, therefore, a highly beneficial change in market design for aggregators.

Another important change in market design refers to the SCR market. Within the PICASSO project, the TSOs of various countries are planning a European aFRR platform. The aim of this platform is the integration of European aFRR markets while respecting the TSO-TSO model to enhance economic and technical efficiency. The TSO-TSO model is a guideline on balancing energy. It states that a balancing service provider will always provide balancing services to its connected TSO. The connected TSO then provides the balancing service to the requesting TSO. The Belgian TSO Elia, the Austrian TSO APG, the Dutch TSO TenneT, the French TSO RTE, and the German TSOs plan to go live with the PICASSO platform in 2020 (TenneT, 2017). By 2021, all participating TSOs should enable trade over the international aFRR platform (ENTSO-E, 2018). This could change the tendering principles once again, which could be a positive or negative development for aggregators.

Figure 14 Members of the PICASSO market scheme (ENTSO-E, 2019b, p.6)

4.5 Imbalance Settlements

Imbalance Settlements are the payments between the TSOs, which act as coordinator of their control zone and any party that has one or more connecting points to the grid and is obliged to balance those, the BRPs. The BRPs can buy and offer electricity within the balancing markets. However, even after the power acquisition in balancing markets, single control zones are sometimes over- or under-covered with electricity because BRPs are not able to achieve their balance in real time. The TSO coordinates all BRPs in its control area and keeps the control zone stable by deploying the necessary balancing power himself. Through this final balancing, costs will occur for the TSO. Consequently, the TSO will charge costs within the imbalance settlements to unbalanced control zones. While the balancing energy refers to actual energy traded, the imbalance settlements are financial transactions that keep the financial balance between the market players.

For deviations within the control zone, the BRPs are penalized through the reBAP ("regelzonenübergreifenden einheitlichen Bilanzausgleichsenergiepreises“) within the imbalance settlements. The reBAP is calculated by the following formula where the TSO is replaced by the NRV, which is the organization of the different TSOs in Germany:

$$reBAP = \frac{\Sigma\, Cost\ NRV - \Sigma\, Revenues\ NRV}{Balance\ NRV}$$

The balance in the denominator represents the difference between the positive energy flows and the negative ones (generation/consumption). If the NRV zone is experiencing a lack of electricity, the "Balance NRV" in the denominator becomes negative. The nominator is the difference between the costs of the NRV and the revenues of the NRV. The costs are made up of the balancing power the TSO must deploy or buy when the control zone is not kept stable. The revenues of the NRV are the revenues the TSOs achieve with the real-time electricity. In the rare case, that different control zones are not stable, but the differences in the control zones balance each other out, the TSO will not have to deploy balancing power. Hence, his costs will be 0, and there will be no financial punishment for the unstable control zones.

In some cases, an unstable control zone could even lead to payments for the BRP. If there is, for example, an over-coverage in control zone A of 10 MWh and there is an under-coverage in control zone B by 5 MWh, control zone B helps to stabilize the overall balance with its under-coverage. The BRP in zone A will have to pay the reBAP for 10 MWh while the BRP in control zone B will receive the reBAP for 5 MWh. Thus, the algebraic sign of the reBAP can have several interpretations depending on the balance within the control zone, as depicted in table 2.

Table 2 Interpretation of the reBAP

reBAP	Balance in the NRV zone	Cost/Earnings for the BRP
+	+	-
+	-	+
-	+	+
-	-	-

Thus, depending on over- or under-coverage of a control zone, the intake or output of electricity from a BRP can lead to costs or profits for the BRP.

In this way, the reBAP punishes behavior that leads to instability in the grid and incentivizes actions that stabilize the grid. Typically, the reBAP is positive when the Balance in the NRV zone is positive and negative when the Balance in the NRV zone is negative. Therefore, payments for regulating services tend to flow from the BRPs to the TSOs.

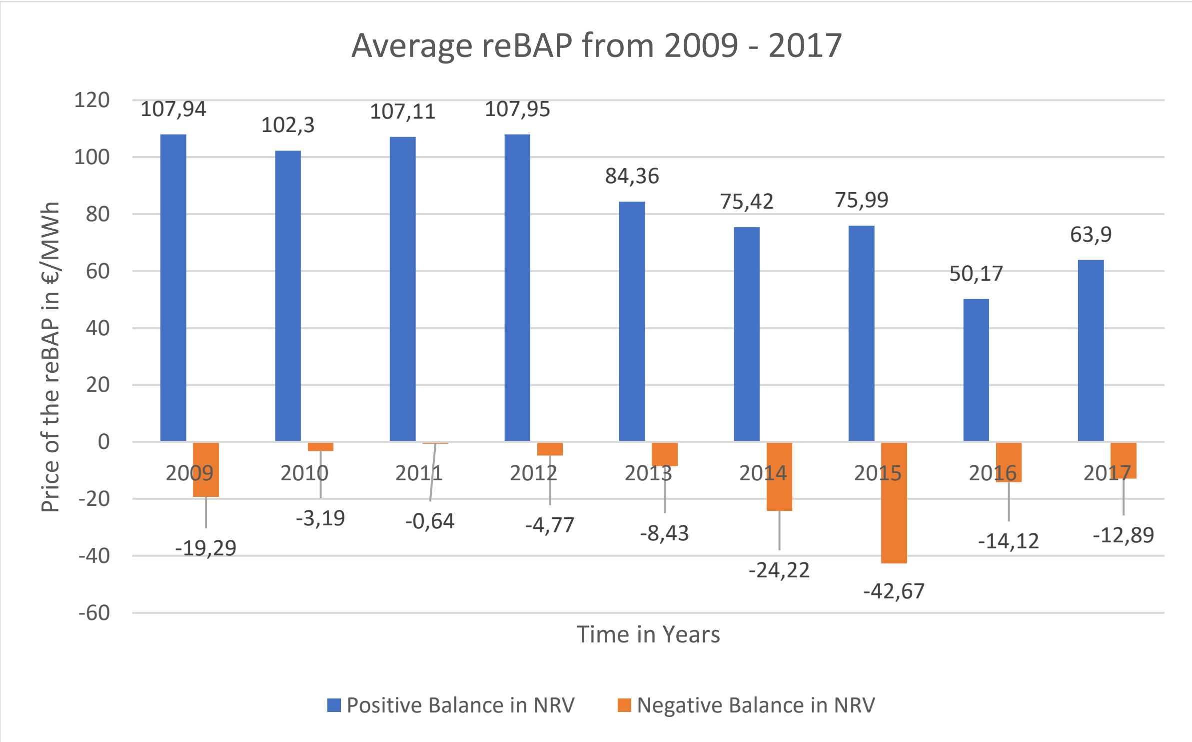


Figure 15 Average reBAP over the last Years own Display based on (Bundesnetzagentur, 2018b)

The reBAP has the same value no matter where in Germany the imbalance occurs. Figure 15 shows the price development of the reBAP in recent years. It distinguishes into “Positive Balance”, when there is too much electricity in the NRV zone, and “Negative Balance” when the NRV zone is under-covered. As explained before, the reBAP tends to be negative when the Balance in the NRV zone is negative and the other way around. Thus, the reBAP usually is a payment from the BRP to the TSO for not keeping the control zone stable.

In October 2017, the reBAP reached an absurdly high value of 24,445 €/MWh because the costs for buying balancing power at the regulating markets were immense for the TSO (Bundesnetzagentur, 2018b). These tremendous values were one of the reasons why the German TSOs changed the tendering mechanism on the balancing market in 2018. While the price from October 2017 is unprecedented, reBAPs are usually higher priced than electricity on wholesale or balancing markets which should incentives BRPs to balance their portfolio as much as possible. Imbalance settlements are completed up to 42 working days subsequent to the physical delivery of the energy and the costs for balance deviations are charged to the BRPs on a monthly basis (50Hertz, 2019; Koliou et al., 2014).

5. Market Price Analysis

5.1 Scope of the Market Price Analysis

The qualitative analysis provided a profound understanding of the German energy market. This understanding of the market design is essential because it helps EV-Aggregators to understand how the different markets and the design of the tendering scheme influence their business model. After introducing the market design and explaining the operating mode of the balancing markets, the following chapters will analyze the prices in the wholesale and balancing markets to evaluate the business model of an EV-Aggregator.

The market price analysis will aim to identify price patterns in the wholesale and balancing markets that the EV-Aggregator can use systematically to minimize the charging costs of the fleet and to maximize revenues from the regulating markets. In order to create a benchmark for Tibber, the Norwegian market prices are compared with the German market prices if the data and the underlying price products suit for comparison.

5.2 Price Analysis of the Wholesale Markets

5.2.1 Seasonal Price Differences

The first price analysis chapter investigates the seasonal price differences in Germany and Norway. Here, one would expect a higher seasonal price dependency of in Norway than in Germany. Comparable to Norway's prices, Germany's electricity prices tend to be higher in the winter. However, the seasonal differences should not be as significant in Germany as they are in Norway. Firstly, Germany does not use electricity for heating like Norway. Therefore, the demand for electricity in the winter is not significantly higher. Secondly, the Norwegian seasonal fluctuations are partly caused by lower rainfall and consequently lower reservoir levels. In Germany, rainfall does hardly affect electricity prices. The German electricity prices highly correlate with the production from wind and solar, as can be seen in figure 16. The green dots in the figure depict the electricity price in the EPEX Spot market (in MW/h) and the capacity of wind & solar (in GW) that was active in the merit order at the time these prices were achieved. The curve fit indicates that a rising capacity of wind and solar leads to lower Day-Ahead market prices.

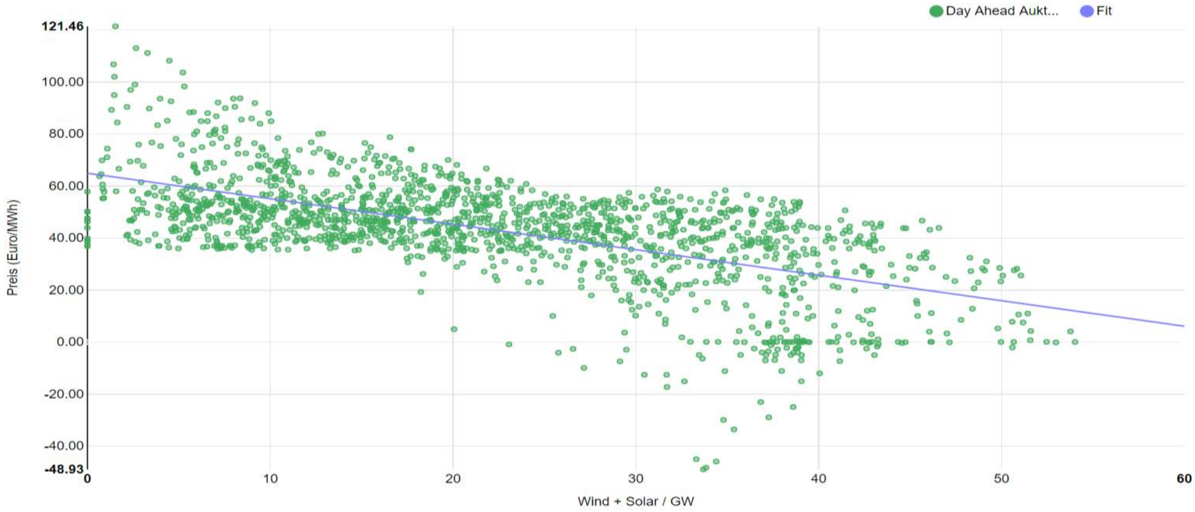


Figure 16 Correlation between intermittent Electricity Capacity and Wholesale Prices (Fraunhofer, 2019a)

Even though wind and solar are seasonal energy resources, they balance each other out in Germany. While solar (yellow and orange bars) is dominant in summer, the wind (green and blue bars) blows stronger in the winter months as can be seen at the following figure based on data from 2018.

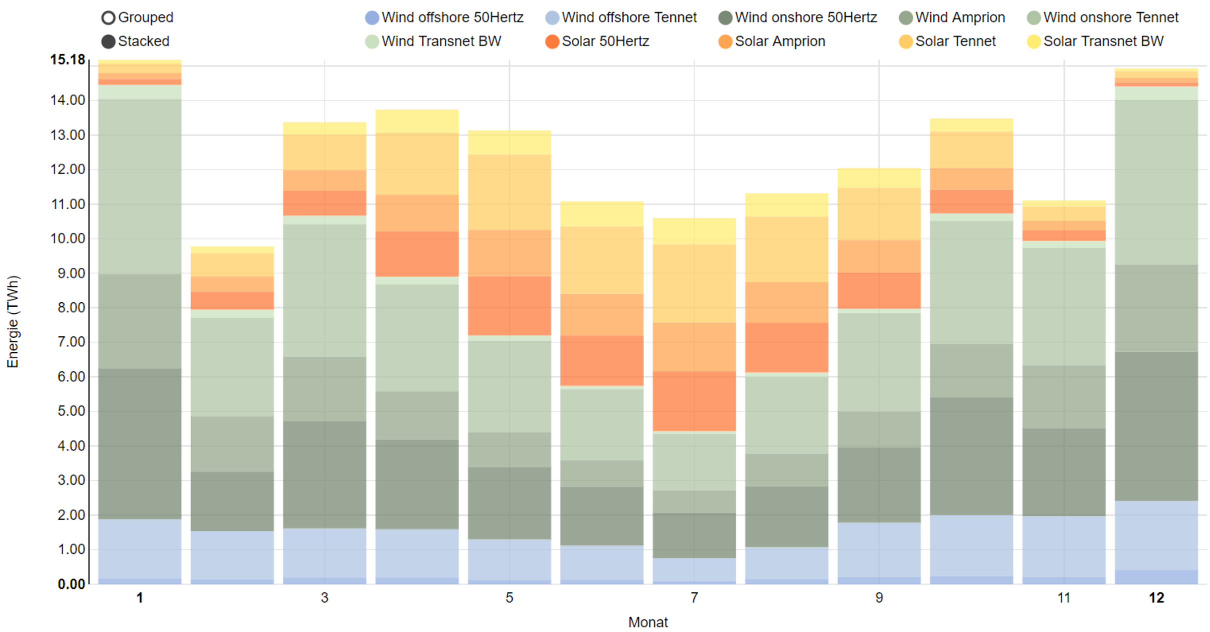


Figure 17 Energy Production from Wind and Solar during the Year 2018 (Fraunhofer, 2019)

In a first analysis, the seasonal differences in prices in the German Day-Ahead market and the Norwegian ELSPOT have been compared. The year has been sorted in summer and winter months and the average Day-Ahead prices from winter and summer months have been compared with the average price for one MWh within the year. The first analysis was performed with price data from 2017 and 2018. Surprisingly, the first analysis resulted in a higher seasonal deviation for the German market with an average standard deviation of 0.88 for the German winter months (Nov-Mar) and an average standard deviation of 0.46 for the Norwegian winter months. Meaning that the winter months in Germany show prices 0.88 €/MWh above average while the Norwegian winter prices are 0.46 €/MWh above the average.

This abnormality can be explained by the extraordinary summer in Norway in 2018. In the Nordics, last year's summer was characterized by abnormally high temperatures and was the driest summer in the history of Norway (Taylor, 2018). As a result, the prices at the Norwegian Day-Ahead market reached up to 51.73 €/MWh in August. These special conditions distort the typical conditions at the Norwegian market.

Hence, an additional price analysis for the seasonal price dependency in Norway was carried out. Computing the monthly averages and their deviation for the years 2015 and 2016, resulted in an average standard deviation of 3.16 for the winter months. This means that the typical winter month in Norway is characterized by prices of 3.16 €/MWh above the overall yearly average. Adjusted for the mean, this results in a coefficient of Variance for the winter months of 0.131 in the Norwegian case and 0.023 in the German case. This result proves the initial hypothesis that seasonal differences are stronger in the Norwegian market. Consequently, an EV-Aggregator has not to fear significantly higher charging costs in winter.

5.2.2 Weekly Price Fluctuations

Next to seasonal fluctuations, the German market is characterized by weekly price fluctuations. Especially on Sundays, when most of the industry stands still, the energy demand in Germany is significantly lower than the rest of the week. Accordingly, the prices for electricity drop on Sundays. In Germany, this effect is expected to be larger than in Norway. The high energy demand from the industry drops significantly on Sundays, and the electricity generation is less flexible in Germany. The analysis of the Day-Ahead market in 2018 resulted in an average electricity price of 33.70 €/MWh. Even though a lower price on Sundays can be observed in Norway, the difference between the average price and the price on Sundays is smaller than in the German market. While the German price on Sunday deviates on average 10.77 € from the overall average, the prices on the Norwegian Day-Ahead market vary only by 2 € and lay on average at 27.05 €/MWh. The significantly lower prices on Sundays in Germany offer the aggregator charging at significantly lower costs. In some cases the aggregator might even benefit from negative prices on Sundays.

5.2.3 Daily Fluctuations

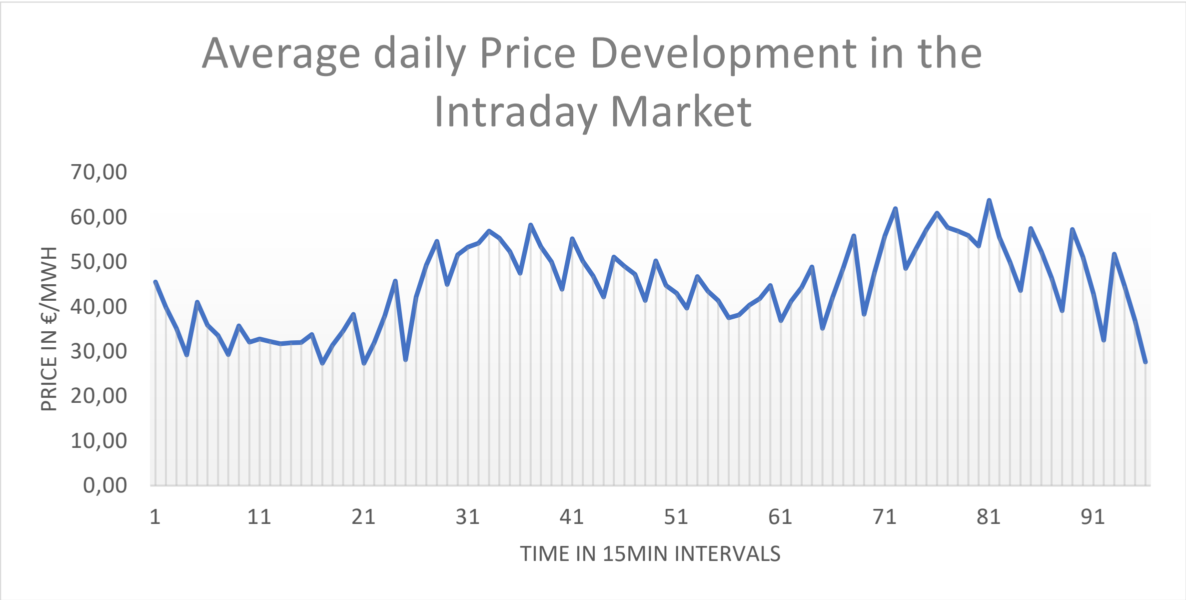


Figure 18 Average Price Development in the Intraday Market

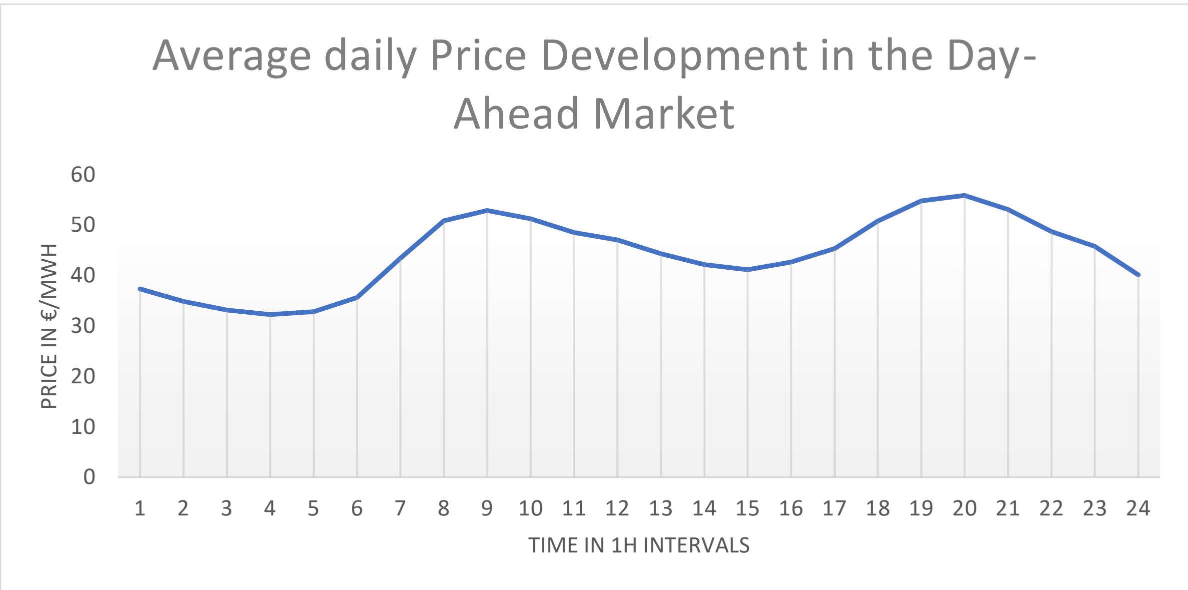


Figure 19 Average Price Development in the Day-Ahead Market

The daily price developments in the Intraday and Day-Ahead market show that there are two price peaks per day. The first peak occurs typically between 8 am and 9 am before people head to work and the second at around 7 pm when people are back home and tend to start cooking or turning on the television or other devices. An EV-Aggregator should try to avoid charging its fleet at peak prices. This can be done, for example, by shifting the charging from the evening peak to night hours, during which the electricity price is lower.

5.2.4 Price Volatility

While the monthly production through wind and solar tends to be stable, daily electricity production can highly fluctuate. This leads to high variations in the Day-Ahead and Intraday markets. An analysis of all 8760 hourly prices in the Day-Ahead market of 2018 resulted in a standard deviation of 17.59, which means that on average the prices vary by 17.59 € from the average price. Compared to the standard deviation in the ELSPOT Day-Ahead market of 5.19, this deviation shows how volatile the prices in the German market are. The 35,040 price points in the German Intraday market vary even more with a standard deviation of 19.0.

Another remarkable difference between the markets is the occurrence of negative prices. While no single negative price can be identified in the ELSPOT in 2018, the German Day-Ahead market had 137 hourly intervals with negative prices. In the Intraday market, there were even 660 occurrences of negative prices. This is particularly interesting for EV-Aggregators since the EVs are a highly flexible electricity consumer. In general, these negative prices occur on national holidays or Sundays when the demand is low and the generation from wind and solar is high.

The volatility of prices during one day is highly valuable for an EV-Aggregator. Ideally, the aggregator could anticipate high electricity generation from wind or solar and bid accordingly. Since there is no pre-defined pattern for wind and solar production, it might be interesting to feed the optimization algorithm of an EV-Aggregator with precise weather forecasts to optimize the charging of the fleet.

5.2.5 Intermarket Spread

An intermarket spread is a trading strategy commonly referred to a sale of a futures contract on one exchange and the purchase of another futures contract on another exchange (Chen, 2018). For an EV-Aggregator, the spread between Day-Ahead and Intraday market is highly interesting. Utilizing the flexibility of the charging process and deploying a good predictive trading strategy, an EV-Aggregator can make use of arbitrage trading between the two markets.

While the average daily prices of Day-Ahead and Intraday market in Germany, show a correlation of almost 100%, the hourly and 15min intervals can vary significantly from each other. Arbitrage can be achieved through rapid and significant price changes in small trading periods. In finance, one does also refer to pairs trading in this context. For pairs trading, a high correlation of two indexes or markets gives the trader security because it is highly probable that the prices will converge again after diverging for a short period. At the same time, significant differences in a short time frame are important, because they allow for arbitrage trading.

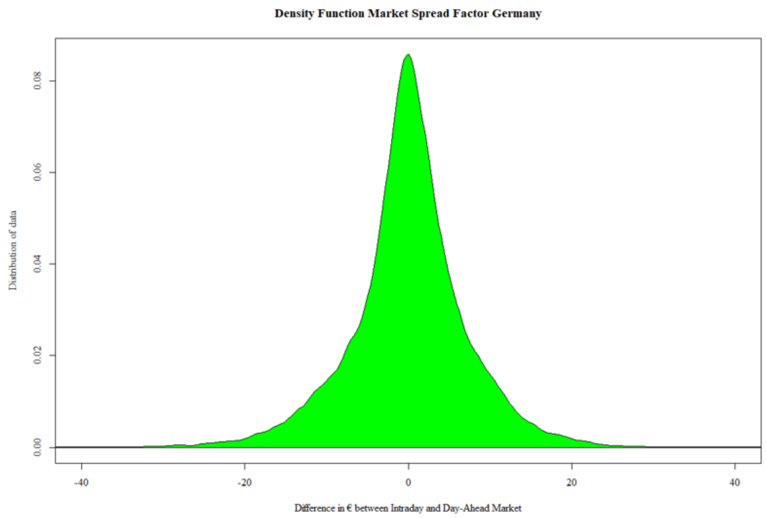
To inspect whether these circumstances are given in the German market, an additional analysis of the Day-Ahead and Intraday market was concluded. For the year 2018, an intermarket spread factor that is made up of the difference between Intraday and Day-Ahead prices was constructed.

$$\text{Intermarket Spread} = \text{Intraday Price} - \text{Day-Ahead Price}$$

Since there are four times as many Intraday prices in the German market as there are Day-Ahead prices, the 35,040 Intraday prices have been allocated to their respective hourly value to calculate the difference between the markets. The attribution has been performed through a nested for-loop in R.

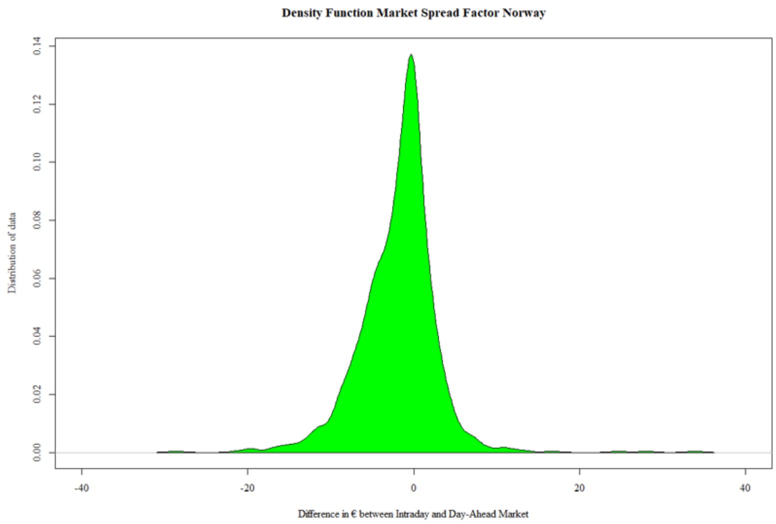
The German analysis is based on the EXAA Day-Ahead and Intraday prices while the Norwegian correlation factor is calculated through the deviation of the ELBAS and the ELSPOT in the NO1 price region. In this case, it is hard to compare the markets, because the Intraday market in Germany has different characteristics, such as smaller trading periods and a higher trading volume. Moreover, the data set lacks comparability two different time horizons had to be compared due to data limitations. For the German intermarket spread all data points from 2018 have been used, while for the Norwegian intermarket spread data from October to December 2017 has been utilized. The following graphs depict the density functions of the intermarket spread factor. The y-axis displays the distribution of the data whereas the x-axis depicts the difference between the Intraday and Day-Ahead markets in €.

In the table next to the graph, one can find the descriptive statistics of the intermarket spread factor.



Market Spread Factor Germany	
Mean	-0.001
Standard Error	0.038
Median	0.080
Standard Deviation	7.188
Sample Variance	51.667
Kurtosis	2.695
Skewness	-0.196
Range	123.710
Minimum	-64.470
Maximum	59.240

Figure 20 Spread Factor Germany Intraday - Day-Ahead Market



Market Spread Factor Norway	
Mean	-1.884
Standard Error	0.137
Median	-1.250
Standard Deviation	4.596
Sample Variance	21.121
Kurtosis	7.667
Skewness	0.194
Range	62.490
Minimum	-28.610
Maximum	33.880

Figure 21 Spread Factor Norway Intraday - Day-Ahead Market

Since the intermarket spread is the difference between Intraday and Day-Ahead prices, the mean of the intermarket spread tells us that the market deviation equals out in the German market. In the Norwegian case, the ELBAS is on average 1.88 €/MWh cheaper than the ELSPOT because the mean of the intermarket spread is -1.88.

The standard deviation in the German market is a bit higher than in the Norwegian market. Thus, there are either more or higher deviations between the markets in Germany. The coefficient of variance cannot be used to compare the two markets in this case since the statistical concept of the value has application problems when negative values are included. The range, which is double as high in the German case, strengthens the assumption that the German wholesale market offers higher potential for pairs trading. Nevertheless, one must remember that the Norwegian spread factor is merely calculated for three months. This constitutes a non-neglectable constraint to the analysis. The range of the intermarket spread factor would probably increase when data for the whole year were utilized.

In a next step, the German intermarket spread factor was analyzed further in the hope of finding insightful patterns that an EV-Aggregator could utilize systematically to minimize the costs of electricity. Therefore, I computed the average intermarket spread factors for every day of the week. Figure 22 illustrates the development of the intermarket spread factor during a day. The different curves each resemble one of the days during a week.

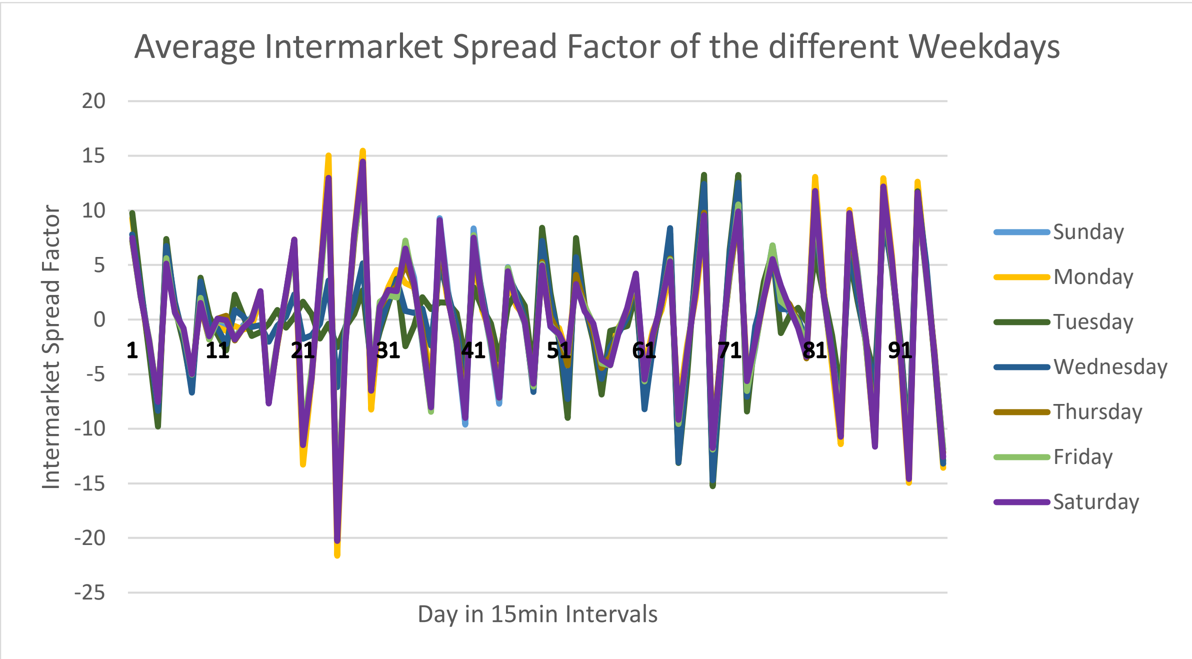


Figure 22 Intermarket Spread Factor of the different Weekdays

Even though the graph merely looks chaotic at first glance, one can detect that every day follows a similar 15min pattern regarding positive or negative values. The intermarket spread factor quickly changes between negative and positive values. Thereby, the value of the first 15min price interval is positive for all the seven weekdays, which means that the first price interval is on average more expensive at the Intraday market for every day of the week. The rhythm in which the spread factor changes from positive to negative seems to be similar for every weekday.

Next to these patterns, one can observe another interesting pattern. When calculating the descriptive statistics of the 96 15-minute price intervals, the intervals 22-29 and 68-74 are characterized by the widest range of the market spread factor. Thus, around 6 am and 6 pm the Day-Ahead and Intraday market differ the most from each other. This is the same time period in which the wholesale markets have their daily peaks. Hence, the spread factor peaks at a similar time as the electricity prices on a daily level.

For an EV-Aggregator it is interesting to know which days of the week are characterized by the highest differences between the Intraday and Day-Ahead market. Therefore, one needs to calculate which day shows the highest intermarket spread factors. Whether there is a high positive or high negative intermarket spread does not matter as much as the degree of the difference between the two markets, e.g. a market spread factor of -5 seems low but shows a higher market difference than an intermarket spread of 3.

When building averages of the intermarket spread, though, the negative and positive values can cancel each other out (e.g. building the average of the spread factors 5 and -5 would lead to an average spread factor of 0 even though there is a high price difference). To identify which day shows the highest intermarket spread factor, one must transform the intermarket spread factor into absolute values. After transforming the intermarket spread factor into absolute values, I plotted those values in the following graph. Figure 23 illustrates the average intermarket spread factor that is based on non-negative/absolute values.

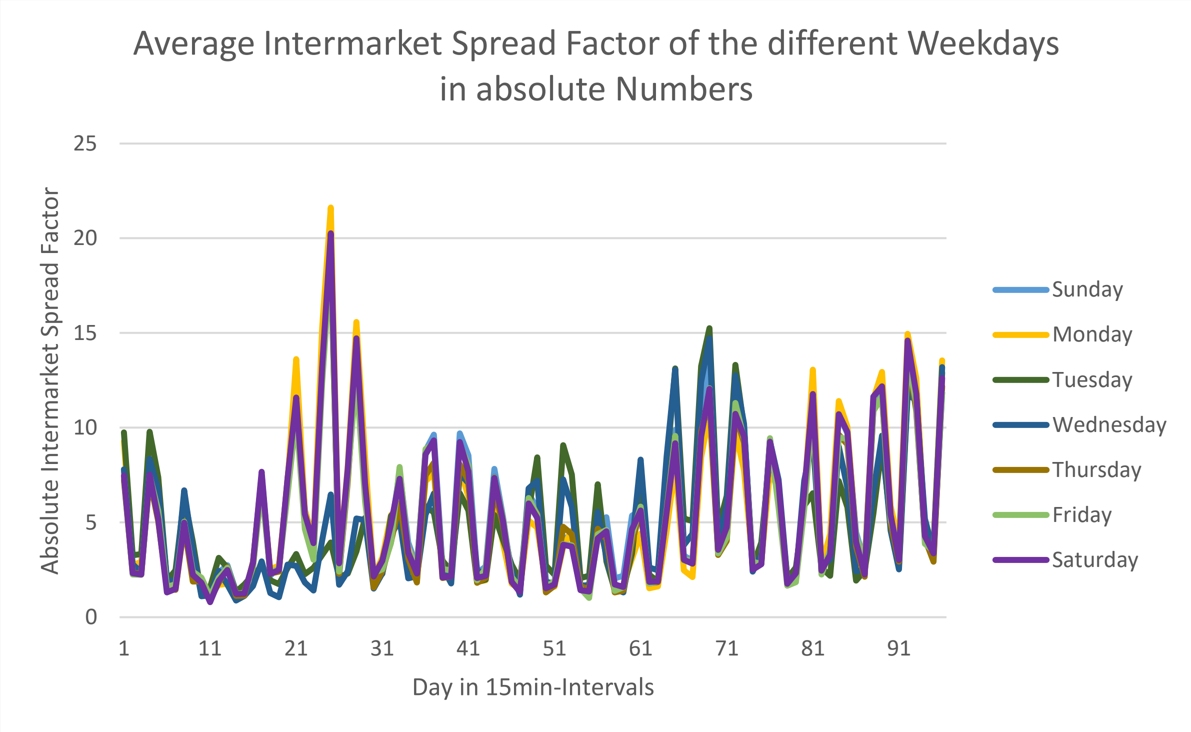


Figure 23 Intermarket Spread Factor of the different Weekdays (calculated with absolute Values)

High values indicate high differences between the Intraday and the Day-Ahead market, which is interesting for EV-Aggregators. The resulting figure shows that Tuesdays (dark green curve) and Wednesdays (dark blue curve) are least attractive for pairs trading due to low intermarket spread factors. Especially during the morning peak on Mondays (yellow curve) and Saturdays (purple curve), the intermarket spread factor rises to 20, which resembles a difference in market prices of 20 €/MWh. For EV-Aggregators, these days seem to be the most attractive for arbitrage trading.

5.2.6 Comparative Analysis of the Wholesale Markets

To set the German market into comparison, the following table depicts the market prices and volatility of the German and the Norwegian market.

Table 3 Overview Wholesale Markets, own Analysis based on Data provided by (Bundesnetzagentur, 2018; EXAA, 2019; Fraunhofer, 2019; Nordpool, 2019)

	Germany	Norway
Market structure	The wholesale market offers possibilities of trading Futures, Day-Ahead and Intraday contracts at multiple	The Wholesale market is constructed in a similar way to the one in Germany. The only small differences are

	electricity exchanges. EEX owns the exchange with the biggest trading volume, offering the Phelix Futures and the EPEX Day-Ahead and Intraday Market. Over-the-counter trading still very popular in Germany, especially for trading with future contracts.	that the Intraday market does not allow the trading of 15min contracts and that fewer electricity exchanges are used. Over-the-counter trading has only a small market share.
Market volumes	EPEX Spot: 133 TWh EPEX Intraday: 47 TWh Phelix Futures: 786 TWh EXAA SPOT: 8 TWh Over-the-counter trading: 5671 TWh	ELSPOT: 281.89 TWh ELBAS: 1.15 TWh (only the NO-zones have been considered)
Average price in the Day-Ahead Market	44.47 €/MWh	29.40 €/MWh
Average price in the Intraday Market	44.46 €/MWh	34.03 €/MWh
Standard Deviation in the Day-Ahead Market	17.59	5.19
Standard Deviation in the Intraday Market	19	10.63
Coefficient of Variance Day-Ahead Market	0.3955	0,1765
Coefficient of Variance Intraday Market	0.4274	0.3124
Average price on Sundays in the Day-Ahead market	33.70 €/MWh	27.05 €/MWh
Average standard deviation of Winter months	0.88 (data from 2017 &2018)	3.16 (data from 2015 & 2016)
Average standard deviation of summer months	-0.88 (data from 2017 & 2018)	-3.16 (data from 2015 & 2016)
Standard Deviation of the intermarket spread factor	7.19	4.60
Occurrences of negative prices in the Day-Ahead Market	137 (hourly intervals)	0
Occurrences of negative prices in the Intraday Market	660 (15min intervals)	3 (hourly intervals)

As expected, the German market is characterized by lower seasonal price effects, but significantly higher overall market volatility. This high volatility can be observed by comparing the standard deviation and the coefficient of variance. The coefficient of variance is the standard deviation divided by the mean. Since a higher mean typically results in a higher standard deviation, the coefficient of variance was computed to adjust for the difference in the mean prices. The higher coefficient of variance in the German case is attractive for EV-Aggregators because they can benefit from high market price volatility due to their flexible demand.

Moreover, high market volatility brings a vast amount of negative price occurrences which makes the German market highly interesting for trading with flexible demand & supply units like electric cars.

Additionally, there is a higher standard deviation of the Market Spread Factor, meaning that there is a higher deviation between Day-Ahead and Intraday market, which is more favorable for pairs trading with the flexibility of the car capacities.

5.3 Price Analysis of the Balancing Markets

5.3.1 Seasonal Price Patterns in the Balancing Markets

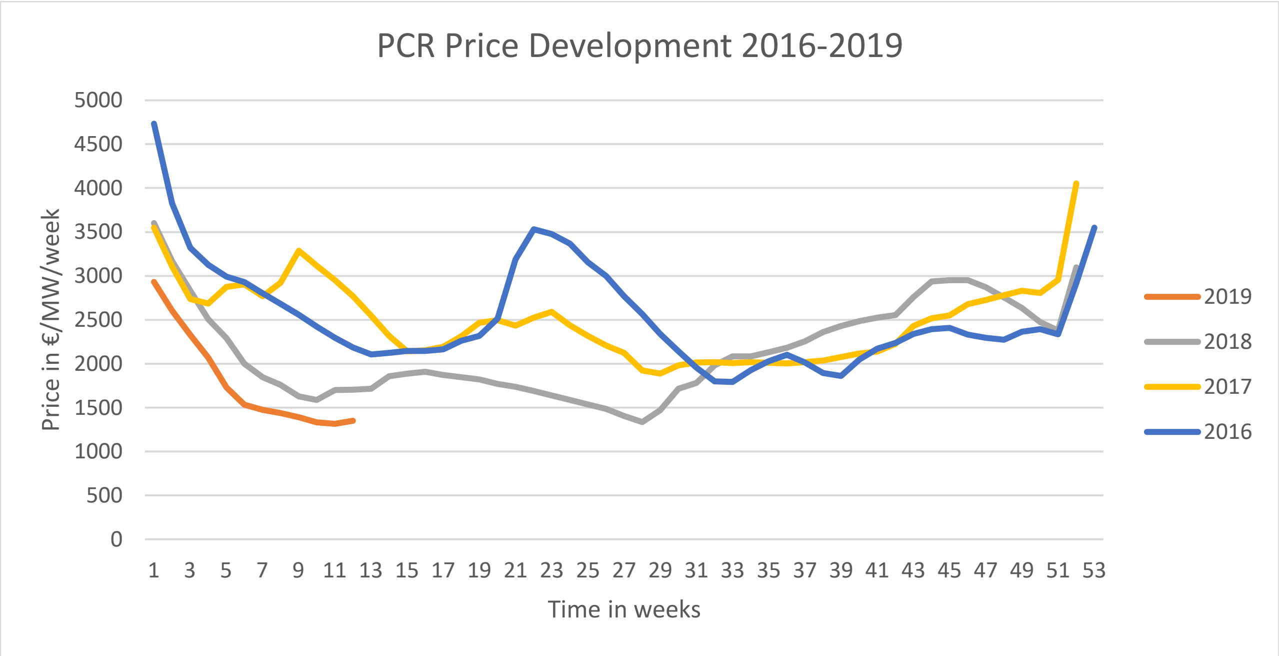


Figure 24 PCR Price over the last Years

For spring, summer, and autumn, no precise statements regarding price developments can be deduced from Figure 24. While 2016 was characterized by high prices in the summer, 2017 and 2018 had relatively low summer prices. Similar statements can be made for spring and autumn. The winter, however, is characterized by higher prices every year from 2016 to 2019. This could be due to three reasons:

1. A power plant that offers its capacity at the PCR market cannot bid in the other electricity markets for this point of time. Consequently, the opportunity costs of these power plants are the prices at the other markets. The traders will always try to find the most valuable market for them. That leads to a correlation between the prices of the wholesale and balancing markets. Since the winter months tend to be higher priced in the SPOT market, the regulatory market prices develop accordingly. However, this correlation is difficult to prove due to the different time slices and conditions between the balancing and wholesale market.
2. As can be seen in figure 17 in the chapter "Seasonal Price Differences", the months December and January are the ones with the highest electricity production from wind. Since this production is hard to forecast, there are more deviations from 50Hz in winter months compared to the other months of the year. Thus, the demand for balancing energy is higher in this period and the prices in the PCR market increase.
3. December and January have comparably many national holidays. National holidays are characterized by a low electricity demand that often leads to negative prices in the wholesale markets. Furthermore, this increases the demand for down-regulation and results in higher PCR prices.

Besides the typically high prices in winter, there is another pattern, which is threatening the business model of an EV-Aggregator; the yearly price development. The mean of all PCR prices in 2016 was 2,540 €. Since then, the mean steadily decreased. While it was 2,450 € in 2017, the price dropped to 2,145 € in 2018 and 1,791 € in 2019 (data available until March). Thereby, the prices of any week in 2019 were lower than the prices of the respective weeks in the years before. Alongside the falling prices in the balancing markets, the potential revenues for EV-Aggregators are decreasing.

Daily patterns cannot be observed in the PCR price spectrum due to the weekly tendering process for PCR. Thus, the author used the SCR market to search for daily or weekly price patterns.

5.3.2 Weekly Price Patterns in the Balancing Markets

There are differences between weekdays and non-weekdays visible for the SCR in the balancing market. Figure 25 and 26 show the SCR positive (up-regulation) and SCR negative (down-regulation) prices. The blue bars depict the average prices, while the orange bar illustrates the average price of secondary reserve power on weekends. As mentioned earlier, the SCR prices are distinguished into a capacity payment and an energy payment that is paid if the reserve gets activated.

For SCR positive, the overall capacity price and the overall energy price are roughly two € higher than the weekend prices. This could be due to the comparable opportunity gains at the Day-Ahead and Intraday market. Since prices in the wholesale markets drop on weekends, more producers shift into the balancing markets, which leads to dropping prices for SCR positive.

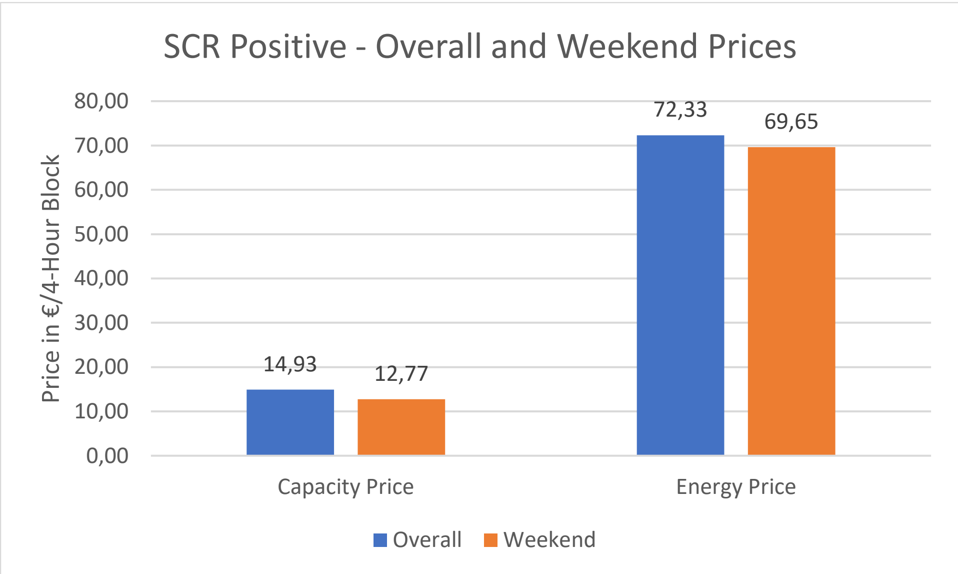


Figure 25 SCR positive – Overall and Weekend Prices

The SCR negative is characterized by more favorable prices on weekends. The interpretation of the prices for negative regulation can seem tricky. A positive capacity price means that companies are getting paid for withholding capacity. The higher capacity price on the weekend consequently refers to a higher payment for down-regulation. Even more impressive, however, is the development of the energy price component. A positive energy price in the negative regulation means that a company, which offers down-regulating power, pays the TSO for receiving electricity. On weekends the price for down-regulation turns negative. On average, the energy price for SCR negative amounts to -9.06 €/MW/4-hour Block. This means that regulating companies receive payment of 9.06 €/MW/4-hour Block for taking electricity in addition to their payments through the capacity price.

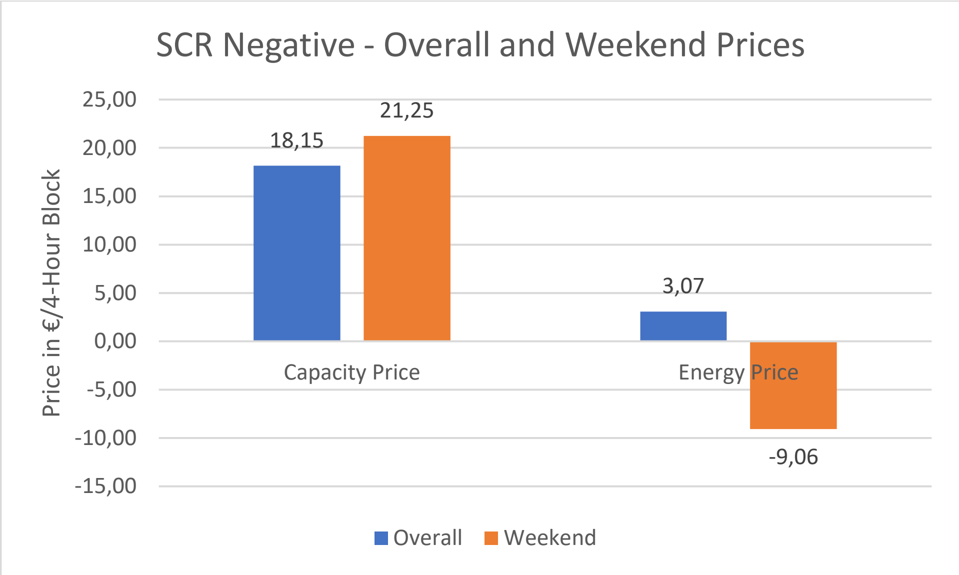


Figure 26 SCR negative – Overall and Weekend Prices

To conclude, the weekends are characterized by a lower capacity price paired with a lower energy price in the up-regulation and a higher capacity price paired with a lower energy price in the down-regulation. As a result, providing SCR positive is more attractive on weekdays while providing SCR negative is favorable on weekends.

5.3.3 Daily Price Patterns in the Balancing Markets

To analyze the daily price patterns in the balancing market, this chapter builds an aggregated price for SCR. This aggregated price is necessary to account for the capacity and the energy component in the SCR markets.

$$\text{Aggregated Price SCR POS} = \text{Capacity Payment SCR POS} + \text{Energy Payment SCR POS}$$

$$\text{Aggregated Price SCR NEG} = \text{Capacity Payment SCR NEG - Energy Payment SCR NEG}$$

For up-regulation or SCR positive, the aggregated price is the sum of average capacity payment and average energy payment in Germany. For down-regulation or SCR negative, the aggregated price is the capacity payment minus the energy payment since the energy price for SCR negative is a payment from the BRP that offers the balancing service.

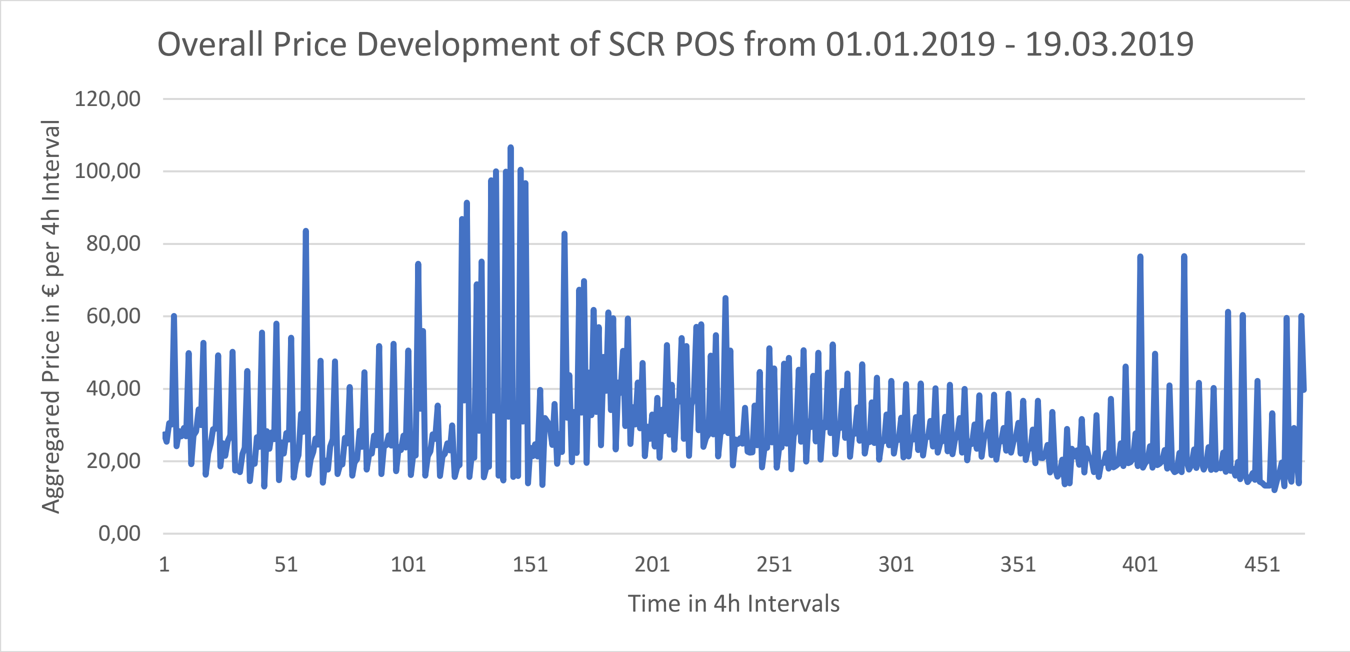


Figure 27 SCR POS January-March 2019

The SCR market follows a weekly pattern. While this pattern might not be visible when observing large time windows, it becomes visible when observing single weeks. To illustrate the typical weekly price patterns, figure 28 and 29 depict the price formation during the third week of 2019 for SCR positive and SCR negative. The third week was selected because it clearly illustrates the typical price patterns in the SCR market.

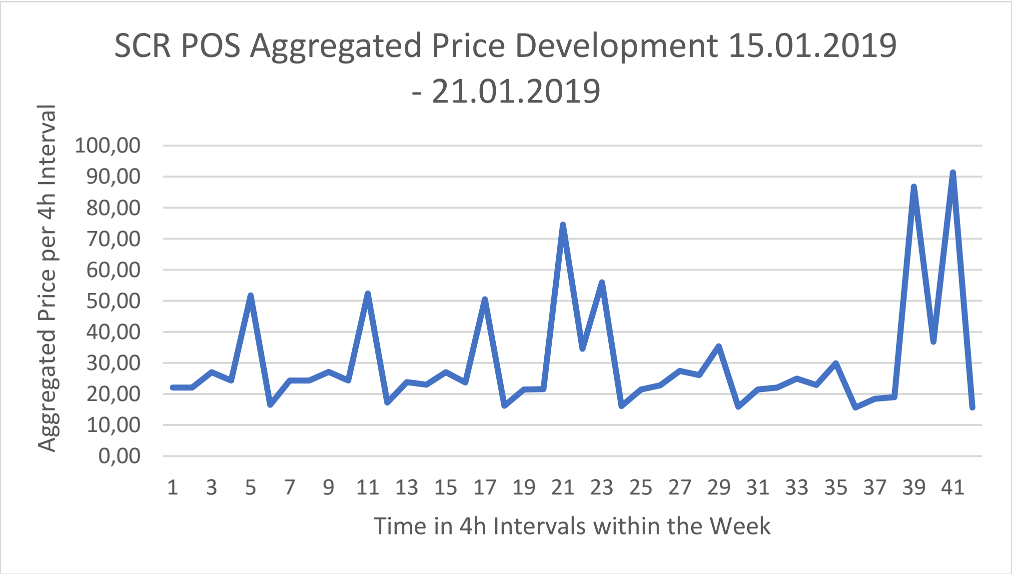


Figure 28 SCR positive in the third week of 2019

For the first three days, one can identify a peak at the 5th interval of every day, which spans from 4 pm to 8 pm. This is the typical daily pattern which can be observed for SCR positive for the other weeks as well. In certain times (here the case for Thursday and Sunday), an additional price peak is visible at the 3rd time interval of every day, from 8 am to 12 pm. For an EV-Aggregator this means that offering positive SCR within a vehicle-to-grid scenario is especially beneficial for the time slice 4 pm to 8 pm and sometimes for the block 8 am to 12 pm.

For SCR negative, the maximum value an aggregator could achieve by offering one MW as balancing power can be observed in the first interval of every day, from 0 am – 4 am. The third week of the year 2019 clearly illustrates this price pattern. The price development is plausible since the period from midnight to early morning is the time with the lowest demand. Besides, too much electricity generation is common during this time. This makes down-regulation highly valuable during this time of the day. As a result, the best time for an EV-Aggregator to bid for SCR negative is in the time slot from 0 am to 4 am.

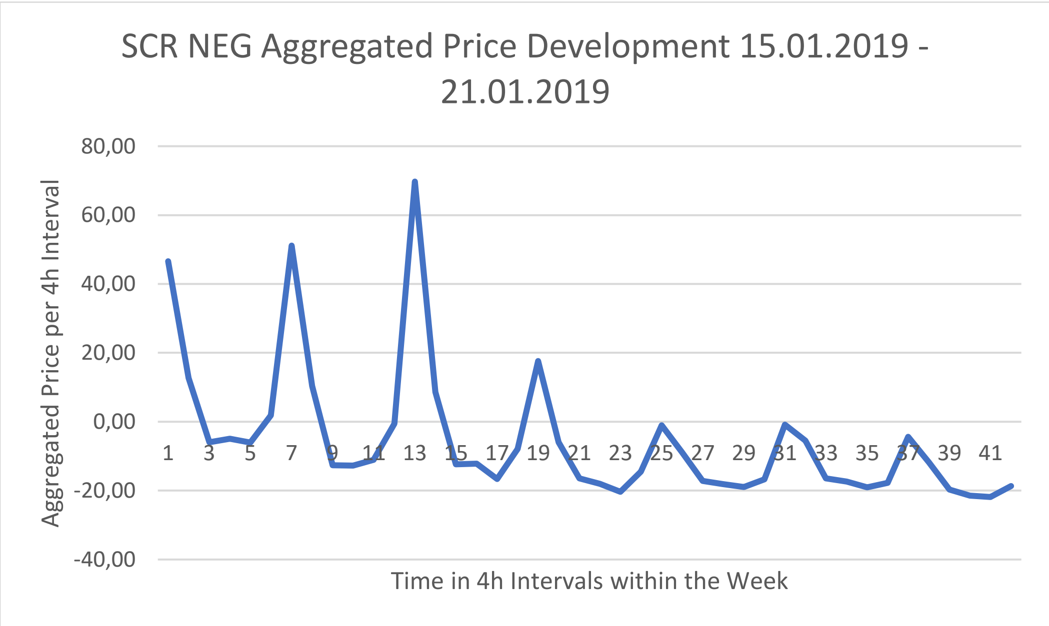


Figure 29 SCR NEG first week of 2019

5.3.4 Price Outlook

So far, the prices for PCR in 2019 in Germany have been significantly lower than in former years. Regelleistung-online (2019a) offers a prognosis on the future development of the yearly revenues with the capacity of 1MW for the PCR. For 2019, the dark blue bar in figure 30 displays the already made revenues in the market per MW from the beginning of the year until now. The light blue bar is the prognosis for the possible revenue per MW in 2019. Regelleistung-online (2019a) expects the current trend of shrinking prices for balancing power to continue. Hence, revenues in the balancing market in 2019 will be significantly lower than in previous years.

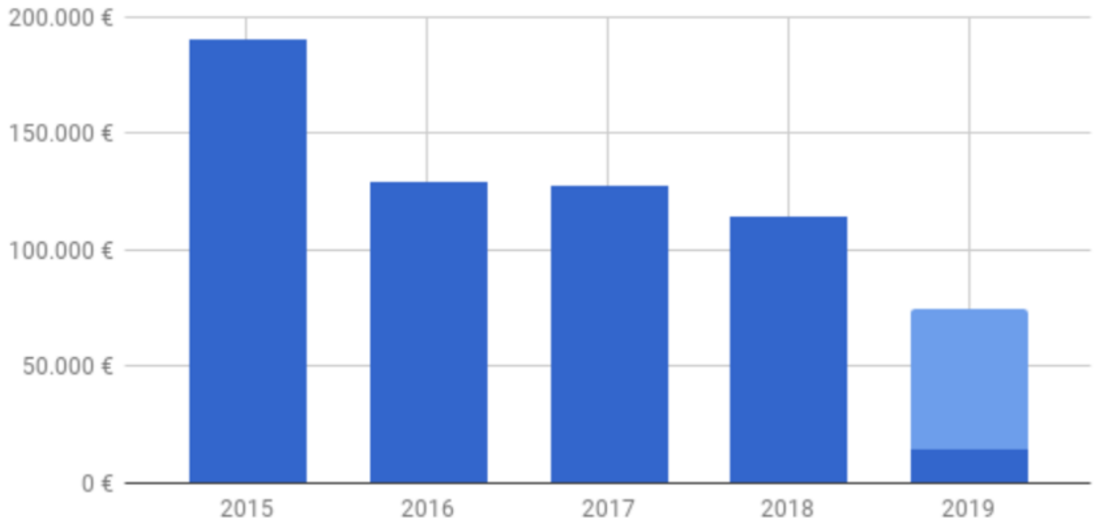


Figure 30 Forecast PCR Price in €/MW/Year (Regelleistung-online, 2019a)

Just as for the PCR, Regelleistung-online (2019a) offers a forecast for the price development of SCR. In figure 31 and figure 32, the expected price/MW/year is depicted in light red/light green and compared to the prices of recent years. However, the figure is based on capacity prices only. While capacity prices rose through the new tendering scheme with aggregated prices introduced last year, the energy prices dropped. Even though the following figures depict rising revenues for the capacity prices, the overall financial value that can be achieved on the SCR markets will presumably decrease further in 2019.

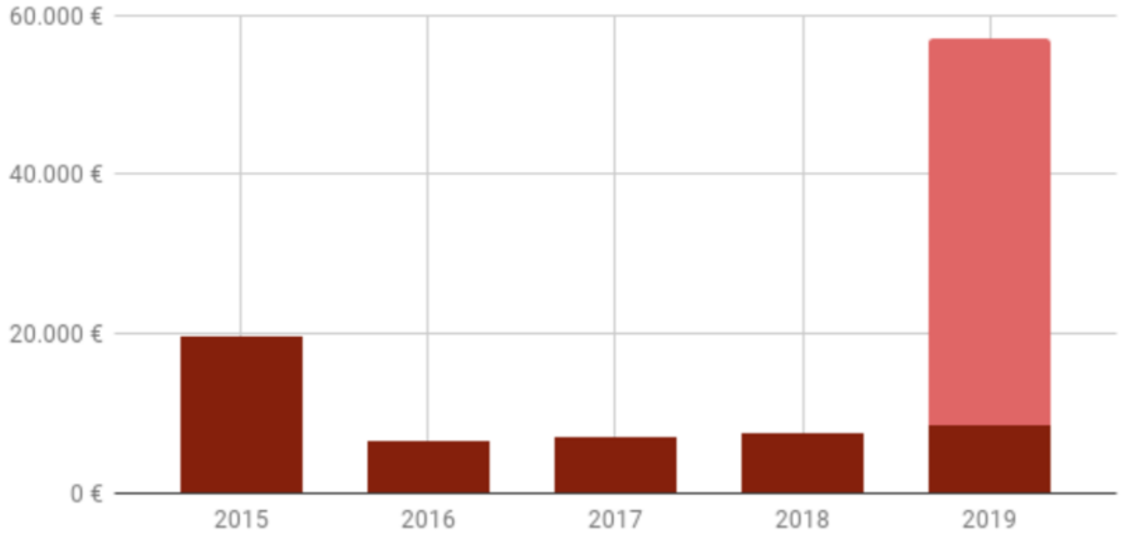


Figure 31 Forecast SCR NEG Price in €/MW/Year (Regelleistung-online, 2019a)

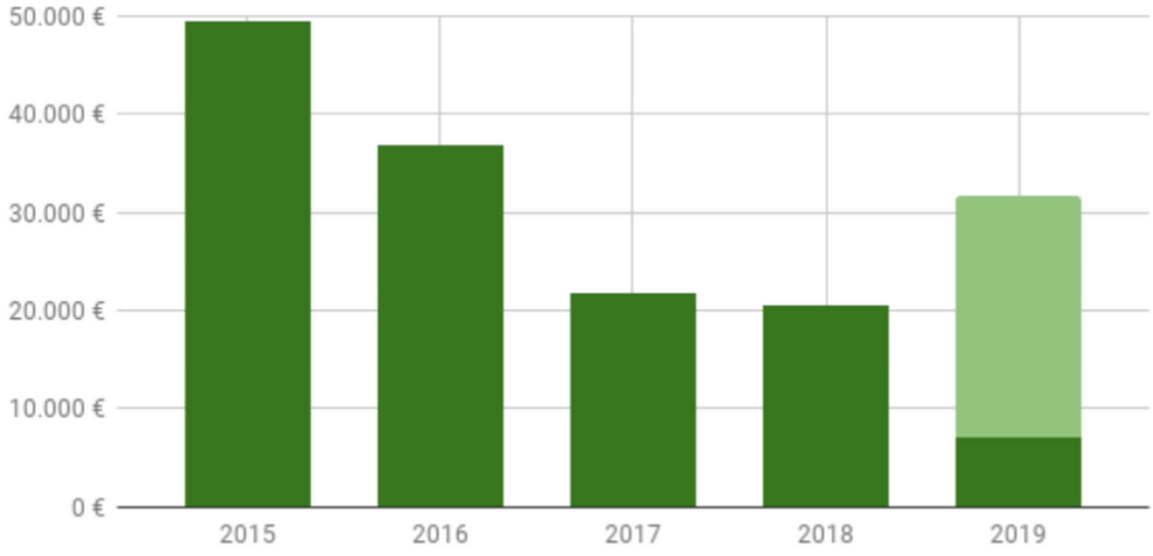


Figure 32 Forecast SCR POS Price in €/MW/Year (Regelleistung-online, 2019a)

6. Bidding optimization

6.1 Car Availability

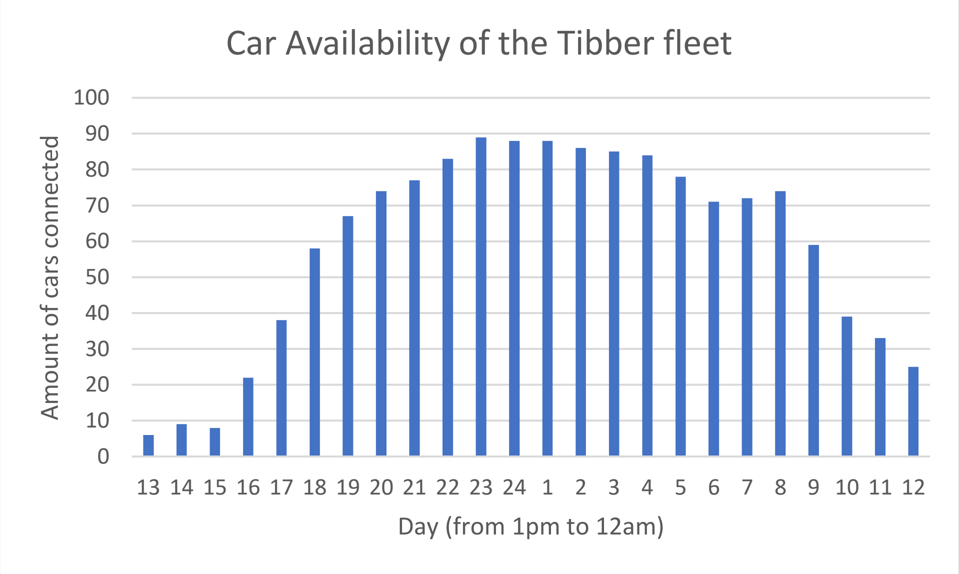


Figure 33 Car availability as measured on November the first 2018

Figure 33 illustrates the car availability of the Tibber fleet. The bar chart depicts how many cars of the Tibber fleet were connected to their charging station during the day. Since the driving behavior on weekdays, according to Tibber, is similar the whole year around, the driving patterns of the 1st of November have been used for the whole optimization. For the fleet observed in this thesis, the availability of cars for flexibility services peaks at 11 pm. The lowest number of cars are connected to the charger at 1 pm. In the peak times for availability from 11 pm - 2 am the cars had a charging power of around 250kW. Consequently, one would need around 600 cars to satisfy the minimum requirements for a participation in the SCR market of 1MW. For the sake of the optimization, this minimum requirement was ignored in the following optimization.

6.2 Bidding behavior

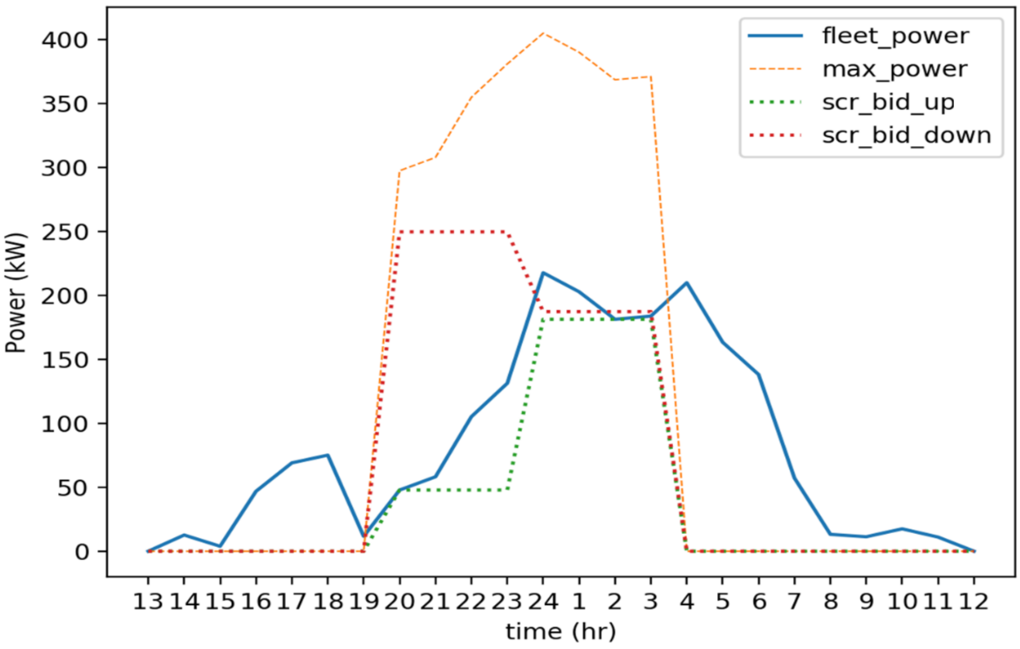


Figure 34 Optimal bidding Behavior for EV-Aggregators in Summer 2018

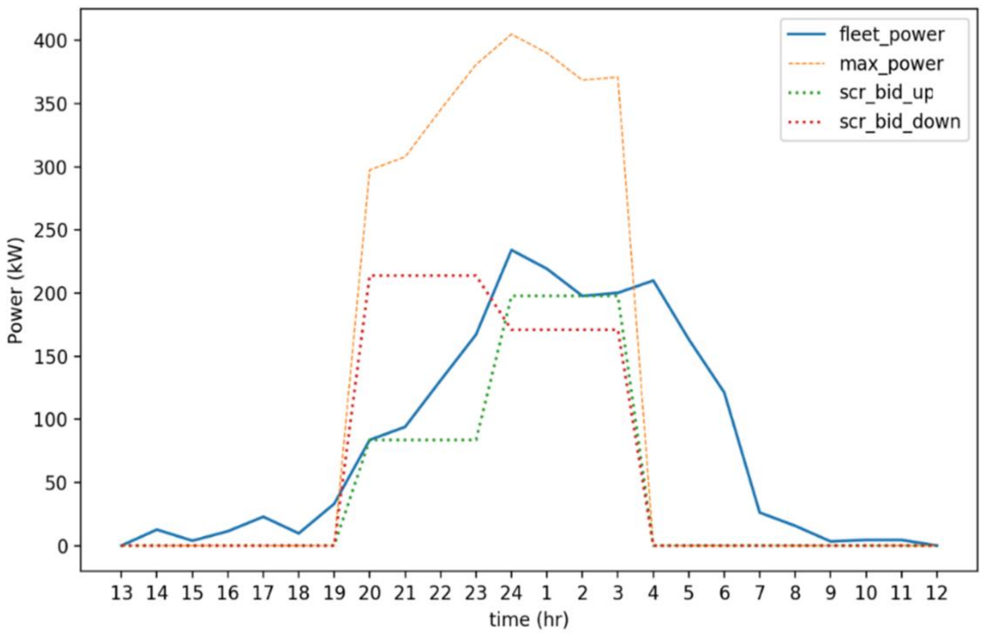


Figure 35 Optimal bidding Behavior for EV-Aggregators in Winter 2018

Figure 34 and figure 35 illustrate the optimal bidding behavior of the Tibber fleet in summer and winter. Max_Power resembles the aggregate maximum possible charge of vehicles at home and not full. Max_Power is only displayed in the times where the fleet participates in a SCR bid. Fleet_Power is the real power if all cars that are at home would charge. In the optimized scenario, the charging is postponed to the night time to avoid charging at peak prices. In contrast to the dumb charging case (see figure 38 and figure 39), the fleet power in the optimal case peaks from 0 am - 5 am instead of during 8 pm.

Moreover, the down-regulation bid for SCR is used to charge the cars. During the night, there are two 4-hour periods (8 pm – 12 pm and 0 am – 4 am) in which the fleet participates in down-regulation. This is saving a significant amount of charging costs. At the same time, the EV fleet is offered for up-regulation (vehicle-to-grid) in two 4-hour periods during the night. This stabilizes the grid and leads to additional income for the EV-Aggregator.

Even though the market price analysis indicated that positive regulation power is most attractive for the block from 4 pm – 8 pm, the optimization bids for SCR positive during the night time. This is due to the availability of EVs. At 4 pm, most of the vehicles are not at home yet, making it difficult for an EV-Aggregator to achieve the necessary minimum bid volume. Hence, the up-regulation bids focus on the period from 8 pm – 4 am.

In Scenario B, participation in balancing markets is not included. Still, the EV-Aggregator saves charging costs by avoiding the evening peak prices and loading in the fleet during the night as can be seen in the following figures.

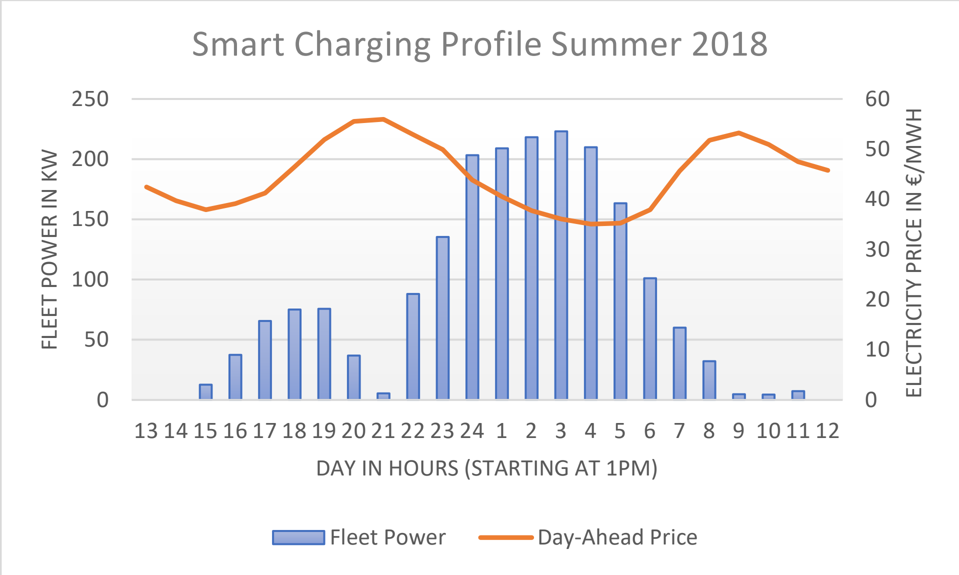


Figure 36 Smart Charging Profile of Vehicle Fleet in Summer 2018

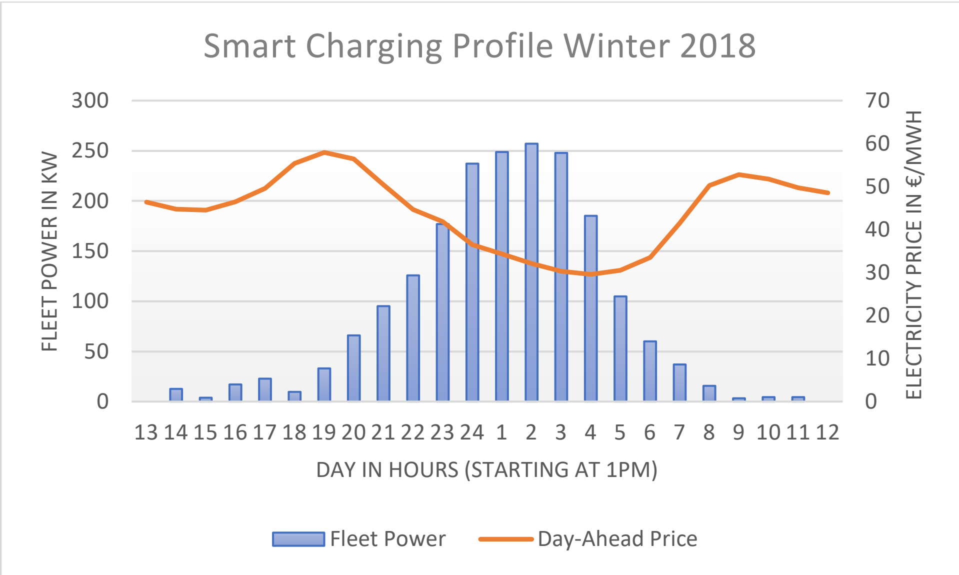


Figure 37 Smart Charging Profile of Vehicle Fleet in Winter 2018

In comparison with the Dumb Charging profile in figure 38 and figure 39, we observe that the fleet power is shifted. Through this shift, performed by the EV-Aggregator, the EV owners can save costs by avoiding the evening peak at 8 pm. In the dumb charging case, a high amount of vehicles are charging at the time of the unfavorable evening peak prices, while in Scenario B the charging time is shifted to the middle of the night where prices are lower.

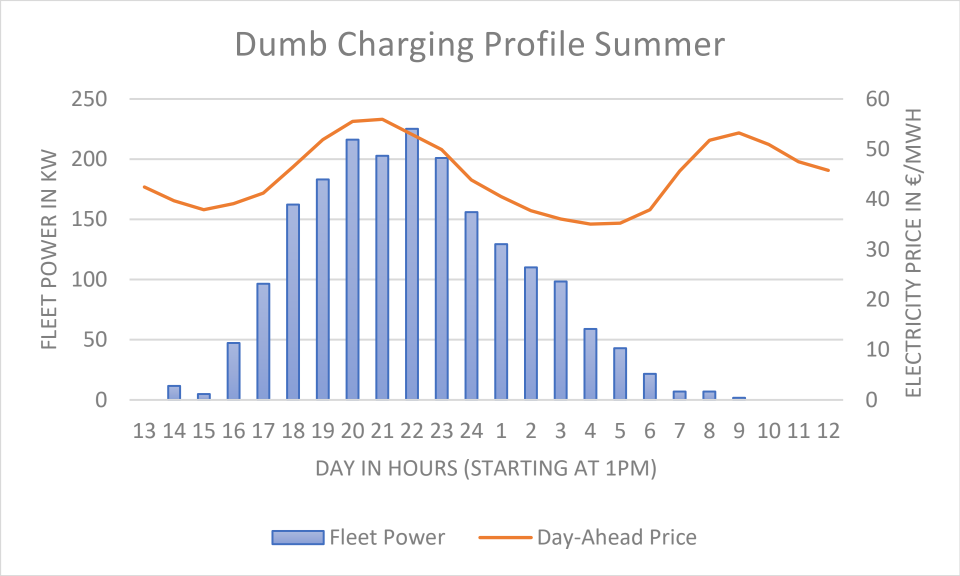


Figure 38 Dumb Charging Profile Summer 2018

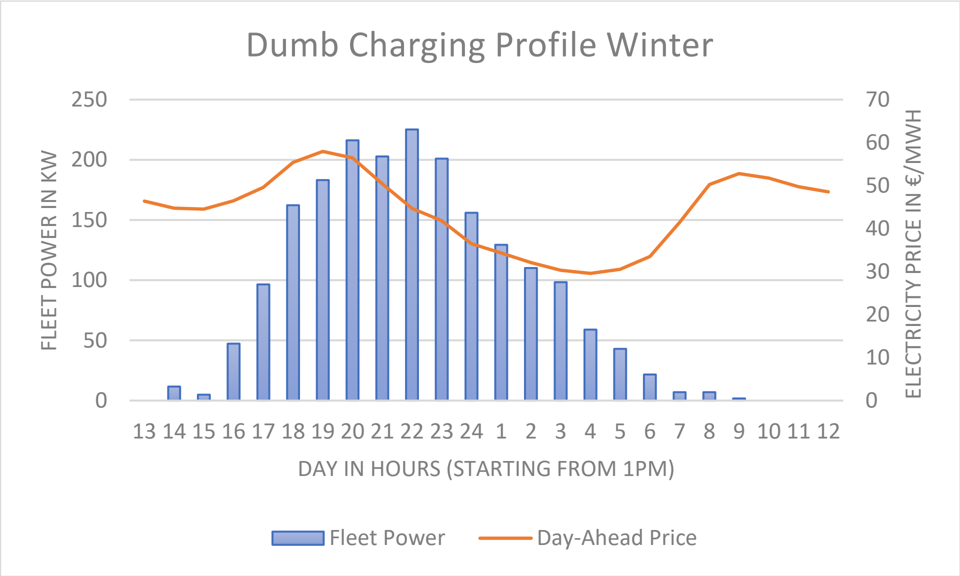


Figure 39 Dumb Charging Profile Winter 2018

6.3 Results of the Bidding Optimization

Table 4 Cost of Fleet for different Scenarios

	Scenario A (Smart Charging with participation in balancing markets)	Scenario B (Smart Charging)	Scenario C (Uncontrolled Charging)
Summer 2018	-12.31 €	81.69 €	93.79 €
Winter 2018	-21.51 €	72.67 €	89.39 €

Table 4 depicts the cost of the different scenarios in the summer and winter case for the whole fleet of 152 EVs. Hence, the cost of 93.79 € in Scenario C for summer 2018 states that the charging costs of the entire fleet for the EV-Aggregator amount to 93.79 €. At first sight, it seems counter-intuitive that the charging costs for dumb charging are higher in summer than in winter because electricity prices tend to be lower in summer months. However, the difference in Day-Ahead price development for the dumb charging profiles in figure 38 and 39 helps to explain why the dumb charging case in summer is more expensive. In winter 2018, the market prices reached their peak before all the cars arrive back home (see figure 39) while the EV owners charge their cars exactly at peak time in summer 2018 (see figure 38). This leads to more drivers charging at lower prices in winter and explains why the dumb charging scenario in summer is more expensive. However, this inconsistency might be explained by the fact that the analysis is based on German market price data but Norwegian fleet driving patterns. A hypothesis that needs to be proven with German driving data is whether the earlier market price peak in winter times in Germany is connected to an earlier arrival of most EV owners in winter.

In Scenario B, the charging costs can be reduced by 16.72 € (in winter) and 12.10 € (in summer) through smart charging (compared to dumb charging). This amount of charging costs can be saved by shifting the electricity demand of the vehicle fleet to night hours where electricity is cheaper.

An additional benefit brings the involvement in the balancing markets through Scenario C. Instead of paying 89-94 € per day for charging the fleet, an aggregator can earn up to 21.51 €

on a typical winter day when he offers the capacities of the BEVs as SCR. On a typical summer day, the return from the participation in the balancing markets reaches up to 12.31 €. This is equivalent to overall daily savings of 106.10 € (in summer) and 110.90 € (in winter) through optimized charging of the fleet (compared to the dumb charging case).

Since Tibber is active in the Norwegian and Swedish market, it is insightful to compare the revenues made through the participation in the balancing markets in Germany with the revenues achievable in the Nordic balancing markets. For the Nordic countries, the results stem from an analysis of Dalton (2018) of selling flexibility at the FCR-N market. Again, this market comparison is problematic since Dalton optimized the bidding behavior for the primary reserve markets, while this thesis optimizes the bidding behavior for the SCR markets. In general, the PCR market is expected to provide the most favorable prices for EV-Aggregators. However, the PCR market in Germany is not yet suitable for EV-Aggregators due to the weekly product slices. Hence, the optimization within this thesis focuses on the SCR market instead of the PCR market. Still, the comparison gives insights on the suitability of the different markets for the business model of an EV-Aggregator.

Table 5 Balancing Market Revenues relative to the charging Costs (Dalton, 2018)

	German SCR Summer	German SCR Winter	NO5 Summer	NO5 Winter	SE3 Summer	SE3 Winter
% of cost of charging	113%	124%	57%	15%	169%	69%

Table 5 compares how much costs can be saved through the interaction of EVs with the balancing markets. Compared to the Nordic market, there are hardly any seasonal differences in the German market. While the participation of EVs in the balancing markets in Norway save slightly more than half of the charging costs in Norway, the charging costs can be saved entirely in the German market by offering the cars as flexibility. Next to eliminating the charging costs, EV-Aggregators could earn money by offering the cars as SCR. With over 100% of cost savings, the German market for EV-Aggregators offers similar relative savings as the Swedish market and seems much more attractive than the Norwegian one.

7. Assessment of the EV-Aggregator Business Model in Germany

The wholesale market in Germany is characterized by high price fluctuations. In contrast to the Norwegian market, there are no significant seasonal price differences. Nevertheless, there is a considerable price difference between weekdays and weekend prices and a substantial difference between peak and off-peak electricity prices. In addition to that, huge fluctuations can occur due to unpredicted weather changes. This makes demand shifting through intelligent energy management highly beneficial and offers EV-Aggregators excellent opportunities for arbitrage trading.

On the other side, several developments must be viewed critically. Access to the balancing markets is laborious. Especially EV-Aggregators must undergo complex pre-qualifications because the TSOs are skeptical regarding pooled generation as balancing reserve. Additionally, an aggregator must be pre-qualified for all control areas from which the aggregator will deploy power. Moreover, the balancing paradox leads to shrinking prices for balancing energy in the last years. This trend is expected to continue, making the balancing markets less attractive since there is still a high generation overcapacity in the German grid. Finally, the rapid price changes within one year through a new market design can seriously threaten EV-Aggregators. The new tendering mechanisms that have been introduced in winter 2018, for example, made the balancing market more attractive for conventional power plants like gas turbine power plants. This led to a further increase in capacity in the markets, which let the prices for balancing power drop even further.

Due to the quick changing price dynamics of the balancing markets, an EV-Aggregator like Tibber should not base a final decision regarding a market entry merely on the quantitative results from the bidding optimization. Hence, one should enrich the quantitative approach of the bidding optimization with a qualitative evaluation of the German market with respect to the business model of an EV-Aggregator. This has been done in earlier chapters of this thesis and will now be concluded by performing a SWOT analysis that states the strengths and weaknesses of the business model in the current context and identifies opportunities and threats for the business model through upcoming developments.

In contrary to Anderson et al. who performed a SWOT analysis on the concept of PHEVs providing regulating power (figure 40), this chapter offers a detailed SWOT analysis that is based on the conditions and future developments in the German market to summarize the suitability of the business model of an EV-Aggregator in the German market in figure 41.

Internal	External
Positive	
Strengths • No cost for being available. • Regulation down is charging of the battery and can be provided cost efficiently. • Fast delivery/acceptance of energy, i.e. short activation time. • Many PHEVs in a system could be seen as a guarantee of stable capacity. • Compared to EVs, PHEVs have the possibility to use gasoline to provide regulation up when battery is empty.	*Opportunities* • Increased demand for regulating power due to increased intermittency (renewable energy) in the power system. • Political will to introduce PHEV and to support electrification of the car fleet. • Liberalization of regulating power market—political pressure to lower entrance barrier. • Other actors also put pressure on the regulating power market to change. • Potential economic incentive for PHEVs to participate is substantial on some markets.
Negative	
Weaknesses • Limited connection capacity. • Limited energy storage in the battery (cannot provide regulation down when battery is full). • Mobile devices—difficult to guarantee constant capacity if a small number of cars participates. • Human factor: people can forget to plug in their cars or feel uncomfortable about the TSO controlling their charging operation. • Regulation up has a high cost. • The cost for delivering up- and down-regulation differs significantly. • Regulation up implies energy losses in charging and discharging of the batteries.	*Threats* • Conservative and inflexible market. • Oligopoly market structure. • High security and delivery requirements. • Large bid sizes. • Long market time frames. • Long contract times. • Infrastructure development needed. • Standardization issues. • Co-operational challenges—automotive industry and power suppliers. • Lower prices on regulating power due to PHEVs on the regulating power market. • Symmetric bids and package prices which makes the bidding system inflexible, and does not allow offering only regulation up/down, etc. • TSOs may not trust PHEVs as regulating power providers. • Risk of technology lock-in, i.e. if charging infrastructure initially is installed without V2G possibilities.

Figure 40 SWOT Analysis on the concept of using PHEVs for balancing power (Anderson, et al., 2010, p. 2759)

Internal	External
Strengths	**Opportunities**
• High short-term price fluctuations in the wholesale market	• Market share of electric vehicles is growing steadily
• Wide range of prices within a day/week	• New German BEV models will enter the market soon and might boost the market share of BEVs
• German market potential high due to many potential electric vehicle owners in the upcoming years	• Further increases of intermittent renewables might lead to heavier price fluctuations in the electricity markets
• Promising political framework for electric vehicles	• Market reforms towards a European market could open up international balancing markets
• Bidding optimization promises high gains from participation in the balancing market	• Battery advancements will enable Tibber to make better use of flexibility
	• PCR market will be changed to 4h Intervals in 2019/2020
	• Rising Coal, Gas, and CO2 prices might lead to higher price fluctuations in the German energy markets
	• Trend goes towards smaller time slices in balancing markets
	• Capacity is dropping out of the grid because of the nuclear phase out and the lignite exit
	• Paragraph 14a in the EnWG allows DSOs to reduce the grid fees on electricity when car is charging during off-peak hours
Weaknesses	**Threats**
• Germans technology skeptical, it might be hard to convince them to give away control over their car's charging behavior	• Solar dropping out of EEG might force people to load the battery of their car whenever the own electricity is available. The car would then offers less flexibility for trading.
• Shrinking volume of balancing energy activated	• First prequalification of an EV-Aggregator might involve difficulties
• Overcapacity in the German market	• Legal issues regarding data transmission within a smart meter
• Tibber has no close connection to the customer, other companies are in better positions to realize Tibbers business model	• The balancing market is highly intransparent. Several competitors work together, making some competitors invisible (not listed as market participant)
• Balancing market characterized by low prices	• Market reforms towards a European market could open up international balancing markets
• Pre-qualification for all four control zones necessary if cars are located in all the control zones	• More companies are pushing into balancing markets
• Market share of electric vehicles is still low	

Figure 41 SWOT Analysis for EV-Aggregator in Germany

Even though most of the entries in the SWOT analysis are self-explanatory for an EV-Aggregator, single aspects might be difficult to comprehend without further explanation. Hence the following paragraphs will be clarified these elements briefly.

The first aspect that might need further explanation is the one about the technology skepticism in Germany in the "Weaknesses" chapter of the SWOT analysis. In a recent survey, 1000 participants were asked about their willingness for grid-friendly electricity consumption. Merely a third of all participants could imagine giving away control over the charging of their EVs for grid-friendly charging (Ener|gate, 2019). This inherent skepticism will be an issue EV-Aggregators must solve when entering the German market.

An additional threat is the dropping out of photovoltaic modules of private citizens from the feed-in tariffs within the renewable energy law (EEG). Starting in 2020, an increasing number of solar power plants from private households will drop out of the EEG, which offered a guaranteed feed-in payment per kWh generated for producers of renewable electricity (Discovergy GmbH, 2018). Consequently, the owner of such photovoltaic modules will not receive any money for supplying their electricity to the grid anymore. This is a clear incentive for the self-consumption of the electricity generated by the modules. People that arrive home early will want to use their solar power to charge their car. This will reduce the flexibility of charging times, which will reduce the influence of EV-Aggregators. However, with an integration of solar power into the smart charging concept, aggregators could offer an additional benefit for customers. Whether this might be a useful concept has to be evaluated by analyzing driving patterns from German EV owners.

Another point that I want to explain further is the overcapacity in Germany. Especially in recent years, Germany was characterized by a rising overcapacity. As discussed, this overcapacity led to a price drop in regulating markets because a rising share of conventional power plants that do not fit into the merit order of the wholesale markets anymore was pushing into the balancing markets. With the nuclear phase-out until 2022 and the phase-out of lignite by 2038, huge power plants will be shut down (Dapp & Hoenig, 2019). As a result, the gap between consumption and generation that is depicted in figure 13 will narrow. This could lead to increasing prices on the electricity exchange and in balancing markets and is, therefore, a promising development for EV-Aggregators.

Legislation has rarely been touched in this thesis due to limits of scope. However, there is one paragraph in the law for energy economics (EnWG) that might become relevant for EV-Aggregators soon and should, therefore, be mentioned. Paragraph 14a deals with the issue of shift able loads. It specifies that the DSO should offer reduced grid fees for consumption that is undertaken by interruptible units - like EVs – in off-peak hours (Bundesministerium der Justiz und für Verbraucherschutz, n.d.). Since grid fees amount to roughly 25% of the electricity price, this is an additional financial incentive to shift the charging of BEVs to off-peak hours, which will make the business model of an EV-Aggregator even more attractive (Bayer, 2015).

Summarizing, the German market seems promising but potentially dangerous for EV-Aggregators. The results from the bidding optimization make the market highly attractive, and a further increase in intermittent renewable energies might intensify price peaks and, thereby, increase the potential of smart charging and providing flexibility. However, Tibber is not the first company to realize this. The German balancing market is highly competitive, and more companies than ever are pushing into the regulating markets. While the aggregation of EVs for balancing power is still a new concept, there are a lot of companies with experience in smart charging or the aggregation of small power plants which could copy the business model of an EV-Aggregator. Aside from that, the current overcapacity led to constantly falling prices for balancing power in recent years. This development is expected to continue in the next years, making it tougher to earn well in the balancing markets. Changes in market design have the potential to better or worsen the situation for EV-Aggregators.

Even though there are many potential threats to the business model, the opportunities slightly outweigh the threats as can be seen in the SWOT analysis. In the case of market entry, an EV-Aggregator should follow an aggressive expansion strategy to bind as many customers as possible to the company's business model before competitors enter the market. Thereby, the focus could lay firstly on offering the easier executable smart charging concept for a broad customer base. The effortful pre-qualification can be realized as soon as a decent customer base is established. Postponing the entrance to balancing markets and firstly focusing on the benefits smart charging brings, offers an additional benefit. It allows the aggregator to observe how upcoming changes in market design will influence the price developments in the balancing markets while gathering the most crucial resource for their business model; owners of EVs.

8. Conclusion & Critical Reflection

Although the market entry in Germany might be difficult due to several pre-qualifications, the bidding optimization shows that the German market is highly attractive for EV-Aggregators. Through an optimized charging that includes participation in the balancing markets, EV-Aggregators can save 113-124% of the charging costs. With a vehicle fleet of 152 EVs, this sums up to around 110 € saved daily. In relative terms, the potential cost savings for EV owners are comparable to the ones in Sweden. In comparison to Norway, the relative cost savings from the participation in the German balancing markets are significantly higher.

Even though these results seem highly promising, EV-Aggregators must deal with a high amount of uncertainty in the German market. Changes in energy market design, upcoming competitors, and legal issues threaten the business model of an EV-Aggregator in Germany. On the other side, several developments such as the dropping out of conventional power plant capacity and a rising share of intermittent renewables are indicators for a promising future for EV-Aggregators in Germany.

Whereas the participation in the balancing markets can be a risky endeavor, the less risky business concept of smart charging offers safer revenues for EV-Aggregators. Currently, an EV-Aggregator with a fleet of 152 cars could save 12-16 € of charging costs daily for shifting the charging time of EVs. This revenue is independent of the balancing market prices and does not require a pre-qualification. Hence, it can be an attractive first concept for EV-Aggregators to adopt when entering the German market.

Through the combination of qualitative and quantitative approaches, this thesis gives insights into the value of the business model of an EV-Aggregator. The monetary value that is generated is highly dependent on the market prices for electricity. Not only the price level but also the price volatility is essential for the successful execution of such a business model. Hence, the results of this evaluation are only valid for a limited time horizon in which the prices stay stable. When price patterns in the German market dramatically change, the business model must be re-evaluated. As prices are merely known in hindsight, this analysis gives no securities whether the conditions in the German market stay favorable in future-times.

The bidding optimization is performed to give companies like Tibber a first impression on the attractiveness of the German market for flexibility. Due to limitations of scope, the optimization has certain limitations (see chapter 3.3.2 Assumptions & Restrictions). A further restriction of this thesis was data availability. Data for the quantitative analysis and the bidding optimization was gathered from various organizations. Due to the high price of data illustrating the market prices of the EPEX, data about the prices from the EXAA was taken to analyze the German market. These limitations must be considered carefully when interpreting the results. Still, the results can enable companies to decide whether the German market is attractive or not.

9. Further Research

The idea of using EVs to stabilize the grid is still relatively new. Hence, there is an abundant need for further research. For EV-Aggregators that operate in the German market, it would be profoundly insightful to perform a stochastic bidding optimization based on driving patterns from German BEVs. Different driving patterns, e.g. earlier arrival of most EVs, could lead to a different optimal bidding behavior. Consequently, the revenues of EV-Aggregators could increase or decrease depending on the driving patterns of German EV owners. Moreover, German driving patterns might explain the inconsistency of higher dumb charging prices in summer that was identified by the bidding optimization. Lastly, based on German driving patterns, EV-Aggregators could evaluate whether the integration of solar power in smart charging concepts would bring additional value for private households as described in the assessment chapter.

Besides this, one could enhance the optimization by including the possibility to trade in the Intraday market. Besides this, for EV-Aggregators it will be exciting to perform ex-ante optimizations that are fed with weather data and will buy electricity and bid capacity taking weather forecasts into account.

Due to the high Intermarket spread, a detailed analysis of the pair trading possibilities between the Intraday and Day-Ahead markets in Europe will be interesting as well. Here, one could compare the differences between various European electricity exchanges to evaluate whether arbitrage trading between the different exchanges is feasible.

The successful integration of EVs is not only meaningful for EV-Aggregators but also for regulators and grid operators. Article 14a of the EnWG will, as stated in the assessment chapter, allow grid operators to lower electricity prices for grid-friendly charging. Major distribution grid providers, such as E.ON, are currently investigating this idea (Frankfurter Allgemeine Zeitung, 2019). This is an important field for additional research. Identifying the Pareto-optimal monetary incentive for grid-friendly behavior would be valuable for policymakers, grid operators, and EV-Aggregators.

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