Energy Research & Social Science xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

User responses to a smart charging system in Germany: Battery electric vehicle driver motivation, attitudes and acceptance

Franziska Schmalfuß[a,*], Claudia Mair[a], Susen Döbelt[a], Bettina Kämpfe[a], Ramona Wüstemann[a], Josef F. Krems[a], Andreas Keinath[b]

[a] Department of Psychology, Cognitive & Engineering Psychology, Technische Universität Chemnitz, 09107 Chemnitz, Germany
[b] BMW Group, Knorrstr. 147, 80788 München, Germany

ARTICLE INFO

Article history:
Received 1 March 2015
Received in revised form 18 August 2015
Accepted 20 August 2015
Available online xxx

Keywords:
Smart charging system for electric vehicles
Acceptance
Usage behavior
Field study

ABSTRACT

Smart charging systems for battery electric vehicles (BEVs) are one promising smart grid technology that has the potential to help balance energy supply and demand. In the present study, we aimed to investigate users' real-life experiences with a smart charging system and their evaluation of it.

In a 5-month field trial, 10 BEV drivers compared conventional BEV charging with smart charging. Via smartphone application, users could modify settings which determined the charging process (e.g., departure times). Before and after experiencing the prototype system, users' motivation, attitudes, willingness to use smart charging and charging behavior were assessed via interviews and questionnaires. Furthermore, participants reported how they experienced and integrated the smart charging system. Results showed that users were motivated and positive about the system at both points of data collection. On average, users agreed that the system is suitable for daily life, reliable and trustworthy. They were willing to use smart charging before and after testing it, but some participants stated that reliability of the system should be improved. In sum, results indicate that a smart charging system like the one implemented in this study is assimilable in everyday life and provide valuable indications for further development of smart charging systems.

1. Introduction

Smart grid technologies are promising solutions for balancing energy supply and demand, saving energy, cutting emissions and integrating renewable energy into the grid. In the transportation sector, there are also several attempts to reduce the consumption of fossil energy and develop more energy-efficient vehicles like battery electric vehicles (BEVs). It is expected that the number of BEVs will grow in the near future, but a promulgation of BEVs will pose additional challenges for grid stability [1]. Conventional uncontrolled charging processes start immediately after the BEV is connected to the grid. They have a fixed charging rate and no dynamic adaptive mechanism that responds to actual grid load. Smart charging systems for BEVs that interact in real-time with smart grids in order to plan charging processes with different charging rates in a way that they could help to overcome, for instance, grid overload problems are very promising [2]. Besides unidirectional charging of BEVs, so called "grid to vehicle" (G2V), "vehicle to grid" (V2G) scenarios have been demonstrated that include bidirectional energy flow [3]. In the present research, we focus on the unidirectional approach.

There are many different ways that G2V systems can be designed and implemented. However, a charging process can only be time-shifted and efficiently managed if departure and/or parking times are available for planning charging schedules. The potential of smart charging systems to avoid demand peaks could further increase if, for instance, BEVs are connected to the grid for a longer period of time and if charging processes are planned ahead more precisely or are more flexible. This is only achievable by integrating additional information obtained from BEV users, such as: realistic/actual departure times and minimum required available range at departure times [4]. Hence, the success of smart charging systems relies on the active participation of BEV drivers when charging their vehicles. Verbong, Beermsterboer and Sengers [5] additionally state that users' willingness to accept changes in their homes and daily routines will determine what smart grids will look like and will have a considerable impact on future acceptance of smart grid implementation. As smart charging concepts like G2V have an impact on a very essential aspect of the daily routine – mobility – a user-centered approach [6] when developing smart grid applications (e.g., smart charging systems) is recommended (e.g., [5]). Within the research project, the usage context was analyzed,

* Corresponding author.
E-mail address: franziska.buehler@psychologie.tu-chemnitz.de (F. Schmalfuß).

http://dx.doi.org/10.1016/j.erss.2015.08.019
2214-6296/

users' requirements defined, the conception completed, mock-ups designed and evaluated and a prototype developed. The evaluation of the prototype was the next important step in the engineering process [7]. As a G2V system with the need for user engagement probably influences people's daily routine (see Domestication Theory [8]), it is important to assess users' experiences when integrating the new technology at home. Hence, this research aims to investigate (Q1) users' experiences, (Q2) motivation, (Q3) perspective, and (Q4) charging behavior when integrating a smart charging system in daily life. Further, the (QExp) experience itself of utilizing a smart charging system can have an impact on users' motivation and evaluation, so pre-post comparisons were obtained.

1.1. State of research

Over the past several years, many studies investigated users' evaluation, acceptance, or usage of different smart grid technologies, as well as their motivation to use this technology (e.g., [9,10]). Some of them examined electric vehicles (EV) and smart charging management systems (e.g., [11]). Gangale, Mengolini and Onyeji [12] analyzed 38 European projects on smart grids with consumer involvement to identify trends for consumer engagement strategies and areas for potential future research. Three motivational factors dominated in the projects: reduction of bills/more control over consumption, environmental concerns and higher comfort. Furthermore, the authors [12] emphasized the importance of trust for a successful distribution of smart grid technologies.

Until now, very little research has been conducted to investigate users' evaluation of, and willingness to use, different G2V approaches. The focus of our review were studies in which BEV drivers experienced a smart charging system, because potential consumers tend to inaccurately predict their interest in products with which they have no experience [13]. Furthermore, previous studies on electric vehicles have shown that experience matters when evaluating different features of an electric vehicle (e.g., [14,15]).

In two field studies, 80 and 10 BEV drivers, respectively, used a relatively simple G2 V implementation without any reward system [11,16,17]. The charging process was time-shifted, so that the PEV was fully charged at a predefined time which BEVs users could adjust via a web application. Participants perceived controlled charging positively and showed a high willingness to participate [11,17]. However, most participants did not adjust their predefined departure times to their real departure times. The main reported reasons for not changing the settings were that the effort was too high and the costs were not compensated through financial or ecological benefits.

In another field study, 15 private EV drivers could set parking times when plugging-in the EVs to achieve smart charging [18]. During the approximately 4 months of data collection, active participation was relatively high. Eighty percent of EV drivers set standing times and 73% acted in accordance with their settings and received the bonus.

As implemented systems varied considerably, results are not completely comparable. However, we can conclude that relatively simple implementations of smart charging systems with little consumer involvement are acceptable to consumers. As described earlier, more promising systems need more information, and therefore, require higher user involvement.

A smart charging system with higher user involvement was implemented in the Swedish project "ELVIIS" [19]. Users could set the time at which the BEV should be fully charged, the range that must be charged immediately and the current used via in-vehicle, web or smartphone interface. Eleven BEV drivers, employees of Göteborg Energi who paid a taxable benefit fee, used the BEV for a period of 1 month and evaluated the system as useful. They indicate that they would use it in the future and also recommend ELVIIS to a friend [19].

However, private users who own or lease BEVs (so called "residential customers") are an important user group. When the market penetration of EVs increases, residential customers who drive an EV might cause significant peaks in energy consumption in the early evening when they come home and plug-in [20]. Thus, it is of high interest how private users evaluate smart charging technology as adoption of these technologies could help to avoid or reduce such peaks. To our knowledge, published results of a field study with private users who integrated a smart charging system with high user involvement in daily life do not exist.

1.2. Relevant concepts and research questions

In research on controlled charging systems, different variables such as users' motives [18], general evaluation (e.g., [11]), willingness to use (e.g., [11,19]), reasons for not using controlled charging (e.g., [11]) and/or actual usage (e.g., [18]) were assessed in order to make conclusions about the costumers' assessment and acceptance of the implemented systems.

Motivational factors are an important topic when investigating smart charging systems, given the need for customer utilization (see [11,12]). Many motivational factors go hand-in-hand with *perceived benefits*. In previous research, shifting charging processes was more strongly motivated by ecological reasons than by economic motives [18]. Financial benefits seemed to be insufficient long-term motivators and other motivational factors like ecological motives are needed [12]. Still, financial benefits are important, especially when perceived user effort is high (e.g., [11]).

However, perceived benefits do not cover all possible motives for a specific behavior. According to *Self-Determination Theory* [21], it is especially important to examine the level of perceived autonomy when behavior such as participating in a smart charging system is externally motivated by others. The sub-theory, *Organismic Integration Theory* [21], specifies the following types of motivation: intrinsic motivation, external motivation and amotivation. *Intrinsic Motivation* refers to the natural drive from inside a person to act in a specific way. *External motivation* comes from the environment and there are four types of behavioral regulation. *External regulated* behavior is behavior in response to external rewards or demands. *Introjected Regulation* refers to regulation in which people have adapted to external rewards or demands, but have not fully accepted the behavior; they do it, because it is, for instance, common courtesy. *Identified Regulation* refers to external influences that are fully accepted and the person thinks it is important to act this way. *Integrated Regulation* is the state of regulation in which the person has integrated all norms, goals and behavioral strategies and is closest to intrinsic motivation. For intrinsic motivation, as well as for identified and integrated regulation, perceived autonomy is high. *Amotivation* implies that there is neither intrinsic nor extrinsic motivation. Regarding smart charging technologies, it is of interest to investigate which type of motivation dominates BEV drivers.

As mentioned earlier, effort points to another variable that needs to be investigated when evaluating smart charging systems – *perceived costs*. Using a smart charging system with high user involvement, as described in the introduction, is associated with (high) costs for the BEV driver: He/she has to plan ahead, set/adjust, for instance, departure times and act according to his/her settings. Depending on the driver's living conditions and habits, system usage could be more or less cumbersome. Furthermore, it is important to evaluate the perceived ratio of benefits to costs, which is labelled 'fairness' by Hujits et al. [22].

In current research on smart grid technologies, *trust* proved to be a relevant factor [12] that also increases acceptance of sustainable