

ROAD TO 2020: IS-SUPPORTED BUSINESS MODELS FOR ELECTRIC MOBILITY AND ELECTRICAL ENERGY MARKETS

Research-in-Progress

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Abstract

Electric mobility is on the rise, as many countries such as the United States of America, Germany, and China intend to bring one million electric cars onto their streets by 2020. This opens up perspectives on new business models, including aggregators for electric vehicles that enter ancillary services energy markets. These intermediaries are of particular interest to the IS discipline, since their market position links research on decision support, electronic markets and energy informatics.

In this paper we present a research agenda to analyze IS-supported business models that cover the entire value chain of such an intermediary. We argue that IS can enhance decision making in the auctions for ancillary energy by improving forecasts of maximum energy prices. Additionally, IS facilitates electronic auctions and scheduling mechanisms that enable the intermediary to aggregate numerous electric vehicles.

Keywords: Electronic Marketplace, Electric Mobility, Energy Informatics, Business Models

Introduction

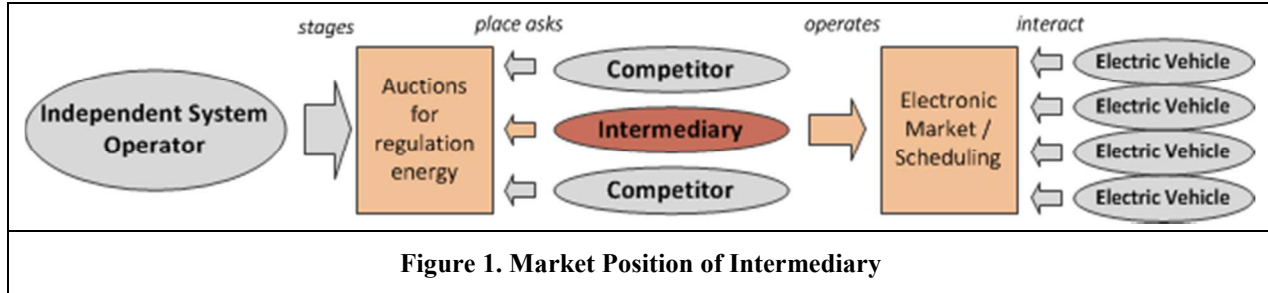
The emergence of electric mobility offers new business perspectives for electrical energy markets. As the U.S., Germany, China, and other countries each intend to bring a million electric cars onto their streets by 2020, this implies a substantial load increase on power grids on the one hand, but an equally significant availability of distributed energy storage devices on the other. This ability of electric vehicles (EVs) to store energy is further enhanced by “vehicle-to-grid”-technology (V2G) that enables the EV to not only charge its battery from the grid, but also supply energy to the grid.

Thus, when connected to the grid, EVs can essentially serve as generators or as loads on demand. This qualifies them exceptionally well for markets for ancillary services like frequency control. Frequency control is a perpetual process that seeks to negate demand or supply shocks in the power system. While common tools for frequency regulation, such as gas turbines or demand-response mechanisms, require some ramp-up time, EV batteries can react to current conditions virtually instantaneously. However, a single EV has only a miniscule effect on grid frequency, such that the aggregation of hundreds or even thousands of vehicles is required to enter ancillary services markets. While in recent years there have been several publications on EV aggregation schemes (e.g. Kempton and Tomic, 2005b; Hill et al., 2012; White and Zhang, 2011), there has yet a comprehensive business model to be proposed.

In this paper we introduce a research agenda that explores IS-supported business models for EV-aggregating intermediaries in electrical energy markets for ancillary services. These intermediaries are of particular interest to IS research, since their market position connects systems for decision support, for electronic market facilitation and for efficient and secure scheduling. Figure 1 illustrates these aspects in more detail. On the one hand the intermediary participates in the market for frequency regulation. This is usually a set of auctions staged by regional independent operators of the transmission system (ISO). During these recurring reverse auctions energy options are traded and the intermediary has to compete with other suppliers of regulation energy, like the aforementioned gas turbine operators. We analyze the benefits of decision support systems (DSS) for the intermediary to optimize its ask prices. On the other hand the intermediary must ensure that the services it offers to the ISO are provided by the EVs. This requires a comprehensive scheduling scheme that needs to be aware of the battery levels of the EVs and the mobility behavior of their users to ensure that the contracted power is supplied, or respectively consumed. Additionally, the scheduling mechanism needs to take incentive effects into account, such that EV owners are encouraged to continue participation in the V2G aggregation program. Finally, depending on the business strategy of the intermediary, prices for EV energy are either contractually fixed or may need to be determined on a competitive basis between EV owners in real time. The latter requires the operation of an automated electronic market by the intermediary.

However, the primary purpose of an EV remains the mobility of its owners. This complicates the operation of both the scheduling mechanism as well as the electronic market. Thus, both systems require an interaction and information exchange between the owner of the car and the system. In this context, the research introduced in this paper specifically aims at providing insight on the following three central issues:

- **To what extent can IS support decisions by the intermediary on optimal offers in the auctions for frequency regulation energy?** While the intermediary may be able to generate profits by using a fixed price for every auction, the highest accepted prices are very volatile. Thus, the intermediary may substantially increase its profit by anticipating price movements.
- **Which scheduling methods enable the coordination of multiple distributed EVs to ensure that power contracts are fulfilled?** The vehicles are owned and operated by many different agents and schedules have to be designed such that they do not interfere with the plans of these agents, requiring exchange of information.
- **How can market-based solutions for energy pricing between the intermediary and EV owners be implemented?** Such an electronic market would need to take into account the preferences of the EV owners and the obligations of the intermediary to deliver regulation energy to determine prices that ensure incentive compatibility for all participants.



This paper is structured as follows. We begin by presenting an overview on research directly related to our work. This is followed by a section on the auctions for frequency regulation and, subsequently, a section on scheduling and the design of the electronic market. The latter two are implicitly linked, since they depend on the business strategy of the intermediary. After this, we provide a summary of the methodology used in our research, before we conclude by summarizing this paper and providing an outlook on our continuing research on this topic. As this is a work in progress, preliminary results will be included directly within the respective sections, when applicable.

Related Work

The rising number of intermittent renewable energy sources like wind and solar energy is likely to substantially increase frequency deviations in the power grid, thereby increasing the demand for regulation energy (Bevrani et al., 2010). Since our research investigates IS-supported business models for aggregating EVs to provide this regulation energy, it belongs to the *Energy Informatics* domain as defined by Watson et al. (2010). According to the authors, Energy Informatics stresses the role of Green IS and Green IT in shaping the power grid of the future. While the IS community has embraced Energy Informatics, Kossahl et al. (2012) show in an extensive literature review that the potential of electric mobility has yet to be addressed by IS researchers. Furthermore, the OECD (2012) has recently emphasized the role of comprehensive business models in the transformation towards a sustainable energy infrastructure and economy.

From a technical perspective the concept of using (V2G-capable) EVs for grid regulation purposes has been researched quite extensively in recent years. A pilot study by Brooks (2002) found that EVs are well suited for frequency regulation because of their very short ramp-up time and negligible costs during idleness. The author presents a framework for vehicle-based grid regulation and calculates annual gross revenues per EV ranging from \$ 1,000 to \$ 5,000, depending on driving profiles.

Kempton and Tomic (2005a; 2005b) compare different power markets with respect to the revenues EV owners can realize. They discern frequency regulation as one of the most suitable markets, arguing that they are associated with low costs per unit of power. Furthermore, they find that EVs can be used for frequency regulation during 96% of the day, as on average they are used for driving only during the remaining 4%. They calculate annual revenues to be \$ 2,554 per EV, but do not address the high volatility of regulation energy prices. Kamboj et al. (2011) report similar results regarding the optimal choice of the power market, citing the short response time of EVs as the main advantage over traditional generators. 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 EVs need to be aggregated, either by companies operating a fleet of EVs, or by an intermediary.

Quinn et al. (2010) stress the importance of a mediating entity in such an aggregation scheme, particularly to facilitate communication between ISO and EVs. While this reduces the revenue per EV, it increases availability and, more importantly, reliability of the ancillary services. Ma et al. (2010) and Agsten et al. (2011) further illustrate the growing importance of communication with an increasing fleet size, since the physical limitations of the grid infrastructure begin to matter if multiple vehicles charge or discharge simultaneously. Han et al. (2010) formulate requirements for a V2G aggregator, but with limited real-world applicability.

Hill et al. (2012) draw attention to the problem of battery degradation, since extensive charging and discharging of batteries for regulation purposes shortens their lifespan. They claim that this becomes a critical parameter for profitability when considering EV fleets. However, Peterson et al. (2010) show that battery degradation depends on the duration of the (dis)charging procedure, as well as the amount of energy transferred and thermal conditions. This is confirmed by Millner (2010), who also shows that small (dis)charging cycles as they would mostly occur during frequency regulation have a negligible impact on battery longevity.

This work presents our progress on the three central research questions described at the end of the previous section. Contrary to related research, we use original data from a large market for regulation energy to estimate expected revenues for the intermediary and possible benefits from a DSS. Furthermore, we argue that the choice of scheduling mechanism and electronic market largely depends on the underlying business model and existing infrastructure of the intermediary. For this purpose, we define a range of comprehensive IS-supported business models that consider the entire value chain of such a regulation service intermediary, instead of only partial markets. This is done by linking data on driving profiles and charging cycles from several pilot studies and an industry partner to produce a representative dataset on electric mobility, as well as analyzing the features of the regulation energy market over an extended period of time.

Decision Support for Regulation Energy Auctions

Electronic markets for frequency regulation have been formed in most ISO regions in the U.S. (e.g. New England, New York, Texas, and California), Canada (e.g. Ontario, Alberta), and in various European countries like Germany, Switzerland, and Denmark (Kirby, 2004). In this section we investigate how information systems can enhance pricing strategies of the intermediary in such a market. We focus on the unified platform of the German Control Reserve Market (GCRM), as it coordinates frequency regulation for an area populated by more than 80 million people, making it one of the largest platforms in the world. However, most other platforms only differ in small details.

Market Design

The GCRM operates daily auctions for primary, secondary, and tertiary control reserve, which most prominently differ in the respective ramp-up time (ENTSO-E, 2012). We focus on tertiary control reserve, as it is the most expensive kind and well suited for EV aggregation by allowing sufficient time to coordinate the EV response. Market participants must be able to supply or absorb a minimum of 5 MW of power over a 4 hour interval with a ramp-up time of less than 15 minutes. Assuming that EVs are able to (dis)charge with a power of 2 kW, which is easily possible at 220V/240V outlets, this would require 2500 EVs. This number decreases when fast-charging technology is incorporated.

Information on the market design and historic market data is available at the GCRM website (Vattenfall Europe, 2012). Figure 2 depicts all auctions for a specific day and a specific frequency control region. The day is split into 6 segments of 4 hours each with one auction for positive energy, as well as for negative energy, for each of these segments. This results in a total of 12 auctions per day. Positive regulation energy implies supplying energy to the grid, either by actually generating energy or by reducing the load and is required if the frequency is below 50 Hz. By contrast, negative energy implies reducing energy generation or adding load and is required if the grid frequency is too high.

However, each auction is a particular kind of combinatorial reverse auction with asks being represented as $\{Power, Service\ Price, Working\ Price\}$ or $\{P, p_s, p_w\}$. Of course, asks must also carry information on which auction they are for, but this we implicitly assume as given for brevity. *Power* is the amount of electric power that can be supplied on demand, while the *Service Price* is the ask price for keeping this power available and is expressed in € per MW. The *Working Price* on the other hand is the ask price for energy that is actually supplied and is expressed in € per MWh.

The ISO determines a certain target quantity of power that it must acquire and accepts asks of increasing service prices until that amount is reached (or exceeded, since asks cannot be split). This target quantity varies for each day and auction, is substantially higher than the energy actually required for regulation to

minimize risk, and is publicly announced by the ISO beforehand. The highest service prices accepted in previous auctions are public knowledge, as well.

The sellers are immediately paid the service compensation R_S , i.e. $P \times p_S$ if their offer was accepted. All accepted asks are then ranked in a merit order list with ascending working prices. Once regulation energy is actually required, offers for energy supply are accepted according to this list, with the cheapest suppliers first. Providers are paid the working compensation, R_W , which we express according to the formula

$$R_W = p_W \int_{t_0}^{t_1} P_a(t) dt \tag{1}$$

with $P_a(t)$ as the actual power supplied at t between the start, t_0 , and the end, t_1 , of the respective period, and $P_a(t) \leq P$.

Assuming that the cutoff values $\overline{p_S}$ and $\overline{p_W}$ for the service price and the working price follow the cumulative distributions Γ_S and Γ_W , which are unknown to the intermediary and vary between the different time slots, the expected revenue from a specific auction $E(R)$ (e.g. between 4 and 8 a.m.) for a given bid is calculated as

$$E(R|\{P, p_S, p_W\}) = (1 - \Gamma_S(p_S)) \left[p_S P + (1 - \Gamma_W(p_W)) p_W \int_{t_0}^{t_1} P_a(t) dt \right]. \tag{2}$$

Thus, the service price affects expected service and working compensation, but service compensation does not depend on the working price. The main objective of a DSS should be to improve the estimation of the distribution functions Γ_S and Γ_W , thereby enabling the intermediary to optimize expected revenues.

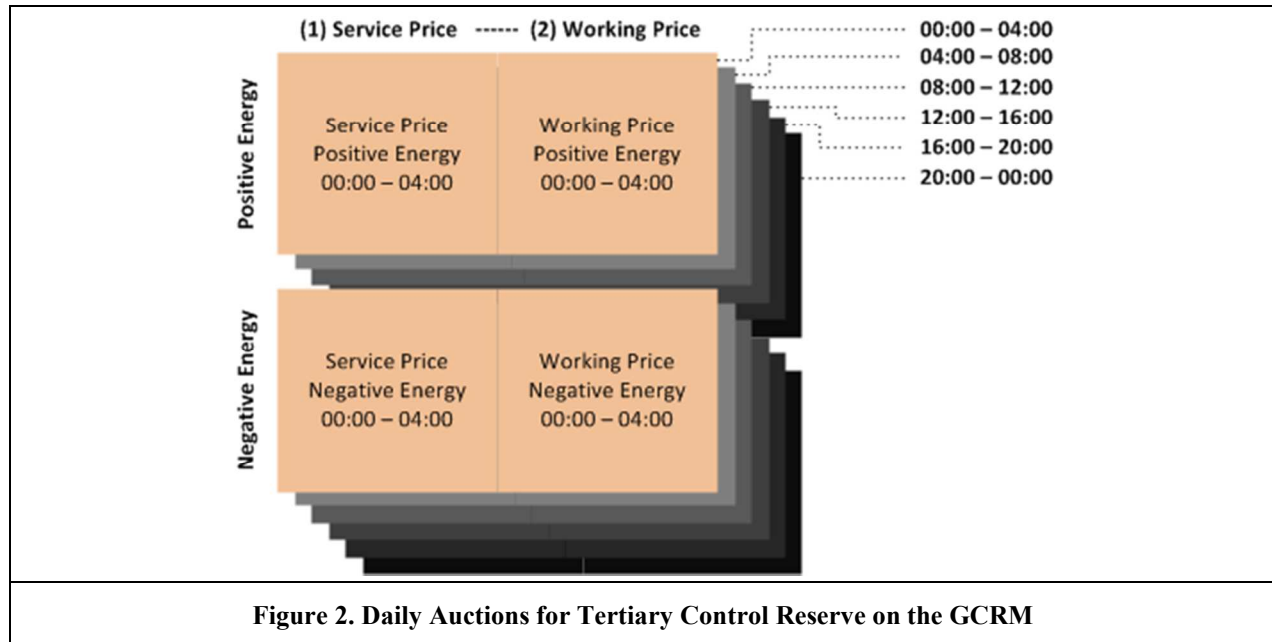


Figure 2. Daily Auctions for Tertiary Control Reserve on the GCRM

Pricing Strategies

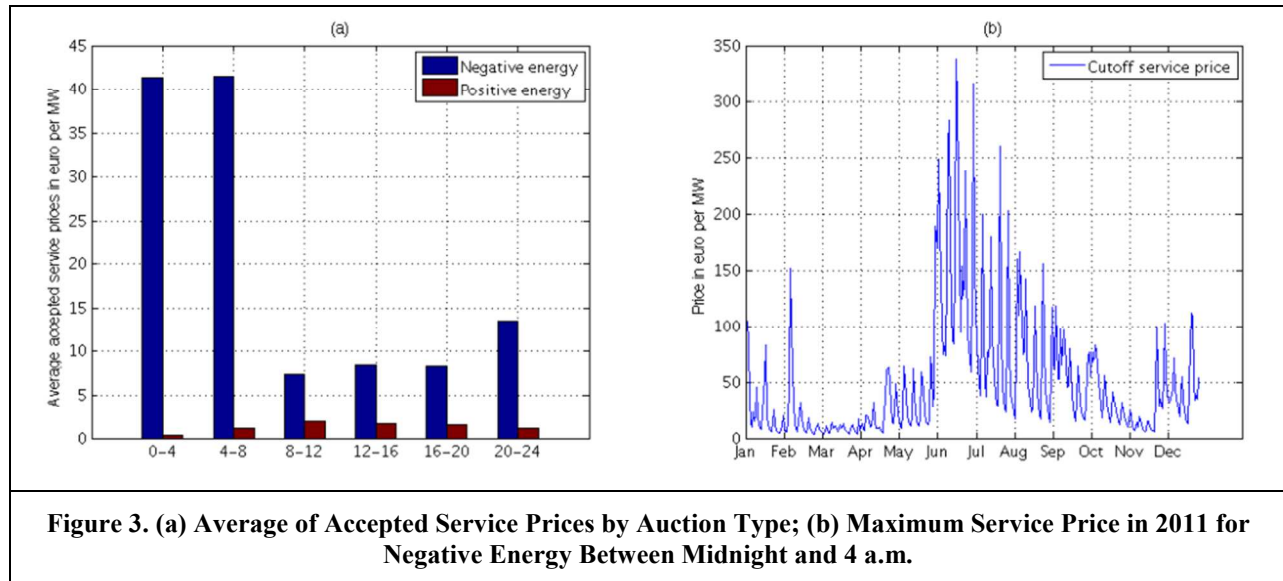
The calculation of point estimates and density functions for the cutoff values is no trivial task, as the only publicly available information is on historic cutoff values and target quantity and, like most energy prices, they are subject to a multitude of exogenous shocks. In the remainder of this section we present increasingly complex pricing strategies that include preliminary results on decision support for service price optimization in an auction for negative energy between midnight and 4 a.m. Negative energy is particularly well suited for EVs, as it implies charging the vehicle battery and no EV owner would

complain about that. Figure 3 (a) shows that the average of accepted service prices for negative energy is exceptionally high between midnight and 8 a.m., since the load on the grid is very small and generators that are inexpensive to shut down have already been shut down. The time between midnight and 4 a.m. qualifies better for EV aggregation than the following four hours, as the vast majority of cars will be parked and plugged for the entire timespan. We focus on the service price for the time being, as historic cutoff values are publicly available, whereas information on historic working cutoff prices can only be derived by inference.

Fixed Price

The most straightforward strategy is always asking for the same fixed service price. This is particularly suited for risk-averse market participants with some level of fixed costs associated with the service provision. Figure 3 (b) traces the cutoff service price for this particular auction during 2011. Evidently, cutoff prices display a high volatility over the course of the year. While some periodicity on the weekly (the small peaks) and annual level (the summer peak) can clearly be discerned, the trace nonetheless seems to be subjected to a multitude of additional shocks. Thus, a conservative pricing strategy that compensates fixed costs plus some profit margin may be optimal for specific market participants and will be used as a benchmark strategy.

EV aggregators face very small fixed costs for negative energy supply. However, a zero-price strategy as a specific fixed price strategy may nevertheless be advantageous for certain business models. The intermediary would be guaranteed to be placed at the top of the merit order list (since we assume $p_W = 0$ and $p_S = 0$ to ensure participation in the market) and could collect revenues by billing the EV owners for the charged energy.



Cutoff Targeting

A DSS has the largest impact when the intermediary tries to continuously hit the cutoff prices to achieve the maximum possible revenue per MW offered during the course of the year. However, this requires sufficiently good forecasting methods for cutoff prices. There are three principal categories for such an information system, which will be investigated in our research:

- **Deterministic Support System.** The bidding strategy is exclusively determined by the information system. So far, we have tested two common tools for price prediction: Fast Fourier Transformation (FFT) and Time Series Analysis. While the FFT provide disappointing results despite some obvious periodicity in the trace, we have also tested several ARIMA models, which are able to explain up to 80% of the variance in the trace and provide annual revenues per MW of about 50% of the theoretical maximum. The main issue is that the time series reacts to large, singular, exogenous shocks with a

delay. One possible solution to this problem is the inclusion of additional predictors for these shocks, thereby decreasing prediction errors and increasing revenue.

- **Recommendation System.** This is another solution to the shock delay problem. The information system is capable of providing very good estimates of inherent price trends without exogenous shocks. Instead of trying to incorporate all possible variables that might cause such a shock in the prediction model, the system provides a recommendation to an expert employee. This expert can then adjust this recommended price based on his or her knowledge about the current market situation.
- **Market Analysis Interface.** This approach regards the price as the realization of current constraints on the underlying energy market. Instead of predicting future prices, the support system predicts supply and demand trends on the market and, subsequently, the resulting equilibrium prices. Due to the market complexity, it is constructed as a recommendation and visualization system for an expert employee by design.

Contract-Based and Market-Based Scheduling

The intermediary faces three essential questions concerning its EV aggregation scheme:

- How many EVs are required to participate in the program to guarantee that the intermediary can supply or consume the amount of energy offered on the market for regulation energy?
- Which of the available vehicles should be used at a given time?
- How are revenues distributed between EV owners and the intermediary?

These questions are related to each other, as an increase of the individual revenue for each participant produces incentives to participate more actively in the aggregation program. Increased activity of each participant, in turn, decreases the number of vehicles required to combat statistical uncertainty. This reduced number of required participants increases the per-capita revenues, creating a positive feedback loop until a steady state is reached.

Similarly, the scheduling mechanism is directly related to the business model of the intermediary and the associated mechanism for revenue distribution. Within our ongoing research we have identified two central concepts for revenue distribution. A **contractual mechanism** defines the conditions for the energy transfer and the payoffs for the program participant in an implicit or explicit contract. The intermediary centrally schedules the activation of specific EV units based on these predefined prices and technical considerations. This includes the objective that all participants should be provided incentives to stay in the program and to increase activity. In contrast, a **competitive mechanism** only defines the basic conditions of the business relationship on a contractual basis. Prices are generated on a market platform by competing program participants. As this implicitly determines the schedule of unit activation, the intermediary does not have to create a centralized scheduling mechanism, but needs to provide the marketplace, instead.

In the remainder of this section we will present a provisional business model for each of these mechanisms.

Contractual Mechanism: Parking Garage

Operators of parking garages are amongst the businesses most suited for expansion into EV aggregation schemes. They display four main advantages:

- **A contractual framework is already in place.** Car drivers enter implicit contracts by entering the garage, getting a ticket, etc. This can be extended to provide e.g. discounted parking fees for EV owners who agree to participate in the aggregation program.
- **A billing system is in place, as well.** Actual energy transfers can easily be reflected on the parking bill.
- **Charging infrastructure is owned by the operator.** Fast-charging technology can be implemented to reduce the required number of EVs.

- **High reliability.** Particularly in high-density urban areas parking spaces are usually rare. With the additional incentive of reduced parking costs, the garage operator can expect a high activity for all parking slots equipped with EV charging points.

Thus, the garage operator as aggregation intermediary already has a uniform revenue management and pricing system installed, as well as homogeneous charging infrastructure. Hence, the major parameters that affect the optimal schedule are the brand and type of vehicle, the current state of charge of the battery, and the time the vehicle is expected to remain in the garage.

In our current research we concentrate on this scenario, as it is the one most likely to be implemented in the near future. For this we cooperate with an industry partner, who operates numerous charge points in an urban agglomeration area, including a parking garage, and compile data from several recent pilot studies on urban electric driving to comprehensively assess mobility profiles and battery states in an urban setting.

Competitive Mechanism: Residential EV Aggregation Program

A market-based mechanism is particularly well suited to conditions where a centralized approach is complicated by missing preexisting infrastructure or a missing preexisting business model (like a parking garage). One such situation arises when aggregating EVs in residential communities in suburban and rural regions. In such a case, a competitive mechanism may outperform the contractual one for the following reasons:

- **Automated price determination.** The lack of a preexisting billing model that allows e.g. reduced parking fees necessitates individual offers adapted to the circumstances of each participant. This is automated by the electronic market.
- **Automated scheduling.** As the ask price of the program participant reflects the technical parameters of the EV, schedules can be constructed on a merit order basis.

Overall, the market-based approach supports the revelation of individual preferences that would be more difficult within a centralized framework. Essentially, the resulting marketplace is very similar to the market for regulation energy with substantially smaller quantities. It is now the intermediary who is bidding for regulation energy and the EVs placing the offers.

Such a competitive mechanism is a long-term research objective. However, the critical number of EVs necessary to facilitate aggregation programs is very likely to be reached in urban areas far before rural regions, due to the higher population density and shorter travel distances, which favor EVs.

Methodology

In our ongoing research we work primarily with computational experiments and simulation analysis.

Computational experiments have been a valid tool in economic contexts for several decades (Kydland and Prescott, 1996). Since they have been successfully applied to auction formats, both within an electricity context (Nicolaisen et al., 2001) and without (Bichler et al., 2009), we use them to analyze the merits of a DSS in the market for frequency regulation. Specifically, we use historic data on offers by energy providers and the overall amount of energy acquired by the ISOs to determine whether a particular price suggested by the DSS would have been accepted and to calculate the annual revenue under a certain DSS regimen.

The other central issue in our research is the coordinated usage of thousands of EVs as distributed stochastic storage devices to deliver the regulation energy sold on the market. Simulation analysis helps us to gain insights on this question. In particular, we have finished implementing a testbed to simulate thousands of EVs in one or multiple parking garages. This simulation is based on data for 37 parking garages with more than 15,000 parking spaces in two major German cities, which includes number of vehicles as well as estimations on parking times and parking durations.

Based on these distributions the vehicles are generated for each day. We analyze different scenarios where the total number of vehicles per day ranges between 1,000 and 40,000. However, the number of cars that are concurrently in the parking garage is much smaller and derived from the aforementioned distributions, as well as the parking durations. Depending on the parking times of each vehicle, the

intermediary can use it to supply regulation energy. At the same time 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 and the simulation uses a first-come first-served algorithm and information on the current state-of-charge for each car to determine which vehicles supply the regulation energy. Currently, we only focus on negative regulation energy, i.e. the vehicles are charged during regulation. Hence, theoretically this energy could be sold to the vehicle owners at a discount rate compared to the retail price of electricity to ensure that vehicle owners are willing to participate.

The goal of this research is to determine the number of vehicles required to reliably supply enough regulation energy and estimates on the overall profitability of such an EV aggregation scheme.

Conclusion

In this paper we have presented a research agenda on IS-supported business models for the aggregation of multiple electric vehicles to participate in the auctions for regulation energy. This is of particular interest to the IS discipline, as the market position of the aggregating intermediary links research on decision support, electronic markets, and scheduling mechanisms.

We have argued that information systems can substantially support pricing decisions in regulation energy auctions by predicting maximum prices paid by the independent system operator. One emphasis of our current research is on improving these prediction methods to further enhance the market position of the intermediary. For this purpose we have collected the market data for all 12 auction types from 2007 to the present. Furthermore, we will investigate additional predictors outside the market that may enhance forecasts.

We have continued by describing business models for the interaction between the intermediary and participants in the aggregation program. Particularly urban agglomeration areas are likely to provide the necessary number of electric vehicles within the near future and businesses like parking garage operators are exceptionally qualified to expand into aggregation programs. Investigating such a business model and the operational requirements that need to be met to realize it is another emphasis of our immediate research. With an industry partner we have collected more than 30 million data points on GPS, battery charge, and trip durations to comprehensively analyze urban mobility profiles.

The unifying goal of this research is to design a business model for an electric vehicle aggregator that spans its entire value chain and is founded in comprehensive real world data at each point of this process.

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