Beyond Mobility - An Energy Informatics Business Model For Vehicles In The Electric Age

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BEYOND MOBILITY – AN ENERGY INFORMATICS BUSINESS MODEL FOR VEHICLES IN THE ELECTRIC AGE

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Abstract

The increasing use of renewable energies such as wind and solar power is one of the most important developments on our path towards a sustainable energy supply. However, the ongoing shift in electrical energy generation raises the question whether a stable power grid is guaranteed if depending largely on suitable weather conditions. Certainly, the need for additional supply and demand reserves to compensate for fluctuations related to environmental conditions in the power grid will increase in the near future.

In this paper we present a business model within the Energy Informatics Framework to use electric vehicles as distributed storage devices that draw or supply power to the grid during frequency fluctuations. Through computational simulations based on real data we show that this solution is able to support power grid stability while generating substantial revenues for the operating intermediary.

Keywords: Electric Mobility; Energy Informatics; Vehicle-to-Grid; Business Models
1 Introduction

The integration of intermittent renewable power sources into the electrical grid has a substantial impact on grid stability. The fluctuating input of wind and solar power will increase the need for additional control reserves. Hence, to ensure power grid stability, innovative ways to provide energy for frequency regulation have to be developed.

Frequency control (or regulation) is a perpetual process that seeks to negate demand or supply shocks in the power system. One prospective solution to stabilize the electrical grid during frequency disturbances is the use of Electric Vehicles (EVs), particularly electric or plugin-hybrid electric cars, as distributed storage devices. When EVs are connected to the grid they are able to draw or supply power instantaneously. This technology is called Vehicle-to-Grid (V2G) and qualifies EVs exceptionally well for frequency control. In contrast to common tools for frequency regulation like gas turbines, EVs are able to react immediately to the current grid situation, without requiring any ramp-up time. However, to enter the market for frequency regulation an operator usually has to provide a minimum participation amount of one to five Megawatts (MW) over a time period of up to four hours (ENTSO-E, 2012). A single vehicle is not able to deal with such magnitudes and only has a minor effect on the electrical frequency. Therefore, a way to aggregate and coordinate the charging of hundreds or even thousands of EVs that rewards vehicle owners for participation is necessary.

In this paper we present a business model for using electric vehicles as distributed storage devices that draw or supply power to the grid during frequency fluctuations. To aggregate a sufficient number of EVs we consider a cluster of parking garages as operating instance. This enables us to coordinate the connected vehicles in real-time and to reward the owners for participation as well, since billing infrastructure is already in place and only needs to be adapted. To get an accurate impression of the profitability of such an approach, we specify our business model based on real data of EV user behavior and occupancy rates of parking garages and simulate the model within a real market for frequency regulation.

This paper is structured as follows. In the following section we set our paper in the context of current IS research and present an overview on related work regarding electric vehicles for frequency regulation and parking garage scenarios. Thereafter, we introduce a business model to simulate several thousand EVs clustered by parking garages within a real market for frequency regulation. Afterwards, we present the results of a data evaluation process based on more than 34 million data points of commercially and privately used EVs provided by commercial and academic partners to specify our model. This is followed by a presentation of the simulation results, which allow inferences on the profitability and feasibility of this approach. Finally, we conclude this paper and provide an outlook on our future work.

2 Related Work

Watson et al. (2010) emphasize the importance of IS research in shaping the energy systems of the future. Their Energy Informatics Framework (EIF) serves as a reference construct for research at the intersection of Information Systems, Computer Science, and Electrical Engineering. This has led to several publications that investigate IS-supported energy management (Baeriswyl et al., 2011; Strüker, 2011; Wunderlich et al., 2012). However, Kossahl et al. (2012) note that the potential of electric mobility has yet to be addressed by IS researchers. To further knowledge in this area, we have previously analyzed the benefits of including electric vehicles into energy management information systems in Brandt et al. (2013). In Brandt et al. (2012) we have first presented the concept of business models for EV aggregation, which will be supported with a specific sample case in this paper.

Aside from this, research on EV integration into electricity markets is mostly limited to questions about the technical implementability. The business models necessary for such an approach are usually taken for granted, resulting in widely diverging estimates of profitability. One of the first pilot projects
in this topic was realized by Brooks (2002). He found that EVs are well suited for frequency regulation because of their short ramp-up time and negligible costs during idleness. The presented framework calculates annual gross revenues per EV from $1,000 to $5,000, depending on individual driving activities.

Kempton and Tomic (2005a, 2005b) compare different power markets and formulate fundamentals to calculate revenues using EV for frequency regulation. Furthermore, they argue that vehicles are parked during 96% of the day and, thereby, may be used for frequency regulation during that time. The authors calculate annual revenues to be $2,554 per EV and year, but do not address the high volatility of regulation energy prices.

In a V2G test by Kempton et al. (2008) a single EV was used to support frequency regulation in cooperation with PJM. The results of the study show that V2G, in addition to providing valuable grid services like frequency regulation, could also prove to be a prominent application in the global transformation towards a green and sustainable energy economy. Kamboj et al. (2011) highlight the short response time of EVs as the main advantage over traditional regulation tools and estimate revenues of $1,200 to $2,400 per year, assuming a vehicle participation of 15 hours a day and a regulation price twice as high as normal. In contrast, the Mini E Berlin field test in Germany, realized by Krems J. F. (2010), shows the current potential of 50 EVs to support the power grid by providing control reserves. The field test assumes an operating time of each vehicle of 4 hours a day and calculates revenue up to 34 Euros per year.

However, Kamboj et al. (2010) note that market participation rules usually require the reliable ability to supply a certain amount of power, which is far beyond what a single EV can manage. Hence, a sufficient number of EVs have to be aggregated by an operating instance to participate in the regulation market. Quinn et al. (2010) also stress the importance of a mediating entity in such an aggregation scheme, particularly to facilitate communication between an Independent System Operator (ISO) and EVs.

The concept of charging EVs in parking garages is also discussed extensively. With the vehicles parking there already, customers are likely to embrace the opportunity to have them charged at reasonable prices. Chen et al. (2012) formulate a deadline scheduling problem taking into account deterministic arrival, departure and charging characteristics. The developed algorithm aims to fulfill the customers’ deadline and state of charge (SoC) requirements in a stochastic setup. Additionally, Tulpule et al. (2011) emphasize the impact on power plants, transmission, and distribution lines, as well as emissions and economics of photovoltaic based charging of multiple EVs at the workplace or parking garages. They argue that this offers new places to charge EVs in addition to the home and, likewise, increases the penetration of renewable energy sources. A cash flow analysis shows that it is possible to build a parking garage with benefits for both vehicle owner and operator. Sanchez-Martin and Sanchez (2011) focus on the optimal management of charging EVs at parking garages. Their EV scheduling scheme produces economic benefits by implementing a management system to deal with battery charging processes, taking into account arrival and departure times of each vehicle. Also, in the research of Kulshresta et al. (2009) an energy management system that controls the power consumption is presented. An event driven simulation allocates power to the vehicle battery chargers and tries to ensure optimal usage of available power, minimize charging time, and improve grid stability.

Thus, the predominantly discussed research question of parking garages for EVs is rather how to charge a large amount of vehicles in a reasonable way than how to use these aggregated resources to generate an added economic value through a comprehensive business model. However, to our best knowledge there exist no models which combine these two approaches - to use aggregated EVs in parking garages for frequency regulation, thereby creating revenues.

In most recent publications frameworks or V2G models are neither based on real data nor evaluated in a real market, which is one of their main flaws. Different assumptions about the state of charge of EVs when they enter parking garages and prices on the market for frequency regulation are often out of
touch with reality. Hence, the revenue highly fluctuates from 34 Euros up to several thousands, even when taking into account different settings with respect to EV user behavior and market conditions. Therefore, an adequate benchmark set that is embedded within a comprehensive business model is needed to calculate the actual profitability and feasibility of such an approach.

3 Business Model

The regulation market requires participants to be able to supply a minimum amount of power over a specific time period. This is one of the main reasons many potential providers of energy storage are not able to participate in the control reserve market. For the aggregation of EVs the number of vehicles is not the only essential factor that determines the ability to supply a certain amount of regulation energy. Smart network architecture and an information system that operates and coordinates the available resources are required, as well. Hence, the business model presented in this paper can be considered an implementation of the Energy Informatics Framework introduced by Watson et al. (2010), as Figure 1 illustrates. The EIF contains four components: a flow network, a sensor network, sensitized objects, and the central information system. Naturally, the flow network is in our context the electrical power grid. The part of the sensor network is represented by the ISO, which senses any instability within the grid. The sensitized objects are the charge points in the parking garage, since they can be activated to charge the EVs and are aware of the batteries’ state of charge. The central information system (operated by the parking garage) collects all relevant information and activates charge points when needed.

![Figure 1. V2G Business Model as an implementation of the EIF](image)

Now, consider the details of the business model. If we assume a minimum amount of power \( a \), which is required to enter the market, and a maximum amount of power \( CP_p \) that the charge point can drain from a single EV, the number of concurrently required electric vehicles \( \#EV \) will be calculated according to the Equation 1.

\[
\#EV = \frac{a}{CP_p}. \tag{1}
\]

If we further assume that EVs are able to (dis)charge with \( CP_p \approx 3.6 \text{ kW} \) (normal 230 volt and 16 ampere outlet) and an amount of \( a = 5 \text{ MW} \) is required for market participation, the business model requires \( \approx 1,400 \) EVs to function in theory. However, the number of concurrently required EVs decreases substantially as soon as fast-charging technology is incorporated. In addition, we have to consider that only a certain amount of the remaining battery capacity can be used for the regulation process. This leads to an individual operating time (OT) for each vehicle depending on the charge point (CP) outlet and the above-mentioned participation amount determined by the difference between the initial state of charge of the battery \( \text{SoC}_{\text{start}} \) and the final state of charge \( \text{SoC}_{\text{end}} \) (both in kWh). Equation 2 calculates the operating time for each vehicle in minutes.
There is an important difference between the operation time and the parking duration, since an EV will be (dis)charged in a very short time using fast-charging technology. Therefore, parking lots with short to medium parking durations and a high flow of vehicles are more suited to this approach.

Figure 2. Simplified representation of the V2G regulation framework

We implemented a V2G model for parking garages that generates a manually quantified number of EVs to simulate their ability to supply 5 MW of power. In order to make the simulation as realistic as possible the vehicle properties, like SoC and arrival or departure times, are exclusively based on real data or on assumptions derived from real data. Each of these EV characteristics will be automatically generated by the simulator. Figure 2 illustrates the V2G model that uses all available vehicles for frequency regulation. The operating intermediary has one or multiple parking garages equipped with charge point stations for EVs. We assume that each vehicle participates in our V2G regulation approach. As a participation incentive the vehicle owner can be rewarded with cheap electrical energy or parking discounts, since a parking garage has the necessary billing infrastructure already in place. The intermediary offers its aggregated energy storage to the regulation energy market as an ask that includes service and working prices for providing frequency regulation (1), as detailed in Brandt et al. (2012). Once the ISO purchases control reserves to stabilize the power grid (2) the ask is accepted or not, depending on the offered price (3). As soon as the ISO requests the offered reserves the intermediary uses the connected vehicles to provide regulation, within the limits of its available resources (4). Hence, the time of day is an essential factor, because the parking garage occupancy rates are especially high during the main parking hours. Assuming that the current EV reserves are not sufficient, conventional control reserves can be used in addition, to support the regulation process. Finally, the provided service of the intermediary gets paid by the ISO (5).

3.1 Simulation and pricing scheme

The intermediary needs to be able to immediately operate each EV in each parking garage, once the offered reserves are requested. As mentioned in the related work section, a specific charge point infrastructure is needed to connect the vehicles to the grid. Furthermore, a single instance – the Charge Point Operator – (CPO) controls the (dis)charging behavior of each vehicle during the regulation process. The CPO is responsible for the schedule and the state transitions of all available resources by operating the CPs inside the parking garages. To express changes in the current load behavior of connected vehicles we define the following four states

- $s_{0\text{idle}}$ – vehicle is connected, but not (dis)charging (i.e. idle)
- $s_{1\text{charge}}$ – vehicle is charging (general charging)
While idle vehicles are connected to the grid without providing any power, charging EVs top up their batteries outside the regulation framework. In addition, EVs which are in the reg state provide negative regulation. Positive regulation is theoretically possible, as well, but not covered in this simulation, since vehicle owners would need to be compensated for the discharged energy. Hence concerning customer incentives, negative regulation is more suitable than positive regulation. Once the owner disconnects the vehicle from the grid, the drive state will be initiated until another vehicle is plugged in again. The above states allow us to define a CP as a deterministic Finite-State Machine (FSM) as described by Arbib (1969). A charge point CP is represented as a 5-tuple \((\Sigma, S, s_0, \delta, F)\), where

- \(\Sigma = \{i_0, i_1, i_2, i_3\}\)
- \(S = \{s_{0_{idle}}, s_{1_{charge}}, s_{2_{reg}}, s_{3_{drive}}\}\)
- \(s_0 = s_{0_{idle}}\)
- \(\delta : S \times \Sigma \rightarrow S\)
- \(F = \{s_{3_{drive}}\}\)

**Figure 3. Charge point station represented as final state machine**

Furthermore, Figure 3 illustrates the different states and all possible transitions through a graphical representation of the deterministic FSM. The CPO is now able to operate each vehicle by using the input alphabet \(\Sigma\) to send a signal to the CPs and thereby change the current state. Using the different state transitions the intermediary is able to coordinate the available resources to supply the requested regulation energy.

In each state a specific revenue will be generated depending on the state duration, charge point power \(CP_p\), price for providing frequency regulation \(p_w\), and price for electricity charged into the vehicle \(p_e\). Depending on the current state the algorithm calculates the revenue \(R(s_i, t_j, EV)\) at state \(s_i\), time \(t_j\), and vehicle EV as follows

\[
R(s_{0_{idle}}, t_j, EV) = 0, \quad (3)
\]

if the EV is idle there is no possibility to generate any revenue except the parking fee which will be neglected, because it is independent from the regulation procedure. Thus, the calculated revenue in state \(s_{0_{idle}}\) is zero given by Equation 3. The next state \(s_{1_{charge}}\) represents the charging state in which the vehicle is connected to the grid and refreshes its batteries via the CP connection, calculated as

\[
R(s_{1_{charge}}, t_j, EV) = 0. \quad (4)
\]
The revenue for charging outside the regulation scheme is equal to zero, as well, because the model only considers revenues which are generated through frequency regulation activities. Certainly, the operating intermediary has to bill the charged electricity to the vehicle owner using a specific electricity price. However, this electricity was not supplied as a result of a frequency disturbance and, therefore, it is not influencing the revenue of our model. Equation 5 calculates the revenue during the regulation process as follows

\[
R(s_{2\text{reg}}, t_j, EV) = \int_{t_0}^{t_1} (CP_p(t) \times (p_w + p_e))dt,
\]

with \(CP_p(t)\) as the current charge point power at \(t\) between start, \(t_0\), and end, \(t_1\), of the respective state duration.

In order to calculate the total revenue of a sequence of state transitions, the following recursive function is used

\[
R(s_i, t_j, EV) = \begin{cases} 
R(s_{i-1}, t_{j-1}, EV) + R(s_{2\text{reg}}, t_{j-1}, EV), & \text{if input } = i_2 \text{ and state } \neq \text{s1\_charge} \\
R(s_{i-1}, t_{j-1}, EV) + 0, & \text{otherwise.}
\end{cases}
\]

Finally, we are able to translate the parking session of each EV into a sequence of state transitions and, thus, calculate for each state the corresponding revenue. According to the recursive function above, the final state which is always \(s3\_drive\) in each sequence determines the total revenue of the parking session. Hence, the CPO is able to coordinate each available resource separately by changing the vehicle state.

4 Data Evaluation

In cooperation with commercial and academic partners we were able to establish an extensive benchmark set for both EV user behavior and control reserve market conditions. The data collection for EVs has taken place in the Netherlands and Germany and the vehicles were privately used over a period of up to two years. The evaluation results were used to derive realistic assumptions regarding the SoC of EVs, as well as the arrival and departure times at the parking facility. The maximum battery capacity values are based on the vehicles used in the original data set and the occurrences of frequency deviations as well as the auctions for regulation energy are simulated within the German Control Reserve Market (GCRM) (Vattenfall Europe Information Services, 2012). The results were used to specify the simulation parameters of our model introduced in the previous section to achieve realistic results. In the following subsections we present the evaluation results separated into EV user behavior, parking garage occupancy and frequency regulation market prices.

4.1 Electric vehicle user behavior

The electric vehicle user behavior determines all relevant values to actually calculate the potential of an EV to be involved in a frequency regulation process. Hence, to specify feasibility and profitability of such an approach we have to analyze the daily routines of EVs to determine e.g. the remaining battery charge at a given time. Therefore, we analyzed more than 34 million data points of privately used EVs to generate probability distributions of the respective parameters for our simulation model. Figure 4a illustrates the average battery charge of an EV during the course of a day. We can observe that the overall SoC is quite high on average, due to nocturnal charging sessions from about 8 p.m. to 6 a.m. In the morning hours the SoC is continuously decreasing on average, because of driving activities until the EV is connected to the grid again.

A grid connection is an essential criterion for the V2G regulation scheme, since an intermediary is not able to operate the vehicle, otherwise. Therefore, Figure 4b shows a distribution of charging, driving and parking times based on our data analysis. This illustrates the times at which EVs are able to serve
as distributed storage resources. As we can see, the very low driving activity of just 4% considered in most publications can be confirmed by our evaluation. The average charging duration per vehicle is with 11% of the day currently very high, however, this time will be reduced in the near future by the installation and commissioning of fast-charging technology. The difference between the idle and parking times is that “idle” refers to vehicles which are connected to the grid, but not charging, whereas parking vehicles are not connected to the grid, at all. Because V2G is not implemented on a large scale, yet, the only purpose of current CPs or grid connections is the charging of the vehicles. This necessitates a SoC of almost 100% if an EV is characterized as idle, since it would be charging with enabled connection, otherwise. Hence, we can see that currently more than half of the day an EV could not be used for a V2G aggregation approach, because the necessary grid connection is not provided. This indicates a need for more CPs and connection possibilities during daily routines e.g. at malls and workplaces, as well as incentive criteria to connect EVs even when the SoC is high.

![Daily SoC courses of EVs](image1)
![EV activity distribution](image2)

Figure 4. Average charging, parking, and driving usage behavior of sample EV in the Netherlands

4.2 Parking garage cluster

In order to create a realistic simulation environment, we have to investigate the average number of EVs in a parking garage at a given time. This is because for simulation purpose, we have to consider a specific quantity of vehicle resources at each time to calculate accurate regulation revenues on the one hand and to determine the feasibility of this approach on the other hand. Therefore, we access the occupancy rates of 37 urban parking facilities in two large German cities with more than 15,000 parking spaces in total. To achieve this, the internal parking guidance systems of the cities of Freiburg (City of Freiburg, 2012) and Frankfurt (PBgmbH, 2012) were requested every 15 minutes over a period of several months to derive a robust parking behavior. The respective replies were stored in a separate database and evaluated after a sufficient collection period. Figure 5 represents the occupancy distribution of two frequently used parking garages in Freiburg. One bar represents a 15 minute time interval. Both figures show an almost normally distributed occupancy rate between 8 a.m. and 8 p.m., although the location and overall number of free parking spaces strongly differs. Most of the remaining 35 parking garages show similar occupancy behavior. While Figure 5a represents the largest parking garage in Freiburg, Figure 5b is up to seven times smaller. Furthermore, the Central Station is characterized by high vehicle fluctuation, due to arriving and departing passengers, which is also visible by the fluctuating capacity utilization in Figure 5b. This is also caused by a 20 minute park for free window at the Central Station parking garage in Freiburg which leads to a low parking duration on average. As we can see, the maximum occupancy is approximately 70-80% from around noon to 4 p.m. According to that, we use an equivalent distribution in our simulation framework, also for parking garages with a high frequency of arrivals and departures. This is because we consider fast-charging technologies and, thus, we are able to (dis)charge an EV in a short time considering the average daily SoC in Figure 4a.
4.3 Market for frequency regulation

In Germany the market for control reserves is designed as a set of auctions staged by the four ISO (ENTSO-E, 2012). In Brandt et al. (2012) the market design of the GCRM is described in detail. During these recurring reserve auctions, energy options are traded and an intermediary with aggregated EVs in clustered parking facilities has to compete with other suppliers of regulation energy. At the same time, the intermediary has to ensure that the offered service is provided by the EVs. This requires a comprehensive scheduling scheme that needs to be aware of the SoC of each vehicle and the mobility behavior of their owners to ensure that the contracted power is supplied or, respectively, consumed. Our data analysis shows that an increased grid frequency occurs twice as often as the opposite case. This implies that the need for negative regulation is higher than for positive regulation. The reason for this is that shutting down generation sources like gas turbines is much cheaper for electricity provider than starting up additional sources. Moreover, regulating the frequency downwards, i.e. by charging a reasonable quantity of EVs, offers better incentives to the owners of the vehicles. Because parking garages already have a billing infrastructure in place, the intermediary is able to bill the charged electricity to the vehicle owners’ account.

![Graphs of occupancy rates for two frequently used parking facilities in Freiburg](a) Karlsbau (b) Central Station)

Figure 5. Occupancy rates of two frequently used parking facilities in Freiburg

In this paper we simulate our model completely based on historical data of the GCRM – both, with respect to prices and to the occurrence of frequency deviations. In this manner we are also able to calculate the annual revenue generated by our business model, since our data analysis has shown that the prices for regulation energy fluctuate substantially with the seasons and other environmental factors. Thus, the assumption of fixed prices is far from reality. The reserve auctions are described in more detail in Brandt et al. (2012), as well.

5 Results

The simulation is written in Python and operates on a MySQL database containing all historical data concerning the frequency regulation process of the GCRM. Figure shows the simulation steps by a graphical representation of the Python program. In a first step the algorithm initializes input values like number of simulated EV, start date, number of days to simulate and offered service in MW (step 0). Thereafter, the EVs will be generated taking into account probability distributions for SoC, maximum battery capacity or arrival and departure time, derived from the data evaluation in the previous section (step 1). In step 2 and 3 the acceptance or decline of the offer of the intermediary at the regulation energy market is determined based on the historic data from the GCRM. If the offer was accepted, revenues are calculated using the recursive function in Equation 6. Hence in step 4, the simulation routine changes the states of currently available EVs, according to Equation 3-5. The algorithm uses a first-come first-served vehicle selection and is only able to provide regulation within its current limits based on the time of day and the characteristics of currently available EVs. If these
resources are not sufficient, the intermediary is able to add additional control reserves from conventional regulation sources like gas turbines as illustrated in Figure 2. This possibility is given by the model, however, it is not taken into account by the algorithm, since that would skew profit calculations. Currently, we only focus on negative regulation energy, i.e. the vehicles are charged during regulation. Thus, the algorithm only considers disturbances that increase frequency, as charging the EVs provides greater incentives to the EV owners to participate. The charged energy can be sold to the vehicle owners at a reduced price compared to the retail price of electricity to ensure that they are willing to participate. Finally, the simulation results are written to an output file (step 5).

Figure 6. Python simulation setup

We evaluate the V2G regulation model using computational experiments and simulation analysis. As we would like to represent the current environment for such a business, we set the starting date as July 1, 2011 and 365 days to be simulated. The offered service is 5 MW as this is the minimum participation amount of the GCRM. We generate four different quantities of EVs to determine their ability to provide frequency regulation. As a consequence, the utilization of the parking garages differs, depending on the different quantities. The business model takes into account high fluctuation rates and the analyzed SoC values of these vehicles at a given time of day. Figure 7 illustrates the simulation output divided into the four quantities. As we can see, a cluster of frequently used parking garages with an average occupancy of approximately 1,125 vehicles is able to provide the necessary 5 MW of frequency regulation during the main parking hours.

Figure 7. Simulation output: Supplied negative regulation by different quantities of EVs

In general, the simulation shows that a quantity of approximately 2,300 concurrently connected vehicles is sufficient to fulfill the requirements of the GCRM. Moreover, providing 5 MW of regulation energy is possible up to 99% between 8 a.m. to 8 p.m. considering an adequate quantity of EV. As we assume each vehicle participates only once a day and we are using high frequency parking
garages the overall number of EV per day has to be high. Nevertheless, a quantity of 2,300 electric vehicles can be achieved by 5-6 medium-sized parking garages during the main parking hours. The pricing scheme generates net revenues of 1.02 million Euro within the previously mentioned simulation period. Thus, a sufficient quantity of EVs is able to provide 5MW over a long timespan and, likewise, generate high revenues for the operating intermediary. In addition we also simulate this approach using different charge point outlets and we found that the use of fast-charging technologies, in this case with an outlet power of 25.2kW, increases the revenues by up to 240%.

Furthermore, multiple parking facilities within one area usually are already operated by a single instance. For example, Q-Park operates 17 parking garages with 7,200 parking spaces in Amsterdam and, thus, would be able to serve as executing intermediary. Moreover, they have already installed charge point stations in multiple parking garages and Amsterdam expects that almost every car will be electric by 2040 (Amsterdam Electric, 2012). Hence, it is quite likely that the business model presented in this paper will become feasible in the near future.

6 Conclusion

In this paper, we have presented a business model for aggregating several thousand EVs to serve as distributed storage devices for participation in the frequency regulation market. We considered a cluster of multiple parking garages to aggregate a sufficient number of EVs to fulfill the minimum participation requirements of the GCRM. In order to achieve a result as precise as possible the model is based completely on real data with respect to electric vehicle user behavior as well as different parking garage occupancy profiles and is simulated within one of the largest markets for frequency regulation in the world. The analysis of privately used EVs showed exceptionally high SoC, caused by nocturnal charging activities. Furthermore, it has been argued that providing negative regulation, i.e. lowering the frequency, is not only more suitable with respect to participation incentives, but also crucially more profitable, due to being able to sell the charged electricity to the customer. Moreover we found that in Germany an increased grid frequency occurs twice as often as the decreased case. Electric vehicle and regulation data in this quantity and accuracy were previously unavailable. Therefore, our results are very close to reality, in contrast to past research. The established benchmark set also provides the opportunity to make existing models comparable, since we have seen widely divergent results regarding the use of EVs for frequency regulation in the related work section.

The simulation of our business model shows that the approach is feasible with approximately 2,300 concurrently available EVs taking into account realistic state of charge values as well as parking durations. The simulation generates net revenues of more than one million Euros within one year, solely by providing negative regulation with a minimum market participation of 5MW. Additionally, the use of fast-charging technologies increased the revenue by up to 240%.

In our future research we will have a closer look at the management of such a kind of business on a large scale. We will also take into account changing parameters like rising electricity prices, increased regulation demands and improved battery technologies to investigate an outlook for 2020.

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