About business model specifications of a smart charging manager to integrate electric vehicles into the German electricity market

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Overview

The European and German aim of reducing Greenhouse Gas Emissions (GHG) by 80 % by the year 2050 (European Commission 2011, Bundesregierung 2010) will require changes in the transportation sector as today it accounts for about 23 % (18 %) of the total European (German) emissions (Eurostat 2013). Furthermore, the share in Europe has considerably increased since 1990 (Eurostat 2013). As individual road transportation is responsible for the main share of those emissions (Eurostat 2013) and fossil fuels seem to have no alternative yet, significant changes of powertrains and fuels seem to be unavoidable (cf. Kay et al. 2013).

Electric vehicles (EV) have been discussed as a more energy-efficient and climate-friendly means of individual transportation. Due to positive developments in the battery technology (Thielmann et al. 2012), battery electric vehicles (BEV) are experiencing a comeback in recent years. Currently, around 40 different EV are offered on the German market (Eckl-Dorna & Sorge 2013) while 12,156 cars have been registered on Januray 1st, 2014 (KBA 2014). Considering that the majority of forecasts for EV diffusion in Europe (cf. Kay et al. 2013) assume that EV will become an important powertrain alternative, the electricity demand from these vehicles will increase considerably. Without managing this demand, it will predominantly occur during peak evening hours (e.g. Jochem et al. 2012). The postponing of the charging event is, however, from a technical point of view easy to implement as all current vehicles and most public charging stations already communicate according to the ISO15118 standard. This communication interface allows an exchange of all necessary information for shifting the charging process in time without affecting the requirements of the vehicle user. As cars are commonly not used during the night and their charging could be shifted into off-peak night hours, a business model focusing on a smart charging manager could emerge. In this paper, such an entity operating on the demand side of the electricity market is analysed. It aggregates individual electricity load profiles from EV and manages the charging processes of these EV in a profit maximizing way, while considering spot prices of electricity and individual user needs with regard to availability.

The paper is structured as follows. Initially, EV purchase probabilities for German households at different points of time are determined with the support of a Bass diffusion model variant (Bass 1969) including a stochastic component (cf. Niu 2002) and calibrated with survey data from 180 EV users. In a next step, individual driving and parking profiles based on microdata from a mobility survey representative for Germany form the basis to determine load-shifting potentials during the charging process of EV. Afterwards, the role of a smart charging manager exploiting the households' load-shifting potentials is introduced. The profitability of variants of such business models is assessed by simulating the smart charging managers' load-scheduling and load-shifting activities in an agent-based simulation model for wholesale electricity markets.

Methods

Based on a survey completed by 180 French and German EV users and respondents who had not yet used EV (cf. Ensslen et al. 2013), a binary logistic regression model is fitted in order to assess EV purchase intentions based on respondents households' income levels, their degree of experience with EV, their car usage frequency as well as the number of cars they have in their households. This model can be used to assign probabilities of EV adoption to households from a representative mobility survey in Germany (Mobilität in Deutschland, MiD). In a next step, an EV diffusion scenario is developed. It includes a variant of a stochastic Bass diffusion model (Bass 1969, Niu 2002) which allows deriving the number of EV on German roads until 2030 in a stochastic manner. Considering that EV purchase intentions as well as corresponding mobility patterns are known for individual households representative for Germany, corresponding electricity demand as well as corresponding load shifting potentials of individual households are determined. The role of a smart charging manager is introduced which can be defined as a smart charging service provider. It offers households with EV the option to shift their load in off-peak hours, so charging becomes cheaper. According to Dütschke and Paetz (2013) utilities should provide simple programs in the sense of being transparent and predictable, i.e. with little dynamics. Accordingly, the following tariff is constructed incorporating the issues mentioned avove of being simple (i), as during a charging process only two price levels occur and of being transparent and predictable (ii), as all parameters are fixed and known to the customers correspondingly before the charging process is started. Furthermore, the tariff introduced here incorporates answers to a range of specific concerns linked to load-shifting actities (cf. Krems et al. 2011). After being plugged in the EV is directly charged to a particular level required by the customer (in case of urgencies) and the smart charging manager guarantees that the EV is completely charged the next time it is needed. Formally, this tariff can be described as:

$$p_i(t) = \begin{cases} p_{max} & , \quad t_{0,i} < t \le t_{1,i} \\ p_{min} + \left((p_{max} - p_{min}) \left(1 - \frac{\min(t_{LSP,i},\, T)}{T} \right) \right) & , \quad t_{1,i} < t \le t_{2,i} \end{cases}$$

The time available to the smart charging manager for load shifting activities, i.e. the period the EV is plugged in, but no charging is required to take place, is defined as $t_{LSP,i}$ and is calculated as follows:

$$t_{LSP,i} = (t_{2,i} - t_{1,i}) - \frac{W_{SOC_i,t_{2,i}} - W_{SOC_i,t_{1,i}}}{P_{max}}$$

The parameter T is defined by the smart charging manager and represents the minimal flexible time for load-shifting activities provided by a customer to the smart charging manager so $p_{min}$is paid between $t_{1,i}$ and $t_{2,i}$ (customer i will pay p_{min} if $t_{LSP,i} > T$).

The remaining variables are defined as follows:

W_{SOC_i}: State Of Charge (SOC) of the battery
P_{max}: Maximum charging power an EV can be charged with.
i $\in \{1, \dots, \mathrm{N}\}$: Customers of the smart charging manager
$t_{0,i}$: Point in time when the EV is connected to the grid
$t_{1,i}$: Point in time when the smart charging manager can start load control charging activities (dependent on the user requirements)
$t_{2,i}$: Point in time when the battery is supposed to be fully charged

Figure 1 illustrates how a potential charging process with load control by the smart charging manager could look like. The two price levels used to charge the EV are illustrated. Furthermore, the smart charging manager's optimization potential in order to maximize profit is illustrated (red rhomboid).

In order to analyse the acceptance of different variants of this tariff, a survey has been conducted comparing these tariff variants to a conventional single price level tariff.

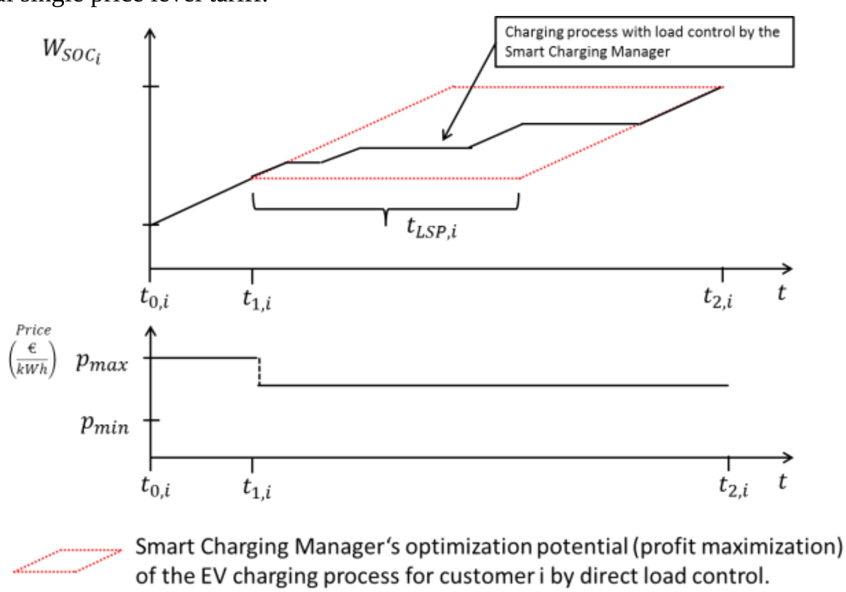

Figure 1: Illustration of the charging process with load control by the smart charging manager

Additionally, the smart charging managers' role as an aggregator of electricity demand of German households is addressed. For that purpose, the additional flexible electricity demand induced by EV and the smart charging manager as a new agent are implemented in the multi-agent simulation model PowerACE (e.g. Genoese et al. 2012), which simulates the German wholsesale electricity market. The smart charging manager's role in the model is to maximize its profit in the day-ahead market based on the tariff structure and the available load-shifting potential. The agent generates endogenously a price forecast for the 24 hours of the following day. This forecast is used to determine the load schedule of all contracted EV. Thereby, the effects of additional EV on the aggregated load and on the spot market prices can be analysed. Integrating EV in an electricity market model allows, furthermore, looking into the general profitbabiliy of the business model of the smart charging manager.

Results

EV diffusion in Germany results in considerable increase of load (e.g. in 2030) particularly during evening peak hours if the EV charging process is not managed in a smart way. Preliminary results show that although the EV are directly charged up to 50 % SOC, new peaks during noon and evening hours could be avoided (on average load during peak times would be reduced by 4 GW, cf. Figure 2).

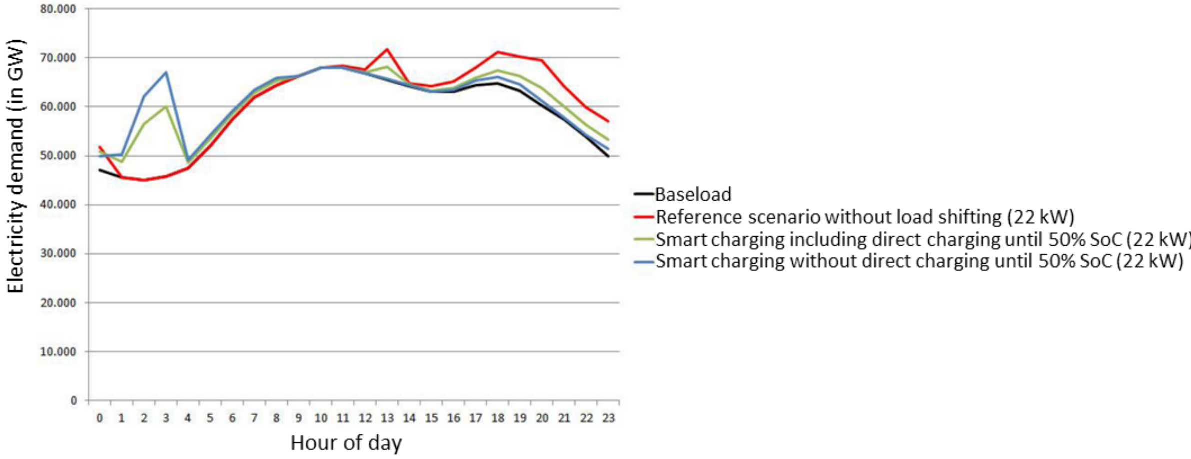

Figure 2: Average hourly impact of charging 8 million EV of German households with different strategies on demand for electricity in Germany in 2030

Furthermore, first results indicate that the business model of a smart charging manager could be profitable as soon as the number of EV on German roads is sufficiently high. This results from lower electricity prices on the spot market during off-peak hours and substantial potential of EV for load-shifting activities (cf. Babrowski et al. 2014). In addition, the smart charging tariff which provides immediate charging up to a specific SOC level could be even more profitable to the smart charging manager, if the parameters of p_{max} and p_{min} and T are chosen adequatly. As the direct charging option represents a service delivering additional utility to the customers, additional willingness to pay can be assumed compared to the smart charging tariff without the direct charging option up to a particular SOC.

An additional aspect for the smart charigng manager could be to provide ancillary services to local distribution grid operators: In times of critical electricity demand, EV could help to avoid bottlenecks in distribution grids.

Conclusions

Based on a survey with 180 respondents who have partly already been using EV and partly not and who have been asked if they could imagine to purchase an EV within the next 10 years in 2012, a binary logit model has been estimated capable of assigning EV purchase intentions to the German representative mobility study MiD. Knowing which households in Germany intend to purchase an EV until 2022, an EV diffusion model has been estimated (i). Furthermore, corresponding mobility patterns including usage and parking times of cars have been analysed. Different strategies of a smart charging manager using households' EV specific load-shifting potentials have been analysed (ii) in order to assess potentials for business model developments (iii) and corresponding impacts on electricity demand in Germany using an agent-based simulation model for electricity wholesale markets (iv). Results show that due to smart integration of EV new peaks can be avoided. Furthermore, first results indicate that the potential for profitably operating the business model of a smart charging manager is considerable.

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