Driving an EV with no opportunity to charge at home - is this acceptable?

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Abstract
In most field studies investigating acceptance of electric vehicles (EVs), participants could charge conveniently at home. Given the reality that EVs are often labelled a ‘perfect city car’ and city residents often do not possess their own garage or carport where charging would be possible, it is of special interest to determine if EVs are acceptable to those who depend entirely on the public charging infrastructure and if the evaluation of acceptability changes over time of EV usage.

Eighteen EV drivers in a 6-month field study relied on public charging stations in Berlin. Data were assessed at three data collection points (before EV acquisition, after 3 and 6 months of usage) and compared with a matched sample of 18 home-charging EV users in a comparable study. Results show that EV-related attitudes and purchase intentions did not significantly differ between the 2 groups at any point of data collection. Except for the general perception of EVs, no significant interaction effects of experience and charging circumstances were detected. Overall, we conclude that EVs also seem to be acceptable for city residents without private charging facilities. The implications for EV market expansion are evident.

Introduction
Electric vehicles (EVs, in this paper, EV is defined as pure battery electric vehicle that is powered only by electricity) represent a promising solution to rising CO₂ emissions (King, 2010). The German government aims to have 1 million registered electric vehicles on the road by 2020 (Die Bundesregierung, 2010). To reach this goal it is critical to have a large market for EVs. Therefore, it is important to determine the acceptability of EVs among likely consumers, particularly typical city residents who do not have a home-based charging option.

Charging circumstances and acceptance of EVs
EVs present additional considerations (e.g. limited driving range, charging) compared to conventional cars and various prejudices exist (Burgess, King, Harris, & Lewis, 2013). Research indicates that long charging duration (e.g. Hidrue, Parsons, Kempton, & Gardner, 2011) and unsatisfying charging infrastructure (e.g.,

Egbue & Long, 2012) are just a few of the barriers to purchase decisions regarding EVs.

In a 6-month EV field study in which drivers could charge at home, drivers perceived the EV positively, were satisfied with the EV and evaluated it as useful throughout the study (Bühler, Cocron, Neumann, Franke, & Krems, 2013). After experiencing the EV, general evaluation of EVs and intention to recommend an EV were even more positive and likely, respectively. At the same time, they perceived charging, including handling of the cable and infrastructure, as less of a barrier and the home-charging opportunity was even reported as ‘great’ advantage by some participants after gaining EV experience. In sum, those users who experienced charging as easy were not perturbed by the charging duration and even preferred it compared to refuelling a conventional car (Franke & Krems, in press). However, in a 7-day trial, British drivers relying on public charging stations and ‘normal’ household sockets for recharging their plug-in hybrid electric car (PHEV) or EV (Graham-Rowe et al., 2012) stated that charging is simpler than expected, but still needs planning or even changing lifestyles due to long charging times and lack of infrastructure. Waiting for the car to be fully charged was considered a major disadvantage, because it reduces flexibility. PHEV and EV drivers also mentioned safety concerns while charging in public (e.g., EV drivers are quite vulnerable, because strangers can easily unplug the charging cable), whereas charging at home was highly valued by some participants. Consistent with these findings, home-charging was found to be an important advantage of EVs in further studies (e.g., Jabeen, Olaru, Smith, Braunl, & Speidel, 2012). In sum, charging an EV seems particularly suitable if EV drivers can charge at home. Yet, the typical inner city-resident has no private parking space at home where an EV can be easily charged. To our knowledge, there are no published studies that directly compare EVs acceptance given different charging circumstances.

**Perception and acceptance of EVs**

Different variables, for instance, attitudes (e.g., Gärling & Johansson, 1999), intention to recommend (e.g., Jabeen et al., 2012) and purchase intentions (e.g., Carroll, 2010), have been used to assess acceptance of EVs. Following Schade and Schlag’s definition (2003) that acceptance is a person’s attitudinal and behavioral reaction after experiencing a product, attitudes and behavioral intentions need to be assessed in order to make conclusions about acceptance. In the present study, attitudes are defined as “predispositions to respond, or tendencies in terms of ‘approach/avoidance’ or ‘favourable/unfavourable’” (p. 2, Van der Laan, Heino, & De Waard, 1997) towards a product. Apart from attitudes and behavioural intentions, some authors investigated general perception of EVs (e.g., Burgess et al., 2013) to draw conclusions about how EVs are evaluated by different groups of potential car buyers. In sum, general perception of EVs, attitudes, intention to purchase and to recommend should be investigated in order to gain a deeper insight into how EVs are evaluated and accepted.
Study objectives

The objective of the present study was to investigate if there are significant differences in perception, attitudes, and behavioral intentions between EV users that can charge at home and EV users that mainly charge at public charging stations.

On the basis of the reviewed literature, it can be concluded that home-charging is perceived as an advantage (e.g., Bühler et al., 2013) and some concerns exist regarding charging in the public (Graham-Rowe et al., 2012). Furthermore, Jabeen et al. (2012) argue that the perceived convenience of home-charging is a significant predictor of acceptance. Relying on public charging stations alone is probably less convenient, more challenging regarding planning and could introduce further problems (e.g., parking space with the charging station is occupied). Therefore, we hypothesize that drivers who rely on public charging perceive EVs less positively (H1a), show less positive attitudes (H1b), lower intention to recommend (H1c) and lower purchase intentions (H1d) than home-charging EV drivers.

In previous studies, it was shown that evaluation of EVs is more positive (e.g., Carroll, 2010) and intention to recommend is higher (e.g., Bühler et al., 2013) after experiencing an EV. Although purchase intentions mostly did not change after real-life experience, we want to investigate if that is also the case for drivers charging in public. Thus, our second research question is if changes in perception and acceptance of EVs depend on charging circumstances.

Drivers who could charge at home seem to highly value home-charging and perceive charging as less of a barrier after experiencing an EV (e.g., Bühler et al., 2013). As public-chargers do not have the advantage of home-charging and might experience additional challenges while charging in public, it is expected that the changes in perception (H2a), attitudes (H2b), as well as behavioral intentions to recommend (H2c) and purchase (H2d) are not as positive as for home-charging EV drivers.

Method

Study design

The present paper aimed to investigate the influence of charging condition (home-charging [HC] vs. public-charging [PC]) on EV perceptions. Therefore, data of two comparable samples selected out of two large scale field studies (first study: Cocron et al., 2011; Krems, Weinmann, Weber, Westermann, & Albayrak, 2013; second study: Krems et al., 2011) conducted in the Berlin metropolitan area were analyzed. In the first large scale study, EV drivers were equipped with home-charging stations. In the second study, 20 participants were required to charge in public within walking distance of their home or work.

In order to match samples regarding their daily mobility, and therefore their prospective charging needs, data were collected via travel diary (i.e., person-based records of all trips in one week; Franke & Krems, 2013) before EV delivery were analyzed. Out of the 20 public-charging-participants, 18 stated at T1 that they used
public charging stations for >85% of charging events (the remainder used the normal socket). Based on their median daily covered distances, 18 home-charging users were selected from the second usage phase of the MINI E 1.0 project, because they drove the EV from spring to the end of summer, like the public-charging participants. Finally, two samples with similar median daily covered distances were selected (Table 1): home-charging users (HC) and public-charging users (PC).

In both studies, data were assessed three times: before receiving the EV (T₀), after 3 months (T₁) and when returning the EV after 6 months (T₂).

Participants

In sum, data of 36 participants (32 male, 4 female) were analyzed. These were on average 47.4 (SD = 11.2) years old. The majority of participants were highly educated (94% held a university degree). Participants lived in two adult (47%), three or more persons (42%), and single (11%) households. The majority of participants had a second car available during the study (one additional car: 49%; two: 23%; three or more: 9%). There were no significant differences between the two subsamples in age, gender, number of persons and cars per household (see Table 1). Participants in the PC group charged significantly less often than HC group (Table 1) and the remaining range when plugging in was significantly lower (Table 1).

<table>
<thead>
<tr>
<th>variables</th>
<th>HC</th>
<th>PC</th>
<th>test of significant differences</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (in years)</td>
<td>M (SD)</td>
<td>49.3 (10.5)</td>
<td>45.3 (11.8)</td>
<td>t(34) = 1.08, p = .289</td>
</tr>
<tr>
<td>Gender</td>
<td>Number</td>
<td>16 m, 2 f</td>
<td>16 m, 2 f</td>
<td>-</td>
</tr>
<tr>
<td>Persons per household</td>
<td>M (SD)</td>
<td>3.2 (1.4)</td>
<td>2.5 (1.4)</td>
<td>t(34) = 1.43, p = .163</td>
</tr>
<tr>
<td>Number of cars</td>
<td>M (SD)</td>
<td>2.4 (0.7)</td>
<td>1.9 (1.0)</td>
<td>t(32) = 0.67, p = .506</td>
</tr>
<tr>
<td>Median of daily covered distances (in km)</td>
<td>M (SD)</td>
<td>27.9 (9.9)</td>
<td>24.7 (16.4)</td>
<td>t(34) = 0.72, p = .479</td>
</tr>
<tr>
<td>Number of charging events per week¹</td>
<td>M (SD)</td>
<td>3.4 (1.2)</td>
<td>2.0 (1.1)</td>
<td>t(31) = 3.49, p = .001</td>
</tr>
<tr>
<td>Remaining range when plugging in (in km²)</td>
<td>M (SD)</td>
<td>81.1 (34.4)</td>
<td>57.2 (28.7)</td>
<td>t(31) = 2.17, p = .038</td>
</tr>
</tbody>
</table>

Note. N = 18 for each group, ¹ Data from travel diary (Franke & Krems, 2013a), ² Data from charging diary (Franke & Krems, 2013b): N_HC = 16, N_PC = 17.

Scales and assessments

First, a scale regarding General Perception of EVs (Bühler et al., 2013) was used at all points of data collection (.64 ≤ Cronbach’s α ≤ .82). The scale includes items that address different EV-related topics, such as the suitability of EVs for daily routines
or the role of EVs in our transportation systems. A 6-point Likert scale from 1 (completely disagree) to 6 (completely agree) was applied for this scale, as well as for all intention items. Second, the Van der Laan Acceptance Scale (Van der Laan et al., 1997), an instrument that contains two dimensions (Satisfaction and Usefulness), was used to assess acceptance. Four of nine semantic differentials (ranging from -2 to 2) comprised the Satisfaction scale (.72 ≤ Cronbach’s α ≤ .83). The other five items represent the Usefulness scale (.70 ≤ Cronbach’s α ≤ .81). Third, one item was utilized to assess the Willingness to Recommend an EV (Bühler et al., 2013). Fourth, three items assessed purchase intentions. As in Bühler et al. (2013), one item assessed the Willingness to Purchase and two items assessed the Willingness to Pay (.62 ≤ Cronbach’s α ≤ .72). The two Willingness to Pay items were anchored on realistic leasing rates (650€ per month) and purchase prices for EVs (1/3 more) that are comparable to the test vehicle in performance.

Test Vehicle

The test vehicle was a converted MINI Cooper, the MINI E (two-seater, 150 kW power, 220 Nm torque, top speed of 150 km/h, range of approximately 168 km on a single charge under ‘normal driving conditions’). A lithium-ion battery pack stored the power and was rechargeable using 32 and 12 Ampere. Besides using the public charging stations that were available in Berlin, EV users in the first study could recharge at home using a “wallbox”. Users in the second study were required to charge at public charging stations close to their permanent place of residence or work. An empty battery took approximately four hours (32 Ampere) to charge. For more details see Keinath and Schwalm (2013).

Results

For analyzing the data, mixed ANOVAs were calculated. Effect sizes were interpreted according to Cohen (1988).

General perception

EV drivers had a positive view of EVs (Figure 1). The PC group (M = 4.69, 95% CI [4.41, 4.98]) and the HC group (M = 4.69, 95% CI [4.46, 4.92]) perceived EVs positively and perception did not differ significantly between groups, F(1, 28) = 0.00, p = .992, η²p = .000.

As displayed in Figure 1, changes in the evaluation of EVs were different in the two groups. At T₀, the PC group showed lower mean scores in the beginning of the study than the HC users. After 3 months, HC users’ perceptions did not differ significantly from T₀ whereas PC users viewed EVs more positively. At T₂, both groups showed their highest approval and had similar means. Results revealed a significant medium sized interaction effect of experience and charging condition, F(2, 56) = 3.34, p = .042, η²p = .107. As the increase for the PC group from T₀ (M = 4.23, 95% CI [3.84, 4.63]) to T₂ (M = 4.98, 95% CI [4.68, 5.29]) is higher than for the HC users (T₀: M = 4.69, 95% CI [4.19, 4.83]; T₂: M = 5.01, 95% CI [4.76, 5.26]), the results did not support hypothesis H2a.
Participants were on average satisfied with the EV and evaluated the vehicle as useful (Figure 2). The Satisfaction scores of the PC group ($M = 1.31$, $95\% CI [1.01, 1.55]$) were lower than the scores of the HC group ($M = 1.31$, $95\% CI [1.32, 1.78]$), but this difference was not significant, $F(1, 33) = 2.81$, $p = .103$, $\eta^2_p = .08$. For Usefulness scores a similar pattern is displayed in Figure 2 (HC: $M = 1.31$, $95\% CI [1.07, 1.55]$, PC: $M = 1.31$, $95\% CI [0.90, 1.39]$) and again, no significant effect was observed, $F(1, 33) = 1.37$, $p = .250$, $\eta^2_p = .04$. These results do not support hypothesis H1b.

Inconsistent with hypothesis H2b, descriptive statistics displayed in Figure 2 did not appear to indicate an interaction effect. This visual impression was supported by the results of a mixed ANOVA; no significant interactions were found, Satisfaction – $F(2, 66) = 0.46$, $p = .634$, $\eta^2_p = .01$ and Usefulness – $F(2, 66) = 0.87$, $p = .868$, $\eta^2_p = .00$. 
Intention to recommend

EV drivers were willing to recommend the EV (Figure 3). The PC group ($M = 4.77$, 95% CI [4.43, 5.01]) was on average less willing to recommend an EV than the HC group ($M = 5.13$, 95% CI [4.81, 5.45]), but this difference was not significant, $F(1, 33) = 2.55$, $p = .120$, $\eta^2_p = .08$, and therefore, hypothesis H1c was not supported. In both groups, the intention to recommend was higher after EV experience (Figure 3). The increase was similar and results revealed no significant interaction of experience x charging condition, $F(2, 66) = 0.60$, $p = .554$, $\eta^2_p = .02$.

Figure 3. Results of Willingness to Recommend.

Note. $N_{HC} = 18$, $N_{PC} = 17$. 6-point Likert scale.

Purchase intentions

On average, participants were undecided as to whether they would purchase an EV after the study (Figure 4, left) and were not willing to pay the given prices for an EV (Figure 4, right).

Figure 4. Results of Willingness to Purchase (left) and Willingness to Pay (right).

Note. $N_{HC} = 18$, $N_{PC} = 17$. 6-point Likert scale.
The HC group ($M = 3.87, 95\% CI [3.16, 4.58]$) was on average more willing to purchase an EV than the PC group ($M = 3.57, 95\% CI [2.84, 4.30]$), but this difference was not significant, $F(1, 33) = 0.49, p = .491, \eta^2_p = .01$. PC users ($M = 2.99, 95\% CI [2.44, 3.53]$) were on average less willing to pay than users that could charge at home ($M = 3.32, 95\% CI [2.77, 3.87]$). Again, results of the ANOVA revealed no significant effect of charging condition, $F(1, 34) = 1.03, p = .318, \eta^2_p = .03$. Overall, none of the results supported hypothesis H1d.

Hypothesis H2d was also not supported by the results. With increasing experience, there was no between-group difference on level of Willingness to Purchase an EV. Again, no significant interaction was found, $F(1.675, 55.275) = 0.38, p = .650, \eta^2_p = .01$. Although, the Willingness to Pay seems to decrease more for the PC group (Figure 4, right), the mixed ANOVA showed that there is no significant effect for the interaction of experience x charging condition, $F(1, 34) = 0.38, p = .539, \eta^2_p = .01$.

**Discussion**

In the present study, data from two comparable samples from two large-scale field studies were analyzed in order to investigate whether EVs are acceptable to users when they cannot charge at home and if there are differences in acceptance due to charging condition. As the typical inner city-resident has no private parking space at home where an EV can be conveniently charged, this question is highly important for predicting potential EV acceptance and expansion of market share.

Different indicators of acceptance (i.e., attitudes, intention to recommend, purchase intentions) were assessed and a significant effect of home charging versus public charging (charging conditions) was not observed. Although results were not significant, the strength of effects is worth discussing, especially when taking into account the small sample size. Charging condition only shows non-significant medium effects on satisfaction and the intention to recommend EVs. The rest of the effects were small. Therefore, the effect sizes do not indicate that there is a large difference between the potential acceptance of EVs for consumers who can charge at home and consumers who can only recharge their EVs at public charging stations. However, one difference between the groups was clear: home-chargers charge more often than public-chargers. At the same time, the remaining range in EVs of public-chargers is much lower than of EVs of home-chargers. One possible explanation is that public-chargers try harder to fully discharge the battery before recharging, because the public charging procedure requires more effort.

Our second research question was if changes in perception and acceptance are different for users who have to charge under different charging conditions. Results indicate that there is an interaction effect of experience and charging condition on the EV perception. However, this effect suggests that changes over time are stronger for participants who charge in public. Moreover, the observed effect was opposite to that which was hypothesized (H2a: for public-chargers changes in perception were expected to be not as positive as for home-charging EV drivers). These findings highlight another interesting point – when it comes to changing perceptions and prejudices regarding EVs, experiencing an EV that can only be charged in public
might be even more important than experiencing an EV with private charging facilities. However, given the fact that there were many missing values and the number of analyzed participants was small, data should be carefully interpreted and this interaction effect should be further investigated. Furthermore, results regarding acceptance do not suggest an interaction effect of experience and charging conditions. Significant interaction effects were not observed for either attitudes or behavioural intentions. Additionally, effect sizes were small.

The results observed here may not be generalisable to the population of German car drivers as a whole, because early adopters were most likely overrepresented in the presented field studies (Rogers, 2010). Nevertheless, studies with early adopters provide important implications for the adoption process of new products.

Overall, the presented results are the first empirical evidence suggesting that access to home charging stations might not dramatically influence EV acceptance. Thus, the lack of an opportunity to charge at home should not reduce potential consumers’ intention to purchase an EV. Yet, the sample in this study had relatively low daily mileages. Generalisability to populations with higher daily mileage requirements (e.g., commuters) should be studied in future research.

**Acknowledgements**

The two projects were funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. We thank our consortium partners Vattenfall Europe AG (Dr. C. F. Eckhardt and F. Schuth) and the BMW Group (Dr. M. Hajesch, Dr. A. Keinath, Dr. R. Vilimek and Dr. M. Schwalm) who gave us the opportunity to conduct our research.

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