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Examining BEV Drivers' Willingness to Share Personal Information in the Context of Smart Charging: Results of a Five-Month BEV Field Trail

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Abstract

Within the present contribution, we provide results from a highly naturalistic five-month smart charging field trial. A battery electric vehicle (BMW ActiveE) was provided to the participants and a smart charging station was installed at their home, where smart charging was remunerated during night-time. $N = 20$ participants took part. They were on average 48 years old and interviewed after 13 (T1) and 21 weeks (T2). Results revealed that participants were most unwilling to provide personal level 3-(deduced) information compared to level 2-(long-term) and level 1-(raw) data. The overall pattern in terms of serious concerns about deduced information and preferred data recipients as well as the perceived trust remained stable over time. Instead, there were significant differences in participants perceived trust between the stakeholders at T1. Most often the participants chose "*all of the four*" presented data recipients to whom they are willing to pass level 1 and level 2 information. However, the majority of participants chose "*none*" of them to pass level 3 information. Participants' perceived trust in stakeholders was able to significantly predict their willingness to share personal information and underline its importance for taking part in smart charging.

Keywords: privacy concerns; preferred data recipients; user research; smart charging experience

1. Introduction

Battery electric vehicles (BEVs) are a promising mobility solution to reduce emissions in the transport sector. However, BEV emissions are still highly dependent on the renewable energy ratio in the electricity grid, whose availability is subject to large temporal and weather-related fluctuations. Smart charging is one effective approach

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here, which contributes to balancing the grid in times of 'green' energy overload or shortage. Furthermore, it promises benefits for different stakeholders: BEV drivers may hope to save money when providing energy flexibility, energy suppliers aim at a reduction of operational costs, and grid operators of the transmission system are interested in a flexible demand side to integrate the growing amount of renewable energy sources (McKenna, Richardson & Thomson, 2012).

However, smart charging requires detailed settings of the BEV drivers' consumption demand and the capture of consumption data. Using smart data processing, precise indicators of activity patterns arise from energy usage in general and charging information in particular. This provokes a conflict between the usage of sustainable, smart appliances and the protection of individuals' privacy. Thus, privacy concerns may be an obstacle to participating in smart charging (Kämpfe et al., 2022). Prior online questionnaire studies indicated differences in the willingness to provide smart charging information of different data aggregation levels and consumers reject providing information including threat potential deduced from this data (Döbelt, Kämpfe, & Krems, 2014). Accordingly, as research in the smart home context showed, the recipient of the data is important to customers (Yang, Lee, & Zo, 2017).

Aside from technical feasibility, diverse smart grid stakeholders also claim for a better incorporation of user perspectives, especially at the early stages, to support the active participation of consumers (Haider, See, & Elmenreich, 2016). Cavoukian, Polonetsky and Wolf (2016) postulated the implementation of mechanisms, which allow consumers to control their electricity consumption and at the same time the release of personal information. This will foster consumers' trust and finally participation in the smart grid. And also other authors (e.g., Kulkarni, Phatale, & Naveed, 2015) claim for: "*Privacy: […] like consumer acceptance, privacy violations needs to be addressed appropriately.*" In addition, it has been shown that experience under real-world conditions has a significant influence on acceptance (Schmalfuß et al., 2015).

Therefore, consumer concerns have to be investigated and described to serve as requirements for the technical implementation. However, the incorporation of consumer perspectives or their respective concerns under real-world conditions are issues that have not been the central focus of smart grid developments to date.

2. Present research

Emerging from the literature the consideration of empirically gathered user perspectives on smart charging systems in particular is rare. Yet results are essential to address them during the system design and therefore foster later participation in smart charging use cases. Hence, the objective of the present contribution was to investigate BEV drivers' willingness to share personal information in the context of smart charging. We also examined BEV drivers' preferred data recipients (i.e. stakeholders involved in smart charging) as well as their perceived trust. Further, we analyzed the influence of real smart charging experience. To this end, the following research questions (RQ) were addressed:

RQ1: How does the willingness to share personal information differ depending on data aggregation level?
RQ2: What influence does real smart charging experience have on the willingness to share personal information?
RQ3: How do stakeholders differ in terms of perceived trust and who are the preferred data recipients?
RQ4: To what extent can the willingness to share personal information be predicted by trust in the stakeholders?

3. Methodology

The study described, was part of the research project "Gesteuertes Laden V3.0", conducted from 2013 to 2015. This project was funded by German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and was conducted by the consortium partners: BMW AG, EWE AG, Fraunhofer-IOSB, Technische Universität Ilmenau, Vattenfall Europe Innovation GmbH, Clean Energy Sourcing AG and Chemnitz University of Technology. Within the project, a user-centered design of a smart charging system was realized and evaluated. For a comprehensive project overview see Pfab et al. (2016).

3.1. Study setup

During the field trial, a smart charging use case was tested with BEV drivers in practice. The field trial has been conducted in Berlin, Germany and contained two five-month phases (10 participants each). A smart charging station was installed at the participants` home and a BEV (BMW ActiveE) was provided to the participants. Participants' settings (e.g., time of departure, state of charge at the time of departure, safety buffer loaded immediately after plugging in the BEV) could be entered via a smartphone application. Furthermore, this smart charging app provided user feedback (e.g., on the amount of charged energy in kWh, the vehicle's actual state of charge in %, the financial compensation in € for using the smart charging mode). Smart charging was remunerated during nighttime between 8 pm and 8 am.

The field trial started with a baseline to familiarize participants with BEV and conventional charging. Afterwards, the trial period with the enabled smart charging mode started. During the field trial phase 1, the baseline lasted ten and smart charging 11 weeks. In the field trial phase 2, there was a shorter baseline of six and a longer smart charging period of 15 weeks (see Figure 1).

Participants in field trial phase 1 and 2 were interviewed after 13 weeks (T1, $n_{T1} = 20$) with at least 3 weeks of smart charging experience. In field trial phase 2, there was the possibility to conduct a second interview after 21 weeks (T2, $n_{T2} = 10$).

Fig. 1. Field trial procedure, including phase 1 and 2, respectively $n = 10$ participants.

3.2. Participants

Participants have been recruited using newsletter- and website announcements. Interested persons could apply for field trial participation via an online questionnaire and were selected primarily based on structural conditions, which allow for the installation of the smart charging system. $N = 20$ participants took part including 18 men and 2 women. They were on average 48 years old ($SD = 8.34$, $Min = 31$, $Max = 60$) and were 'well educated': the majority (70%) holds a university degree, followed by 25% that hold a degree of a university of applied science and 5% who hold a high school graduation. Half of the participants indicate at the beginning of the field trial, that they already had electric driving experience with a hybrid electric vehicle or a BEV, but their previous driven kilometers differ widely from $Min = 0$km up to $Max = 12500$km ($M = 476.38$, $SD = 2103.45$).

At T1 participants reported to have charged their ActiveE during an average week $M = 6.2$ times ($SD = 1.77$, $Min = 2$, $Max = 9$). The percentage of smart charging events at T1 amounted to 84.7% ($M = 5.3$, $SD = 1.66$, $Min = 1$, $Max = 7$). At T2 participants reported to have charged their ActiveE on average $M = 6.5$ times ($SD = 1.57$, $Min = 4.5$, $Max = 10$). The percentage of smart charging at T2 was also 84.7% ($M = 5.6$, $SD = 1.07$, $Min = 4$, $Max = 7$).

3.3. Measurements

The data collection was done with paper and pencil during individual face-to-face appointments. All variables were assessed at T1 and T2.

3.3.1. Willingness to share personal information. Participants' willingness to share personal smart charging information was assessed on a 4-point scale ranging from 1 = *never willing to provide* to 4 = *always willing to provide* with 45 items categorized into three data aggregation levels: level 1 - raw data (19 items), level 2 - processed long-term data (10 items), and level 3 - deduced information (16 items) for example: "*Location of the charging station where I have charged*." (level 1), "*Evaluation of my charged energy amount per week.*" (level 2), and "*Whether my household is unattended when I leave the house*." (level 3).

3.3.2. Trust in stakeholders. Trust for each of the presented stakeholders involved in smart charging (i.e. 'aggregator', 'energy supplier', 'grid operator', 'vehicle manufacturer') was gathered by a short scale (Pavlou, 2003) consisting of three items per stakeholder. Respondents were asked to indicate their agreement on a 7-point agreement scale (from 1 = *I don't agree at all* to 7 = *I agree completely*) to e.g. following statements: "*I trust the [stakeholder] because he looks after my interests*.", "*The [stakeholder] is trustworthy*.", and "*The [stakeholder] is someone who keeps promises and commitments*.".

3.3.3. Preferred data recipients. The participants could chose, from "*none*", to *one* of the four different stakeholders (i.e. 'aggregator', 'energy supplier', 'grid operator', 'vehicle manufacturer'), "*all four*", or "*all four and third parties*", they would pass the presented information (same 45 items as for willingness to share personal information).

4. Results

Regarding RQ1 (How does the willingness to share personal information differ depending on data aggregation level?) the results showed significant differences between the three levels at T1 ($F_{T1}(1.44, 27.44) = 60.35$, $p < .000$, $\eta_p^2 = .76$) and T2 ($F_{T2}(2, 18) = 51.70$, $p < .000$, $\eta_p^2 = .85$; see Figure 2). Post hoc tests revealed significant differences between level 3 and level 2 ($p_{T1} < .000$, $p_{T2} < .000$) as well as level 3 and level 1 ($p_{T1} < .000$, $p_{T2} < .000$) at both times of measurement. Between level 1 and level 2 participants' willingness to share personal information did not differ ($p_{T1} = .715$, $p_{T2} = .785$).

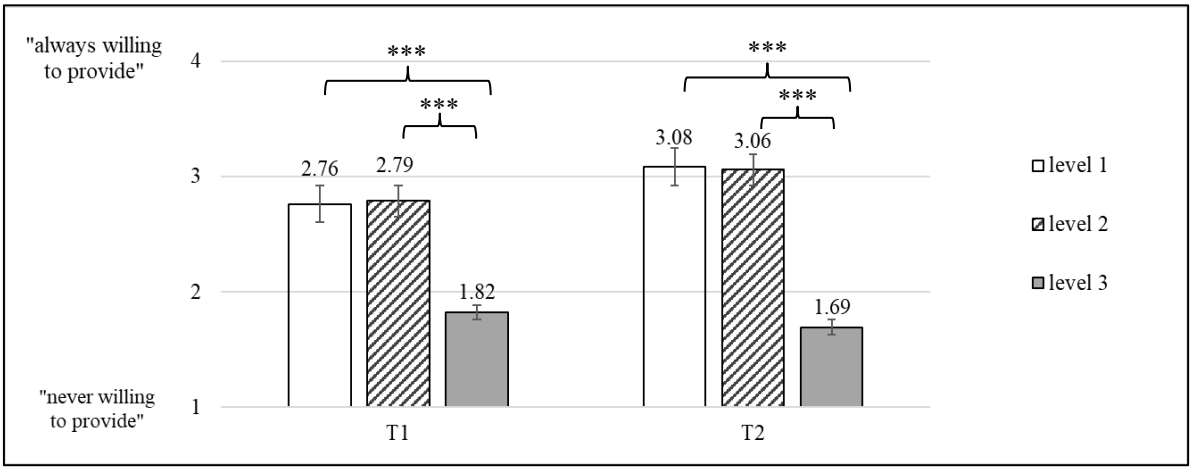

Fig. 2. Participants' willingness to share personal information between data aggregation level 1, level 2 and level 3 at T1 and T2.
Note. $N_{T1} = 20$, $N_{T2} = 10$. Items were rated on a 4-point scale ranging from 1 = *never willing to provide* to 4 = *always willing to provide*. Error bars represent standard errors, *** marks significant differences $p < .000$.

As can be seen in Figure 2, participants were most unwilling to provide level 3-information compared to level 2- and level 1-information. Participants were most unwilling to provide the information: "*what I earn*" ($M_{T2} = 1.00$, $SD = .00$), "*who is part of my social network*" ($M_{T2} = 1.10$; $SD = .32$), and "*that I`m not at home*" ($M_{T1} = 1.15$; $SD = .49$).

With respect to RQ2 (What influence does real smart charging experience have on the willingness to share personal

information?) no significant differences regarding participants' willingness to share personal information between T1 and T2 could be identified (p_{level1} = .101, p_{level2} = .100, p_{level3} = .314).

Regarding RQ3 (How do the stakeholders differ in terms of perceived trust and who are the preferred data recipients?) results showed significant differences in participants' perceived trust between the four stakeholders at T1 ($F_{T1}(3, 57) = 5.40$, $p = .002$, $\eta_p^2 = .22$), but not at T2 ($F_{T2}(3, 27) = 2.79$, $p < .060$, $\eta_p^2 = .24$; see Figure 3). Post hoc tests revealed only one significant difference between the grid operator and the vehicle manufacturer at T1 ($p_{T1} = .028$). Participants' perceived trust between the four stakeholders did not change from T1 to T2 ($p > =.317$).

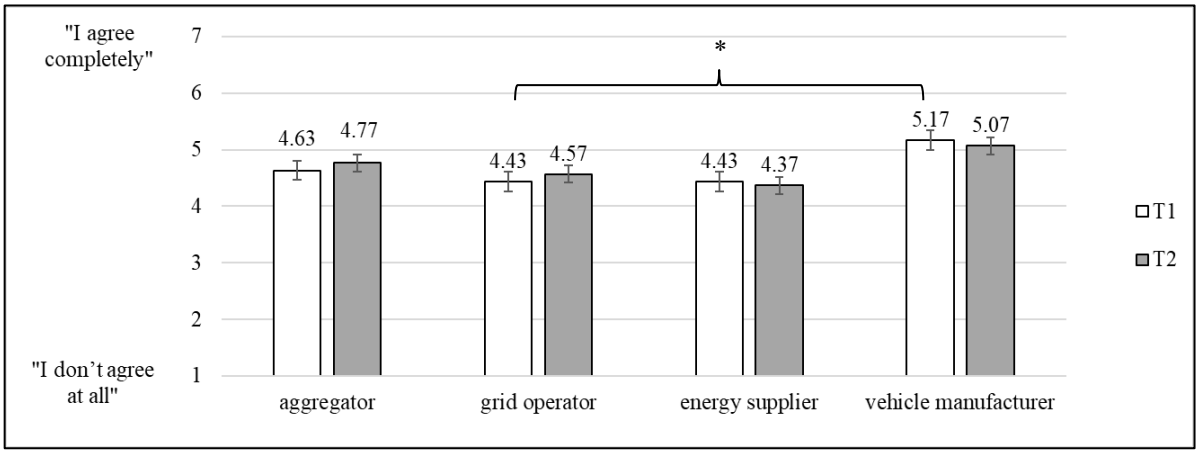

Fig. 3. Participants' perceived trust in stakeholders at T1 and T2.

Note. N_{T1} = 20, N_{T2} = 10. Items were rated on a 7-point agreement scale ranging from 1 = *I don't agree at all* to 7 = *I agree completely*. Error bars represent standard errors, * marks differences $p < .050$.

As there were also no significant differences regarding participants preferred data recipients between T1 and T2, we summed up preferences for both times of measurement. Most often the participants chose "*all of the four*" presented stakeholders to whom they are willing to pass level 1 (50%) and level 2 information (54%). In case they were willing to pass level 1 and level 2 information to *one* of the presented data recipients, they chose most often the energy supplier (level 1 = 11%; level 2 = 12%) or the aggregator (level 1 = 9%; level 2 = 12%). However, the majority of participants chose "*none*" of the stakeholders as the preferred data recipient to pass level 3 information (63%). For detailed information see Table 1.

Table 1. Participants' preferred data recipients in percent to pass level 1, level 2 and level 3 information.

	Level 1	Level 2	Level 3
none of the stakeholders	17.74	13.36	**62.66**
aggregator	9.05	11.46	4.34
energy supplier	11.41	12.21	1.95
grid operator	4.14	3.50	.49
vehicle manufacturer	5.07	1.54	2.78
all four stakeholders	**49.56**	**54.42**	22.45
all four stakeholders and third parties	3.03	3.50	5.32

Note. N = 20. Average percentage between T1 and T2. Most preferred data recipient for each data level are marked in bold.

To examine RQ4 (To what extent can the willingness to share personal information be predicted by trust in the stakeholders?) we conducted linear regression analysis for each data level at T1. Participants' perceived trust in

stakeholders significantly predicted their willingness to share personal information for each data level ($R_{adj}^2{}_{level1}$ = .451, $F(4,15) = 4.9$, $p = .010$; $R_{adj}^2{}_{level2}$ = .536, $F(4,15) = 6.5$, $p = .003$; $R_{adj}^2{}_{level3}$ = .616, $F(4,15) = 8.6$, $p < .001$). To share level 1 information, the grid operator could be identified as the most important stakeholder ($b = 1.35$, $p = .015$). In addition to the grid operator ($b = 1.76$, $p = .001$), the energy supplier ($b = 1.34$, $p = .008$) was identified as particularly important to share level 2 information. For level 3 information, no stakeholder could be identified. For the detailed regression coefficients see Table 2.

Table 2. Participants' perceived trust in the stakeholders as predictor of their willingness to share personal information at T1.

Predictor	*b*	*SE*	*T*	*p*
Level 1				
aggregator	.22	.16	.79	.437
energy supplier	.97	.29	2.03	.061
grid operator	**1.35**	**.34**	**2.74**	**.015**
vehicle manufacturer	.10	.17	.44	.663
Level 2				
aggregator	.01	.16	.02	.981
energy supplier	**1.34**	**.28**	**3.06**	**.008**
grid operator	**1.76**	**.33**	**3.91**	**.001**
vehicle manufacturer	.20	.17	.98	.343
Level 3				
aggregator	.16	.10	.72	.483
energy supplier	.34	.18	.84	.412
grid operator	.35	.21	.86	.405
vehicle manufacturer	.06	.11	.32	.752

Note. $N = 20$. All variables were assessed at T1. Most important data recipient for each data level are marked in bold.

5. Discussion

5.1. Summary of results

The results of our smart charging field trial showed that participants were most unwilling to provide level 3 information compared to level 2 and level 1 information (RQ1). This overall pattern in terms of serious concerns about deduced information and preferred stakeholders as well as the perceived trust remained stable over time (RQ2). As the sharing of level 1 and 2 information is considered as much less critical so that it is also readily shared with all stakeholders. Contrary, level 3 information should not be shared with any stakeholder (RQ3). However, participants' willingness to share personal information could be significantly increased if the trust in the involved stakeholders increases (RQ4).

5.2. Implication

Our findings are in the light of previous research. The differences between participants' willingness to share level 1, 2 and 3 information found by Döbelt, Kämpfe and Krems (2014) could be confirmed. We were also able to prove the importance of the data recipient postulated by Yang, Lee and Zo (2017). However, the positive influence of experience according to Schmalfuß et al. (2015) could not be confirmed for participants' willingness to share personal information. Maybe a period of three to eight weeks is not sufficient to detect the effects of this variable. However, participants' willingness to share personal information and also the perceived trust in stakeholders involved in smart charging seems to be stable constructs, which were little influenced by real-world experience (at least between T1 and T2). Unfortunately, the BEV and charging experience gain and thus the influence on the variables between vehicle handover and T1 remains unclear.

Nevertheless, participants' general willingness to share level 1 and 2 information with all stakeholders involved in the smart charging system must be critically questioned. A possible reason seems to be the lack of adequate problem awareness that level 3 information can be derived from level 1 and 2 data. Though, a problem awareness is required to act in a privacy-preserving manner: Only those who perceive their privacy as 'worth protecting' will engage respective behavior at all (Döbelt & Günther, 2021).

Furthermore, participant' previous experiences with the involved stakeholders seem to serve as a trust reference in the context of smart charging. For instance, a few participants who had uncomfortable experiences with the energy supplier (e.g., incomprehensible price increases) expressed more skepticism in the face-to-face interviews. And although the aggregator is a new player and has a rather unknown role, participants assumed that he was more likely to represent their interests. On the other hand, participants perceived the energy supplier and grid operator as more likely to have their economic interests.

Moreover, participants assumed that the vehicle manufacturer know best about the vehicle itself. Further, the direct contact provided by BMW during the vehicle handover and field trial was considered very valuable and positive by the participants. This possibility of having a personal contact person seems to have a significant – and positive – influence on trust building; even in times of increasing digitalization.

Thus, it is important to present involved stakeholders transparently to strengthen their image. All processes should be communicated clearly and comprehensibly to users. And the possibility of personal support also promotes trust-building.

5.3. Limitation and future research

Some methodological limitations have to be considered when interpreting our results to derive broader conclusions. First, the samples that participated in the field trial phases were not representative of the general population. Participants were more likely to be male, well-educated, and BEV-experienced.

Second, not being able to conduct a T2 interview in field trial phase 2 reduced the already very small sample size and limits the reliability and validity of the T2 results.

Third, different durations of the baseline and smart charging condition add noise to the data. The passing of time, different mobility and charging profiles of the participants, and random events that might have occurred throughout the field trial are very difficult to control for statistically, and cannot be discounted as possible sources of the effects that we found. These limitations have to be considered when interpreting results from naturalistic field trials comparable to ours with strong external validity.

Finally, no statement can be made about what specific kind of previous driving experience participants already had. Also, the influence of certain previous experiences (e.g. positive or negative) with the stakeholders involved and why trust differs, remains unclear.

Future research should address further predictors of privacy concerns and privacy-preserving behavior, also the relationship between individual differences (e.g. affinity for technology) could be part of future research questions.

6. Conclusion

Within the present contribution, we provide results from a field trial investigating smart charging in a real word setting. This improves previous research restricted to hypothetical smart charging situations, by creating a highly naturalistic environment that lets participants choose their times and modes to charge their BEVs. Thus, we were able to investigate the influence of real-world smart charging experience on participants` privacy concerns, assessed as their willingness to share personal information.

The strong and stable rejection of sharing level 3 information shows that users recognize a long-term risk potential for their privacy in the context of smart charging independent of the extent of experience. To reduce possible obstacles, we argue that the initial decision for privacy prevention should be anchored top-down by system designers from the very beginning; e.g., by considering *Privacy by Design guidelines* (Cavoukian, Polonetsky, & Wolf, 2010). Subsequently and bottom-up, users can clarify to what extent they want to be informed or control data sharing to trusted stakeholders, which is crucial for the willingness to share personal information and finally take part in smart charging.

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