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# Understanding user acceptance factors of electric vehicle smart charging

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A B S T R A C T

Smart charging has been the focus of considerable research efforts but so far there is little notion of users' acceptance of the concept. This work considers potentially influential factors for the acceptance of smart charging from the literature and tests their viability employing a structural equation model, following the partial least squares approach. For a sample of 237 early electric vehicle adopters from Germany our results show that contributing to grid stability and the integration of renewable energy sources are key motivational factors for acceptance of smart charging. In addition, the individual need for flexibility should not be impaired through charging control. Further well known influential factors like economic incentives do not seem to have a significant impact in the sample group under scrutiny. These and further findings should be taken into account by aggregators when designing attractive business models that incentivize the participation of early adopters and ease market rollout.



## 1. Introduction and background

Electric Vehicles (EVs) have the potential to transform individual mobility habits and substantially reduce transport related emissions. In order to harness this potential EVs must be recharged with electricity from sustainable sources. Since these sources are predominantly volatile in their generation patterns, EVs as a flexible load must adapt their charging demand in such a way as to use the available energy for charging in a smart manner, while still fulfilling the mobility requirements of the EV user. Since EVs are quite a new technology in their current form, much attention is still devoted to the assessment of the technology as a whole and in particular to the technical components like the battery, that play a crucial role for range capabilities and economic prospects. Our work goes one step further and analyzes the consumer attitudes towards smart charging concepts.

### 1.1. Research approach

Smart charging approaches have been under thorough investigation with respect to the employed mechanisms, the different objectives such as grid support or economic optimization and the overall effects in EV adoption scenarios in the context of smart grid research (Sortomme and El-Sharkawi, 2011). Most studies find beneficial effects that can be harnessed

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from shifting of charging times of EVs, ranging from the reduction of individual charging costs or emissions to enabling peak demand clipping and loss minimization in distribution grid settings.

However, most studies assume that users either participate fully on a voluntary basis or are part of a mandatory program in the corresponding charging coordination approach. This in turn neglects the fact that successful technology adoption is also determined by the acceptance of the users. In this context we want to address the following main research question: *How do users perceive control interventions in their charging behavior and what are the main factors driving the acceptance of smart charging programs?*

In order to answer these questions we perform a survey-based analysis directed at early adopters of EV technology. Our analysis encompasses the formulation of a PLS-based structural equation model (SEM) which enables us to identify significant relationships between relevant factors of smart charging acceptance. Our results are based on a sample of 237 valid answers of EV early adopters from Germany.

### *1.2. Background and related work*

One of the first to consider EVs as a flexible resource on the demand side in the power system for a contribution to peak load reduction was Heydt (1983). Since then a multitude of further work assessing the different possibilities for EV charging management and coordination has been performed. Most work is dedicated to assess the effect of shifting of charging times to fulfill a given technical or economic objective. This encompasses for instance distribution loss minimization options (Acha et al., 2010), cost minimizing purchase strategies given variable prices (Rotering and Ilic, 2010), power system cost impact assessments (Sioshansi and Miller, 2011; Waraich et al., 2013), charging infrastructure deployment planing based on user preferences (Yang et al., 2016), or renewable energy system integration abilities (e.g. balancing of wind generation (Galus and Andersson, 2011)). Charging coordination, or "smart charging" can be performed in different control architectures. These can either be direct load control options of the grid operators or control by the owners of the EVs given a price incentive (Schuller et al., 2015; Flath et al., 2012). Recently a hybrid form of both paradigms has been introduced and evaluated which consists of a hierarchical or mediated control architecture through the role of an aggregator (Schuller et al., 2015; Gonzalez Vaya and Andersson, 2012; Bessa et al., 2012). EVs have also been evaluated as short term storage devices for the power grid and for the provision of ancillary services, which is known as vehicle-to-grid (V2G) (Kempton and Tomić, 2005). These options were found to be slightly profitable even under consideration of battery degradation (Peterson et al., 2010), but mostly do not account for uncertainty of grid availability and power price developments. All of these options, and in particular V2G, rely on the ability to control the charging process of the EV. This is one of the reasons why this study is further focusing on the acceptance of smart charging as a facet of demand response in the smart grid.

Table 1 gives an overview of related studies and the identified acceptance factors that were the focus of investigation in these papers. It can be observed, that most sources consider the impact of monetary incentives and their design on the acceptance and effectiveness of smart charging (Paetz et al., 2012b; Ensslen et al., 2014). The ability of smart charging to support the integration of RES is assessed in most studies, e.g. in (IZT, 2012). Grid stability is regularly addressed in the theoretical work mentioned above, but is not (yet) often investigated as a motivational aspect for smart charging in empirical studies. Further aspects, such as the trust in the involved institutions, are still under scrutiny and involve different national regulatory environments. The effects of reduced potential flexibility with respect to the mobility requirements is often considered since range anxiety is attributed to EV users (Franke and Krems, 2013b) even though most mobility requirements can be fulfilled on average (Pearre et al., 2011).

Other studies focus more on the characteristics of EV users and their attitudes toward the abilities of the battery rather than on the capability of the vehicle to shift its load according to a selected objective, cf. (Axsen et al., 2015; Bailey and Axsen, 2015; Franke and Krems, 2013a). Recently one of the most comprehensive studies with respect to the current group of active EV users in Germany, their demographics, their driving behavior as well as an evaluation of the overall experience was conducted by Frenzel et al. (2015). This rather descriptive study has similarities to the presented work, in particular with respect to the characteristics of the participant sample, but it does not further investigate potential determinants for the successful implementation of smart charging. This is where our work contributes to guide further design decisions for smart charging regimes that take into account the experience and the attitude of early adopters of EV technology. Thus we consider in particular the design requirements of aggregators, grid operators and energy service companies that plan to offer a product which includes utility-influenced or smart charging.

## 2. Model, methodology and data

In this section we first formulate the main hypotheses with respect to influential factors for smart charging acceptance and secondly, derive the structural model for further analysis. Additionally, the survey characteristics and response data are described.