Introducing Human Factors Psychology to Vehicle-to-Grid Technologies

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1. Introduction

Electromobility may be powerful in reducing the CO_2-emission inherent to traffic. Electric vehicles do not directly emit CO_2. The overall CO_2-emission of the vehicles may be reduced to almost zero, assuming that energy used for charging is based on renewable energy sources (Brake, 2009; Heider, Büttner, Link & Wittwer, 2009). Technological solutions like vehicle-to-grid (V2G) concepts link renewable energies and electromobility by optimizing the integration of the electric vehicles into the grid. The charging process is controlled by a technological unit (intelligent load management system, ILMS). The ILMS is an interface between the vehicles and the grid encouraging a smart integration of the vehicles. That is, the system charges the vehicle’s battery when energy is available. In times of raised energy demand in the grid, the battery may serve as storage providing energy to the grid. In the future, smart integration of electric vehicles might constitute a broad framework including smart homes, electric vehicles, and smart grid technologies. Figure 1 demonstrates such a scenario: The ILMS controls the energy flow between the energy grid, the smart home and the electric vehicle. Self-generated energy (e.g. from photovoltaic systems) may be used for charging or stored in the vehicle battery for future demand. The technological requirements of such systems are uncontested and decisive for the economic as well as the ecological success of electromobility. However-besides technological demands-the consideration of user variables is crucial in the context of a smart integration of electric vehicles. The present paper introduces psychological theory and methods as well as inferences from studies focusing on user variables related to a smart integration of electromobility.

2. Psychological Research in the Context of V2G- State of the Art

Figure 1 illustrates the impact of user variables on constituents relevant to a smart integration of electric vehicles. The three components *electric vehicle*, *ILMS* and *smart home* are directly affected by user variables. The impact of user variables differs depending on the constituent. Behaviour patterns (*habits*) are especially important in context of smart homes and electric vehicles. *User participation* and *skills* are most relevant in drivers' interaction with ILMS that require information about upcoming trips to set a time interval for optimized charging. System characteristics and its impact on users' behavioural patterns affect the appraisal of each component. The appraisal-in turn-strongly affects the market success of each technology.

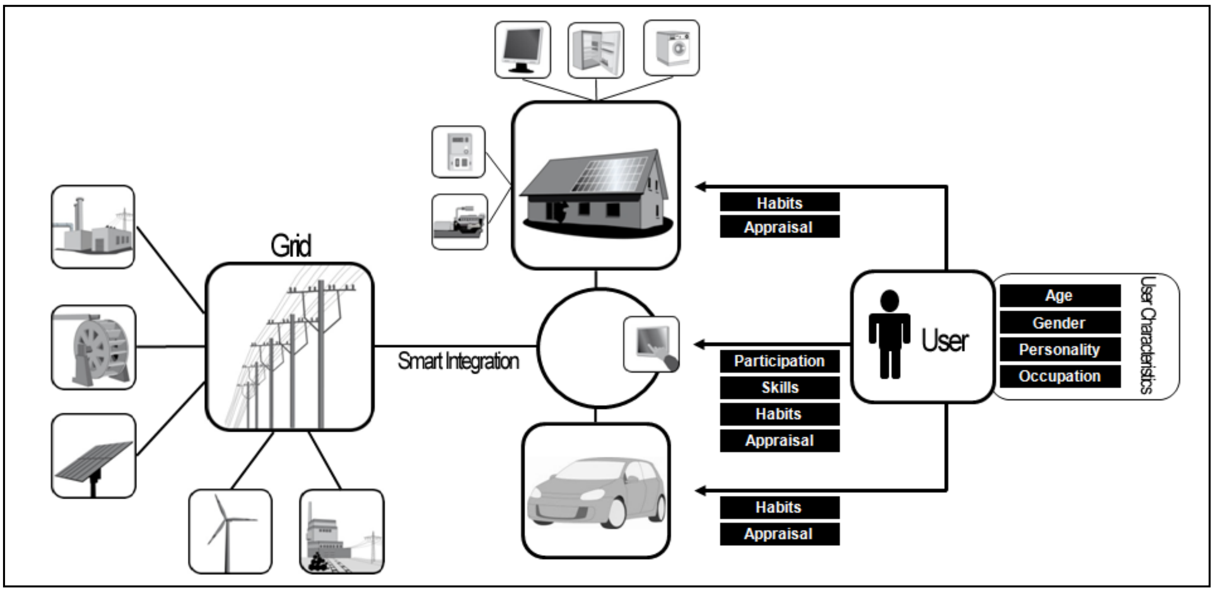

Figure 1. A schematic illustration of user variables relevant in future V2G scenarios.

2.1. Smart Homes/ Energy Consumption

From the current perspective, mobility seems to be fairly independent of habitation. The simultaneous development of electromobility and smart home concepts may approximate mobility and housing. Unlike conventional vehicles, electric cars can be charged at house-hold sockets. Increasing installation of domestic photovoltaic and block heating systems enables future house owners to charge their vehicles with self-generated energy.

Concepts of smart homes may provide valuable advantages in comfort and energy efficiency but are accompanied by considerable changes in user behaviour. Currently, it is still unclear how inhabitants react to such changes like increasing automaticity and to what extent they are willing to change their behaviour in the context of smart homes.

Studies have provided first information about the influence of energy related feedback on consumption behaviour and the stability of domestic behaviour patterns (Schleich, Klobasa, Brunner, Gölz et al., 2011; for an overview see Abrahamse, 2005). Different effects of feedback on energy consumption reaching from 5 to 15 % have been reported (Darby, 2006). Findings in terms of stability of the effects are

ambiguous. While some studies report continuous energy saving in the medium-term (Bittle et al. 1979) others report declining effects on energy saving over time (Van Dam et al., 2010).
In a recently conducted research project more than 2000 households have been observed in their usage behaviour of an individual feedback-homepage. One major result shows that the log-in numbers tremendously declined after the first month of usage. This indicates that most inhabitants are open to information about their own energy consumption but further interventions are necessary to affect behaviour sustainably (Sunderer, Götz, Gölz, in print).
Findings can be partially transferred to smart home concepts and indicate a general tendency to respond to individual energy related information and to change habitual behaviour in the domestic domain. Nonetheless, results inferred from feedback studies only display an excerpt of the broad range of smart home concepts. For example, inhabitants' reaction to increasing automaticity has not been investigated in previous research and need to be assessed by future studies.

2.2. Electromobility

In Figure 1, electromobility is separated from ILMS and defined as an independent component. From a human factors perspective, this distinction is reasonable to discriminate between drivers' mobility patterns, their appraisal of electromobility and their skills to plan their mobility as demanded by ILMS.
The impact of ILMS depends on market success of electric vehicles. Small numbers of electric vehicles do not strain the grid and do not necessarily demand a smart integration of the vehicles (Birnbaum et al. 2008). In this case, the ecological impact would be fairly small. Hence, research is necessary that allows for accurately determining factors relevant to the market success of electromobility. Findings would enable future research and development to concentrate on influencing variables of electromobility in order to enhance user acceptance as well as market success of the technology.
Previous research predominantly focused on technological differences between electric vehicles and common combustion engine vehicles like cruising range or charging time. Studies analysing mobility data showed that average daily cruising ranges are between 28 and 45 kilometres (Birnbaum et al. 2008; Wu et al., 2010). Such ranges are feasible by most current electric vehicle models (Brake, 2009). Nonetheless, objective data do not assess the users' subjective needs and constraints related to mobility. Research showed that driving does not constitute an entire rational action (Steg, 2005). Hence, although people only drive short distances

with their current vehicle, they may have the encompassing need to cover long driving ranges when desired. In this mind, cruising ranges based on solely objective data will not necessarily be evaluated as being adequate by the user. This may lead to negative evaluation or even rejection of electromobility. First studies point to a considerable difference between objective driving behaviour and subjective needs regarding mobility. A questionnaire based study revealed that only 50 percent of current drivers accept cruising ranges of electric vehicles of less than 300 kilometres. Even 30 percent of all users wish cruising ranges between 450 to 1000 kilometres (VDE, 2010).

Research investigating the influence of market penetration on the evaluation of hybrid electric vehicles has shown that ratings of different vehicle features like cruising range depend on the users' perceived market penetration of the vehicles (Axsen, Mountain & Jaccard, 2009). That is, when participants assumed that a lot of people use hybrid vehicles, they accepted shorter driving ranges, higher prices and/or less warranty (Axsen et al., 2009).

Psychological research investigating organizational change processes revealed individual differences in reacting to changes in the environment. These individual dispositions also influence the appraisal and usage of innovative products (Oreg, 2003). Such findings indicate that consumer decisions are affected by individual dispositions rather than entire rational processes strongly related to users' real behaviours.

2.3. Intelligent Load Management Systems (ILMS)

ILMS are highly reliant on users' participation and skills. The efficiency of the technology strongly depends on the utilization of intelligent loading processes as well as users' predictions of their mobility. Misestimations may lead to inefficient loading processes or-even worse-to insufficient battery levels.

Besides technological studies, psychological research is needed focusing on the user, providing information about drivers' motivation and skills to forecast upcoming departure times and route lengths. Planning of future trips undeniably constitutes a change in current mobility patterns. The predetermination of future trips might be perceived as restricting flexibility. Currently, it is unclear in how far users are willing to take part in this process.

Moreover, future research also needs to concentrate on the skill perspective, assessing users' ability to accurately forecast upcoming departure times and route lengths. First studies investigating drivers' ability to plan their own mobility on a general level provide first insights. Gärling, Gillholm and Gärling (1998) asked participants to predict their mobility behaviour of the upcoming week. Subsequently, subjects recorded their actual mobility behaviour using a provided logbook. Participants were also asked to classify their trips so that the influence of trip type (work, leisure and shopping) on the accuracy of mobility forecasts could be assessed.

Findings indicate an effect of trip type on the accuracy of mobility predictions. Estimations were best for leisure trips. Shopping trips had the worst prediction rate. The accuracy of work trip estimations was between that of leisure and shopping trips. In sum, participants tended to underestimate their mobility behaviour. That is, people err on the unsafe side, predicting to be less mobile than they actually are. In the context of electromobility, we consider underestimations as being critical to safety since spontaneous or early trips may result in insufficient battery levels.

Results were partially replicated in a study by Jakobsson (2004). In this study, participants also predicted their mobility behaviour for one week in advance. In addition, subjects also forecasted the length of each trip. Again, the number of real trips exceeded the number of estimated trips. Estimations of trip length were fairly accurate (on average 3.35 km). Analysis of trip type revealed that shopping trips had the worst prediction rate. In contrast to Gärling et al. (1998), the most accurate estimations were yielded for work trips. The error rate of leisure trips was between that of work and shopping trips.

Although the reported studies did not explicitly focus on ILMS and related mobility predictions, these studies give a first insight into humans' ability to estimate their future mobility behaviour. However, past studies used long prediction intervals of one week. Future ILMS do not demand to predict the mobility behaviour of such long time periods. Additionally, previous studies did not assess estimations of departure time.

In the framework of a final thesis project conducted in the work group of the authors of the present paper, drivers' abilities to forecast their own mobility were tested in conditions similar to ILMS scenarios (Maiwald, 2011). Findings allow for more accurate assumptions about drivers' abilities related to ILMS as compared to studies investigating mobility forecasts on a general level. For two weeks, participants were asked to estimate departure time and route length of their next trip after arriving at home with their own car. Real mobility behaviour was reported in a logbook. Additionally, GPS tracking devices were installed in the vehicles to verify reported mobility data.

Findings showed that in general, the number of actual trips exceeded the number of predicted trips. This is in line with previous studies indicating that subjects tend to underestimate their own mobility (Gärling et al., 1998; Jakobsson, 2004). Also, participants' estimations of departure times and trip lengths-as demanded by ILMS-were fairly accurate. This holds for estimations of trip lengths in particular (average absolute error: m = 8.1 km). The average absolute error in departure time estimations was 30.87 min. Trip type had a significant effect on the accuracy of departure time as well as trip length estimations. The best predictions of departure time were yielded for work trips, followed by leisure and shopping trips. There was no difference in the accuracy of trip length estimations between work and shopping trips while error rates of both of these were significantly lower than those of leisure trips. In general, findings with respect to trip type were replicated in an ILMS scenario but show important differences between departure time and trip length estimations. These differences need to be considered in the development of ILMS.

3. Conclusion

The present paper introduces human factors psychology to the field of V2G-concepts. We suggest a multi-facet approach including users' habits, needs, participation, and skills. The influence of these user variables varies between the components smart home, ILMS, and electromobility.

Previous research regarding habits in the domestic domain mainly concentrated on energy consumption and its changeability trough feedback. The rising technological efforts in the development of smart home concepts demand studies assessing users' responsiveness to information provided in the broader context of smart homes. Since reported effects of feedback on energy consumption were partially instable (Van Dam et al., 2010), we suggest dynamic approaches providing the user with varying information over time. In addition, solutions based on one control unit are desired to focus the user's attention on one system rather than installing several independent units. This, however, requires a certain degree of standardization to guarantee conformance and in particular interoperability of several devices connected to one control unit (Rohbogner, Feuerhahn, Zillgith, & Wittwer, 2010).

The future market success of electromobility is still uncertain. Previous studies predominately focused on real mobility behaviour (Birnbaum et al., 2008; Wu et al., 2010). Research analyzing real mobility data is valuable but inferences based entirely on objective data might be distorted and do not cover consumer decisions comprehensively. To gain more information about perceived user needs regarding mobility as well as differences between real behaviour and subjective needs, research is needed which combines subjective and objective data. Based on such studies, determinants influencing users' appraisal of electromobility may be assessed more precisely offering an empirical base to more accurately predict the future market success of the technology.

Increasing market penetration of electromobility will raise the need for a smart integration of electric vehicles. Solutions based on ILMS are promising but demand users' participation and skills. Findings from mobility research are necessary to adapt future ILMS to users' abilities. First results reveal that the majority of drivers' mobility predictions as required by ILMS are fairly accurate but extreme values need to be taken into account. Further, battery security buffers should be based on empirical data to avoid negative experiences with the system. First results from studies applying ILMS scenarios indicate an effect of trip type on mobility forecasts and suggest the development of ILMS that consider such differences in forecast accuracy between trip types to yield more efficient optimization (Maiwald, 2011).

Technological ambitions to encourage electromobility and its smart integration in the future energy grid are far-reaching but most systems are still at a prototype stage. Thus, it is difficult to comprehensively anticipate future conditions. Nonetheless, it is necessary to take user variables into account in an early developmental stage to construct technology that is adapted on users' strengths and weaknesses. Technological solutions which fail to meet users' expectations and needs are likely to fail market success. In the context of a smart integration of electric vehicles, this would be particularly consequential since electromobility has the power to substantially reduce local as well as global CO_2-emissions.

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