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Fast-charging station here, please! User criteria for electric vehicle fast-charging locations

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ABSTRACT

The present research reports an empirical study targeting the analysis of evaluation criteria for fast-charging locations regarding both position and concrete realization. Involving both current and potential users of electric mobility technology discovers criteria for public acceptance as well as a description of possible drawbacks. A questionnaire study was carried out in which participants were asked to provide information about desired locations as well as their requirements for both the charging process and charging stations. In a second step, the evaluation criteria based on earlier studies were ranked. An overall consensus could not only be detected in previous focus group discussions but also in this quantitative approach. Outcomes show that motorway service stations, shopping facilities, and traditional fuel stations can be visualized as potential fast-charging station locations. It is shown that users' willingness to accept waiting times or detours cannot be expected. Dual use, reliability, and accessibility prove to be very important criteria for site evaluation of charging locations. In relation to user diversity, significant differences in terms of both prior use of battery electric vehicles and gender as well as occasional variations for age were found.

1. Introduction

Major challenges like global warming mark the reduction of CO_2-emissions as a highly important goal (The Royal Society, 2005). The production of greenhouse gases is caused and accelerated by humans; e.g., air pollution is partly based on people's use of combustion engines (Umweltbundesamt, 2014). New technologies can provide an opportunity to change running systems and define new strategies to create a healthier and more sustainable way of living without limiting the full range of mobility we need every day.

With the help of technological development, the opportunity emerges to reduce greenhouse gas emissions by adopting new ways of traveling. One possible solution that obtained considerable support is traveling by battery electric vehicles (BEVs). The federal government of Germany postulates in its "National Electro Mobility Development Plan" of 2009 that the number of electric cars in use should be increased to at least 1 million vehicles by 2020 (Bundesregierung, 2009). Sustainable mobility and electric cars did receive a mostly positive assessment from the public, as several surveys show (Hoffmann, Hinkeldein, Graff, & Kramer, 2014; Ziefle, Beul-Leusmann, Kasugai, & Schwalm, 2014). It is expected that this technology will progressively gain market share in the next few years (Plötz, Gnann, & Wietschel, 2012; Kihm &

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Trommer, 2014). The car industry has seen the potential of this solution and already addressed it by developing a new generation of battery electric vehicles that provide a range of up to 150 km, like the BMW i3, the VW e-Golf, or the Nissan Leaf.

Recent research did elaborate the potential of electric mobility from different angles like the technical (Frischknecht & Flury, 2011; Werther & Hoch, 2012), economic (Kley, Lerch, & Dallinger, 2011; Hackbarth & Madlener, 2016), environmental (Sourkounis, Ni, & Broy, 2011), and psychological (Ziefle et al., 2014) point of view. Unfortunately, there are still challenges that need to be taken care of such as the time needed to recharge the batteries (Hidrue, Parsons, Kempton, & Gardner, 2011) and the limited range of BEVs in comparison to conventional vehicles with combustion engines (Jarass, Frenzel, & Trommer, 2014; Barth et al., 2016). Another barrier stems from the currently still fragmentary charging network (Egbue & Long, 2012; Halbey, Kowalewski, & Ziefle, 2015). Both the limited range of BEVs and the limited charging options are presently still major impediments to a fast adoption of electromobility and contribute to the so-called range anxiety, a form of psychological stress, which is the object of research in several studies, dealing with driving BEVs in critical range situations (Rauh et al., 2015), the concept of range comfort zones (Franke, Günther, Trantow, Rauh, & Krems, 2014), or the user's charging behavior (Franke and Krems, 2013; Bühler et al., 2013).

Nevertheless, electric vehicles can be valid alternatives for traditional automobiles (Claas, Marker, Bickert, Linssen, & Strunz, 2010; Winter, Kunze, & Lex-Balducci, 2010). In Germany, the average range driven is 43 km per day, which matches the possible range of BEVs (Follmer & Lenz, 2008). This implies that daily trips to work, grocery stores, or visits to a nearby city are covered by current battery capacities (Jarass et al., 2014). Other studies showed similar results on the range of BEVs being sufficient for average daily travels (Morrow, Karner, & Francfort, 2008; Pearre et al., 2011). This means that users could already replace their combustion engine vehicle with an electric vehicle with limited range without substantial adjustments of their mobility behavior. However, long-distance traveling beyond the usual daily trips is still a major challenge for battery electric vehicles, because it requires recharging during the trips.

Therefore, fast-charging, which allows the driver to recharge the battery to 80% of its capacity in less than 30 min, might be a good solution to cope with both the necessity to travel long-distances and long recharging times. However, especially in Germany, there is still a lack of fast-charging opportunities since the implementation of the charging network is still in its infancy. Additionally, there is yet a lack of knowledge about user requirements related to the expansion of said network and the positioning of specific charging stations in particular. Previous approaches to factor in the user during the planning process of charging networks are usually limited to discrete-choice and origin–destination models (Bernardo, Borrell, & Perdiguero, 2013; Namdeo et al., 2014) or activity-based approaches (González et al., 2014; Shahraki, Cai, Turkay, & Xu, 2015) that cannot fully cope with the users' needs and requirements regarding concrete location decisions.

Concerning the location evaluation by users, it is necessary to take user diversity, especially prior experience with BEVs, into account for several reasons: For example, Bühler et al. already revealed that experience with electric vehicles has a significant, positive effect on the general perception of electromobility (Bühler, Cocron, Neumann, Franke, & Krems, 2014). Furthermore, Rauh et al. showed that BEV driving experience reduces range anxiety (Rauh, Franke, & Krems, 2014) and users become more comfortable with both the lower range levels of BEVs and undertaking longer trips with their electric vehicles (Franke, Cocron, Bühler, Neumann, & Krems, 2012; Franke, Rauh, Günther, Trantow, & Krems, 2015), which is likely to impact the users' requirements for the locations of charging stations. This may result in problems regarding the planning of charging infrastructure: On the one hand, the locations and concrete arrangement of charging stations should encourage users, who are accustomed to cars with combustion engines, to switch to BEVs. That is, the charging network should be structured in such a way as to ensure the charging infrastructure is no longer perceived as an impediment to adoption by potential users. On the other hand, the charging stations have to fit the requirements of experienced BEV-drivers and those may differ from the needs and wishes of prospective users. These possible differences regarding the evaluation of charging locations have to be explored to plan and construct a both demand-driven and technology disseminating charging network that satisfies both user groups.

Also, effects of age and gender have to be addressed, because previous studies revealed that these user factors, among others, have effects on users' technology acceptance in other infrastructure contexts, like the placements of electric pylons (Zaunbrecher, Arning, Özalay, Natemeyer, & Ziefle, 2015) or communication network masts (Arning, Kowalewski, & Ziefle, 2014), and on decision-making processes in general (de Acedo Lizarraga, de Acedo Baquedano, & Cardelle-Elawar, 2007). Although age and gender effects are often mediated by underlying factors, it is reasonable to consider them directly in this context, since normally, next to vehicle ownership and traffic data, only basic demographic data on the population within regional areas are available and provide the data basis during city and transport planning processes.

In order to identify at which locations users would expect and prefer fast-charging stations and to reveal the underlying evaluation criteria, qualitative research studies have been carried out. Halbey et al. tried to contextualize the topic in focus group studies by concrete placements of stations on maps (Halbey et al., 2015). Further, subsequent discussions were conducted to disclose reasons for the placement. Thereby, eight main evaluation criteria for fast-charging locations regarding both position and concrete realization were identified: dual use of time and route, habit compatibility, accessibility, visibility, reliability, safety, connection to the public transportation network, and necessity (Philipsen, Schmidt, & Ziefle, 2015).

However, a quantitative analysis of the identified criteria and their relative weighting was still pending. Therefore, the present study aims at both exploring which evaluation criteria are important and necessary for localization decisions during the planning and establishment of a fast-charging network and revealing the criteria's relationships to user diversity in terms of the variables gender, age, and experience with BEVs.

2. Method

An online questionnaire study was conducted to gather user requirements related to the charging process, the preferred locations for fast-charging stations, as well as the weighting of the applied evaluation criteria. The methodological approach is constructed as follows: First, the questionnaire will be presented. Second, the data preparation and evaluation methods will be briefly introduced. Last, the gathered sample will be described in detail.

2.1. Questionnaire

The developed questionnaire consisted of three main parts. First, personal data were collected. These include demographic data (age, gender, etc.); information regarding occupation, income, and residential area. Details about (e-)vehicle use, the general attitude towards electromobility, and charging possibilities including the possibility to use fast-charging were also collected. Second, the participants received a scenario-based introduction to the fast-charging technology to guarantee a common minimum knowledge. The used scenario stated a range increase of 100 km after a fast-charging time of 25 min. Third, the following user requirements were gathered:

2.1.1. Locations of charging points

Six-point Likert scales ranging from "not important" to "very important" were used to measure where charging stations should be placed from a user perspective. The sites to be evaluated were derived from (Philipsen et al., 2015): (1) shopping facilities, (2) leisure facilities, (3) motorway service stations, (4) gas stations, (5) workplaces, and (6) educational institutes.

2.1.2. Users' requirements related to the charging process

In addition to the preferred charging locations, the participants' requirements relating to the charging process itself were gathered. First, the willingness to accept potential drawbacks was polled. A distinction was made between (1) the willingness to make detours for immediate access to a charging place, (2) the willingness to accept waiting times before charging, and (3) the willingness to move the own car after completing the charging process to free the terminal. Some requirements concerning the design of the charging station itself were also surveyed. Participants had to express their opinions toward the required business hours, illumination, and roofing in terms of weather protection of the charging places. Again, six-point Likert scales were used to obtain the participants' attitudes ranging from "I don't agree at all" to "I fully agree." Both positively and negatively formulated statements were used to avoid a bias in answers, e.g., "I'm willing to accept waiting times due to occupied charging stations" and "I would like to charge, without having to wait for a free charging station."

2.1.3. Criteria for site evaluation

Finally, the participants were asked to rank seven evaluation criteria by relevance for their own assessment of charging sites, also derived from (Philipsen et al., 2015): (1) dual use (of charging time and routes), (2) reliability, (3) accessibility, (4) habit compatibility, (5) safety for the driver and passengers, (6) safety for the car, and (7) connection to public transport. An overview of the criteria and related descriptions to introduce the items can be found in Table 1.

A structured overview of the current survey design including the gathered variables is shown in Fig. 1. All Likert scales used in the questionnaire to collect users' attitudes intentionally had no neutral answer option. An even-numbered scale was used to avoid different interpretations of mid-point and to compel participants to make more differentiated choices. Furthermore, the study's topic is not highly sensitive, which makes a neutral response option not mandatory. The calculated, theoretical neutral approval rating was 2.5 (min = 0, max = 5). All mean and standard error values were rounded to two decimals for reasons of clarity.

2.2. Participant acquisition, data preparation, and analyses

To include not only active e-mobility users, who already utilize the available charging infrastructure, but also potential future users, who might see the current (lacking) charging infrastructure as a barrier to adopting e-mobility technology, drivers of battery electric vehicles as well as drivers of internal combustion engine vehicles were surveyed. Participants were

Table 1
Evaluation criteria for charging locations and the related introductory descriptions.

Criterion	Description
Dual use	"Here I can combine the charging with a daily transaction/activity."
Reliability	"There are plenty of charging stations available and the parking time usually does not exceed the charging time, so I can be sure to find a free charging space."
Accessibility	"The place is centrally located and easily accessible from many directions."
Habit compatibility	"It is already a habit to visit the place. There is no need for acclimatization."
Safety for driver and passengers	"Here I feel (even at a late hour) safe from crime while my car charges."
Safety for the car	"Here I can feel safe to recharge and park my vehicle."
Connection to public transport	"From here, I have good access to the public transportation network."

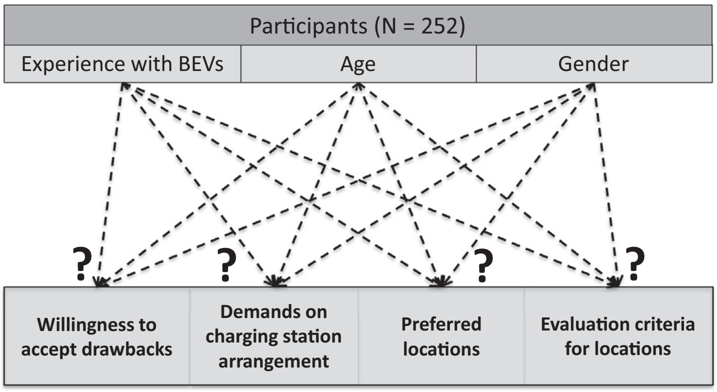

Fig. 1. Structural figure of current survey design.

acquired in the personal environment of the authors, at the university, as well as in (online-)communities dealing with both electromobility and general automotive topics. There was no reward for participating.

In total, 394 participants started to fill in the questionnaire. Dropouts in terms of participants who already quit during or immediately after the section on personal data have been removed during the preparation of the data set. Furthermore, 40 participants, who stated that they have absolutely no interest in electromobility at all, were excluded from analysis to focus on current and potential future users.

The remaining 252 data sets were analyzed by descriptive analysis and, with respect to the effects of user diversity, analyses of statistical interference. Two-tailed tests were used for significance testing and the level of significance was set to $\alpha = .05$. Although the sample size was not small, negatively skewed, light-tailed distributions were found for most dependent variables. Furthermore, subgroups of the sample showed heteroscedasticity to a small extent. Therefore, statistical methods that are based on the comparison of standard means were not appropriate. To avoid problems with median-based methods caused by tied values, trimmed means ($\overline{X_t}$) with a trimming of 20% were used as measures of location (Wilcox & Keselman, 2003; Wilcox, 2012). The robust Yuen–Welch-method (Yuen, 1974) was applied to compare groups and the results were additionally verified with bootstrap-t methods based on Yuen's procedure (Wilcox, 2011). Kendall's τ was used to analyze correlations and the Mann–Whitney test for ranked data.

2.3. Participants

A total of $N = 252$ participants completed the survey and stated that they were interested in electromobility. The mean age was 39.22 years (SD = 12.20) and ranged from 19 to 75 years (Mdn = 38.50). Age was non-normally distributed but skewed right (bimodal) with a skewness of 0.30 (SE = 0.16) and kurtosis of −0.97 (SE = 0.31). 184 (73.0%) participants were male and 68 (27.0%) were female. 47.6% ($n = 120$) reported a university degree as their highest achieved level of education. 14.7% ($n = 37$) had completed a vocational training while further 26.5% ($n = 67$) answered to have the A-level. The remaining participants reported a vocational diploma, a secondary school certificate, or a doctor's degree. Asked about the possibility of charging an electric vehicle at home, 58.4% ($n = 146$) indicated to be able to do so; 41.6% ($n = 104$) did not have this option. Charging an electric vehicle at the workplace would be possible for 29.1% ($n = 72$) of the participants, 52.2% ($n = 129$) would not be able to do so, and 18.6% ($n = 46$) did not know if they could. Concerning annual mileage, 71.0% of the participants reported to drive more than 10,000 km per year.

2.3.1. BEV users

Almost a third (31.3%, $n = 79$) reported to use an electric vehicle. 75 of them used a BEV as first or second private car, while 13 use a BEV as company car. 70 users gave detailed information about their cars' connector types: 51.4% ($n = 36$) were equipped with fast-charging compatible plugs, like CCS, CHAdeMO, or Tesla-Supercharger, while 38.6% ($n = 34$) were limited to slow charging speeds. The typical e-vehicle user in the present sample is male (97.5%, $n = 77$), has an average age of 43.81 years (SD = 10.02), is rather educated (89.9% ($n = 71$) with A-level or higher), uses his electric vehicle on a daily basis (73.4%, $n = 58$), achieves an annual mileage of more than 10,000 km (76.0%, $n = 60$), and is able to drive an average range between 100 and 150 km per battery charge (67.1%, $n = 53$). Therefore, the present e-vehicle user does not deviate much from early adopters of electromobility in Germany as specified by Jarass et al. (2014) or Plötz, Schneider, Globisch, and Dütschke (2014).

3. Results

This section presents the results of the statistical evaluation and is structured as follows: First, the results concerning locations of charging points will be shown. Second, the results of user conditions concerning the charging process will be described. Finally, a ranking of the derived criteria for site evaluation will be presented.

3.1. Locations of charging points

Fig. 2 shows the evaluation of different possible locations for charging points. All locations received rather high approval ratings.

Motorway service stations ($\overline{X_t} = 4.95$, SE = 0.04) are perceived as the most important locations for recharging opportunities. Charging points at *workplaces* ($\overline{X_t}$ = 3.96, SE = 0.13), *gas stations* ($\overline{X_t}$ = 3.93, SE = 0.13), and *shopping facilities* ($\overline{X_t}$ = 3.86, SE = 0.12) were rated almost equally and also considered as very important. *Leisure facilities* ($\overline{X_t}$ = 3.07, SE = 0.09) and *educational institutions* ($\overline{X_t}$ = 3.01, SE = 0.13) received the lowest ratings, although they were still desired.

When taking prior experience with battery electric vehicles into account, Fig. 3 shows that both BEV users and interested non-users prioritize *motorway service stations* and *gas stations* as important locations for fast-charging stations. While no significant differences based on e-vehicle use were found for these sites, all other locations were considered significantly more important by the non-users. Regarding *leisure facilities*, the differences between the stated importance levels were rather low but still significant ($t_{Yuen}(84) = 1.992$, $p = .050$, $\sigma_t = .21$). Similarly, users and non-users differed in their average importance rating with regard to *shopping facilities*. Although both groups evaluated these locations as important, the difference was significant with $t_{Yuen}(82) = 4.269$, $p = .001$, $\sigma_t = .35$. The level of importance of the aforementioned locations differs between the groups but shows comparable trends regarding the general assessment. In contrast, *workplaces* and *educational facilities* got fundamentally different ratings by users and non-users. *Workplaces* as suitable locations for fast-charging infrastructure were very important to non-users, while BEV users had a rather neutral opinion ($t_{Yuen}(53) = 4.483$, $p = .001$, $\sigma_t = .48$).

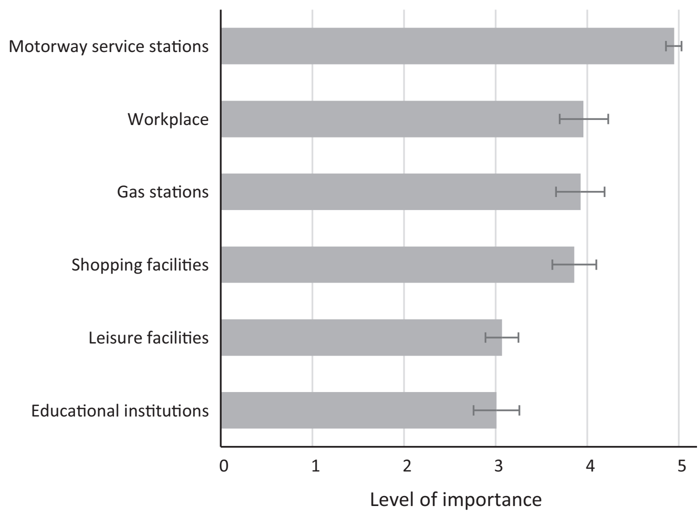

Fig. 2. Average importance of different locations for charging points ($\overline{X_t}$, min = 0, max = 5) and related 95.0% CI.

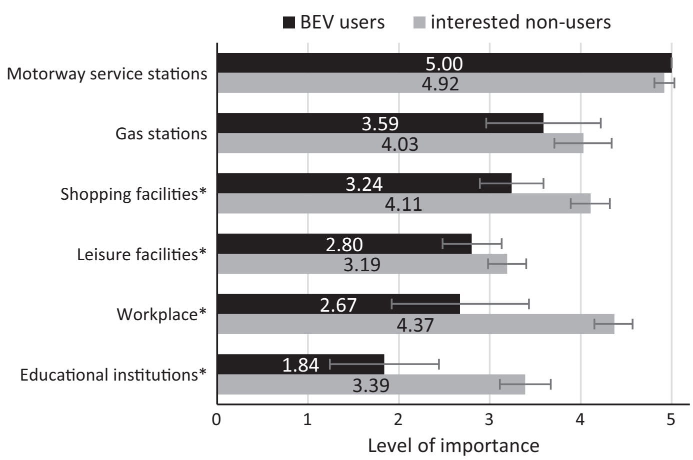

Fig. 3. Average importance of different locations for charging points ($\overline{X_t}$, min = 0, max = 5) and related 95.0% CI depending on e-vehicle use (∗ = significant difference).

The difference became even more distinct regarding *educational facilities*: Non-users rated them as important, whereas users considered them as rather unimportant locations. This difference was significant with $t_{Yuen}(63) = 4.743$, $p = .001$, $\sigma_t = .57$.

A further distinction between e-vehicle users whose cars are capable of fast-charging and those who are limited to slow charging speeds revealed no significant differences concerning the evaluation of potential locations for fast-charging infrastructure.

However, gender and age had significant effects on the evaluation of all locations for charging points. As shown in Fig. 4, all locations were rated higher by women than by men. Especially *gas stations* ($t_{Yuen}(144) = 5.657$, $p = .001$, $\sigma_t = .47$), *shopping facilities* ($t_{Yuen}(102) = 3.251$, $p = .002$, $\sigma_t = .37$), and *educational facilities* ($t_{Yuen}(103) = 3.291$, $p = .001$, $\sigma_t = .33$) were significantly preferred by women than men, with small to medium effect sizes. Furthermore, charging points at *leisure facilities* ($t_{Yuen}(118) = 2.259$, $p = .026$, $\sigma_t = .19$), *workplaces* ($t_{Yuen}(119) = 2.520$, $p = .013$, $\sigma_t = .24$), and *motorway service stations* ($t_{Yuen}(109) = 2.163$, $p = .033$, $\sigma_t = .20$) were more important to women than men. However, the effect sizes were rather small regarding the rating of these potential charging locations.

In contrast, age had a significant effect on the evaluation of different locations only in one case: It was positively and significantly related to the rating of *shopping facilities* as possible locations for charging stations, $\tau = .10$, $p = .041$.

3.2. Users' requirements for the charging process

The results of conditions for the charging process will be presented starting with the participants' willingness to accept drawbacks. As shown in Fig. 5, *willingness to make a detour* ($\overline{X_t} = 3.47$, SE = 0.09) was the most accepted factor; *vacating the parking lot* ($\overline{X_t} = 2.22$, SE = 0.10) was slightly rejected and *accepting waiting times* ($\overline{X_t} = 1.07$, SE = 0.07) was strongly rejected.

Prior experience with BEVs had significant effects on *willingness to make a detour* and *willingness to vacate the parking lot* after finishing charging. BEV users showed a higher willingness to make detours to reach a charging location ($\overline{X_t} = 3.94$, SE = 0.15) than non-users ($\overline{X_t} = 3.31$, SE = 0.11). This difference was significant with $t_{Yuen}(95) = 3.428$, $p = .001$, $\sigma_t = .29$. Furthermore, non-users slightly reject interrupting an activity to vacate a parking space after charging ($\overline{X_t} = 2.03$, SE = 0.12) whereas users showed a rather neutral attitude ($\overline{X_t} = 2.64$, SE = 0.19). This difference was significant, too ($t_{Yuen}(89) = 2.775$, $p = .007$, $\sigma_t = .28$). Again, the capability to use fast-charging did not result in differences within the user groups.

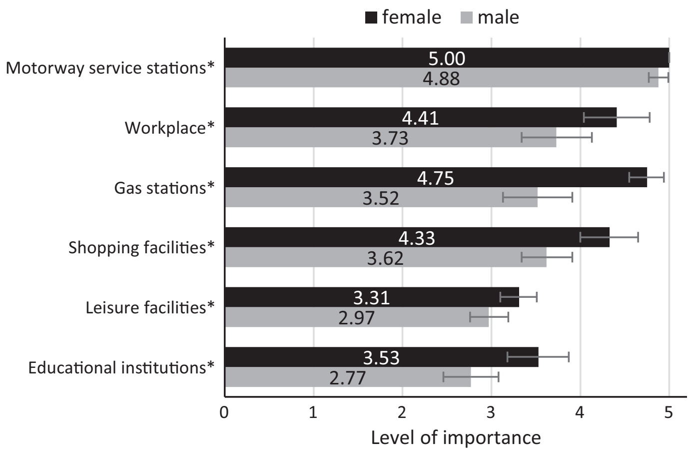

Fig. 4. Average importance of different locations for charging points ($\overline{X_t}$, min = 0, max = 5) and related 95.0% CI depending on gender ($*$ = significant difference).

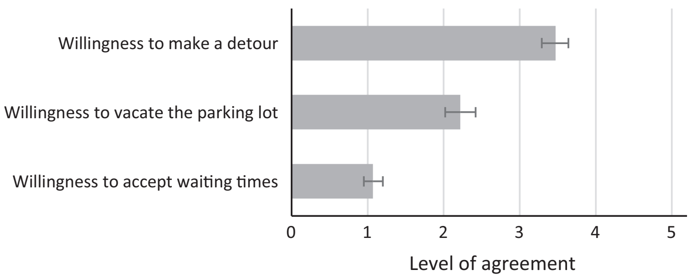

Fig. 5. Average willingness to accept drawbacks ($\overline{X_t}$, min = 0, max = 5) and related 95.0% CI.

Supplementary, the ratings of different types of willingness dealing with the charging process were also influenced by gender and age. That is, men are more willing to vacate their parking space ($\overline{X_t}$ = 2.36, SE = 0.12) than women ($\overline{X_t}$ = 1.79, SE = 0.20) ($t_{Yuen}(70) = 2.477$, $p = .016$, $\sigma_t = .24$). However, both genders reject moving the vehicle after charging in order to free the spot to another user.

Concerning age, there were no significant effects found regarding the acceptance of possible drawbacks. Neither the willingness to make detours, nor the willingness to vacate the parking space after charging, nor the readiness to accept waiting times was related to age.

Furthermore, there were additional important conditions regarding the charging process (see Fig. 6). Most important was that charging stations should be open around the clock ($\overline{X_t}$ = 4.93, SE = 0.04). A good lighting of the charging station ($\overline{X_t}$ = 3.39, SE = 0.12) was also perceived as important. A covered charging station ($\overline{X_t}$ = 1.55, SE = 0.13) received the lowest rating and, thus, this was not perceived as an important condition during the charging process.

Prior experience with BEVs influenced the requirement for charging stations that are open around the clock. Although this condition is very important to both users ($\overline{X_t}$ = 5.00, SE = 0.00) and non-users ($\overline{X_t}$ = 4.89, SE = 0.06), the difference was significant ($t_{Yuen}(103) = 2.047$, $p = .042$, $\sigma_t = .15$). Good illumination of the charging location is significantly less important to users ($\overline{X_t}$ = 3.02, SE = 0.18) than to non-users ($\overline{X_t}$ = 3.60, SE = 0.14) with $t_{Yuen}(104) = 2.593$, $p = .011$, $\sigma_t = .26$.

Additionally, gender had a significant effect on the evaluation of conditions related to the arrangement of the charging stations (see Fig. 7). Accordingly, a well illuminated charging station was more important to women ($\overline{X_t}$ = 4.15, SE = 0.17) than to men ($\overline{X_t}$ = 3.13, SE = 0.11) ($t_{Yuen}(77) = 5.233$, $p = .001$, $\sigma_t = .43$). The lighting requirement was significantly related to age, too, $\tau = .13$, $p = .005$.

3.3. Ranking of criteria for site evaluation

Fig. 8 shows the ranking of the derived criteria for site evaluation of charging stations. *Reliability* (Mdn = 1) was the most important criterion, followed by *dual use* with the same median rank but a lower quartile. The third most important criterion for site evaluation of charging stations was *accessibility* (Mdn = 3), followed by *safety for the driver and passengers* (Mdn = 4). *Safety for the car* (Mdn = 5) and *habit compatibility* (Mdn = 6) jointly occupied the penultimate rank, if the middle 50% are used as assessment criteria. *Connection to the public transportation network* (Mdn = 7) was assigned the last rank.

Concerning this matter, the experience with BEVs influenced the ranking with regard to *dual use*, *reliability*, and *accessibility*. Although *reliability* was the most important evaluation criterion for both groups, it was significantly more important to BEV users (Mdn = 1) than non-users (Mdn = 2) with $U = 4873.00$, $z = -3.35$, $p = .001$, $r = -.21$. Similarly, there was a significant difference in the ranking of *accessibility* ($U = 4835.00$, $z = -3.36$, $p = .001$, $r = -.21$) between participants with prior BEV experience (Mdn = 2) and without (Mdn = 3). Finally, BEV use affected the ranking of the *dual use* criterion. Unlike the previous results, *dual use* was more important to the non-user group (Mdn = 2) than the user group (Mdn = 3), with $U = 4743.50$,

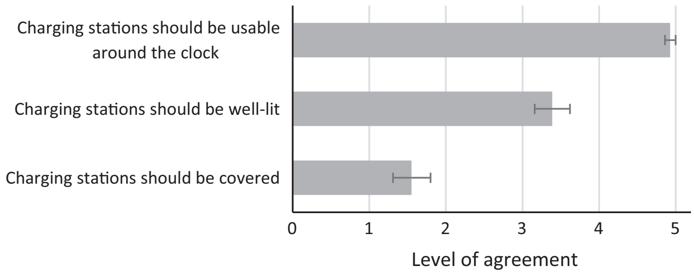

Fig. 6. Average agreement levels regarding requirements for the charging station arrangement ($\overline{X_t}$, min = 0, max = 5) and related 95.0% CI.

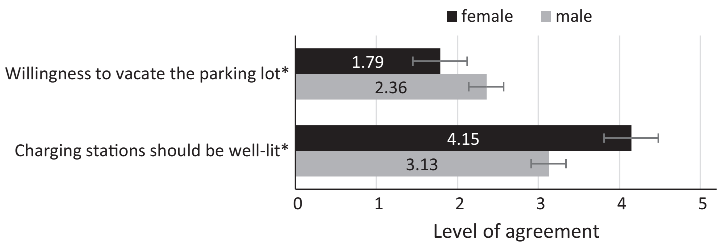

Fig. 7. Average agreement levels regarding requirements for the charging station arrangement and the willingness to accept drawbacks ($\overline{X_t}$, min = 0, max = 5) and related 95.0% CI depending on gender (∗ = significant difference).

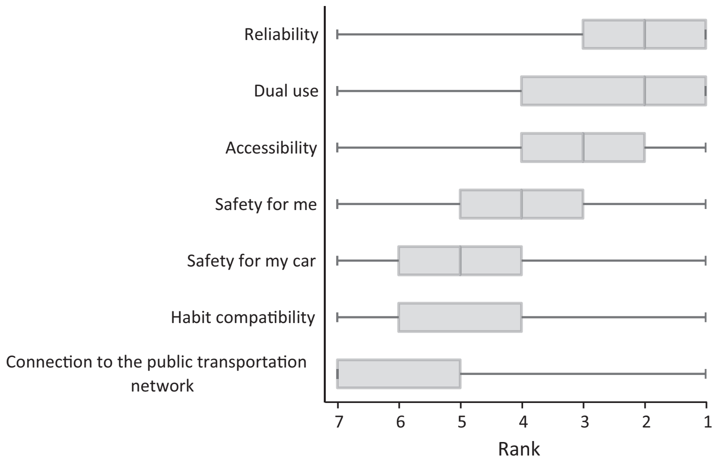

Fig. 8. Boxplot of evaluation criteria rankings (highest = 1, lowest = 7).

$z = -3.56$, $p < .001$, $r = -.23$. In contrast, the capability of fast-charging did not yield significant differences regarding the ranking within the e-vehicle user group.

Furthermore, significant effects were found with respect to gender. Even though there were no differences regarding the overall median ranks between genders, *dual use* ($U = 4830.50$, $z = -2.47$, $p = .013$, $r = -.16$) was more important to male than to female participants. *Accessibility* of charging locations was ranked higher by women than men ($U = 4654.50$, $z = -2.82$, $p = .005$, $r = -.16$). In contrast, there were no significant effects concerning age regarding the order of priority.

4. Discussion

The present study was conducted to understand which concrete locations users prefer for fast-charging infrastructure and how they evaluate the respective sites. Additionally, users' conditions for the charging process have been researched. The gathered insight into the impact of user perspective on the positioning of charging stations is a basic prerequisite for planning and establishing a nationwide fast-charging network that is able to cope with users' needs and requirements.

Strikingly, the general willingness to accept drawbacks is rather low. There was a slight consent to accept detours to get to a free charging space, which coincides with previous focus group findings about the willingness to accept small detours of up to 5 km or 10 min (Philipsen et al., 2015). Although the general willingness was proven, it still has to be quantified in further studies. In contrast, there was no willingness to vacate a parking space after the completion of the charging process or to accept waiting times due to occupied charging stations. These findings have to be taken into account during the planning of such stations. First, the number of charging connectors has to be sufficient relative to the demand, because even short waiting times are major impediments to acceptance. Second, the sites should be chosen in such a way that leaving the parking lot is done automatically after charging; an interruption of another activity to move the car cannot be assumed.

Regarding the requirements related to the concrete arrangement of charging stations, recharging should be possible around the clock. The average rating values for these requirements were close to the maximum of the scale, clearly underlining their importance. Furthermore, a good illumination should be assured. Interestingly, participants regarded roofing in terms of weather protection as rather unimportant, which contradicts conventional gas stations that usually provide a canopy. At this point, the user seems to clearly distinguish between charging stations and gas stations which was not always the case during the qualitative preliminary works. However, it matches findings that leaving the car during bad weather to plug in the charging connector is no impediment to the general acceptance of the charging process (Papendick, Brennecke, Sánchez Márquez, & Deml, 2011).

The ranking of evaluation criteria revealed that the two most relevant issues received approximately the same average importance whereas the remaining criteria feature gaps in their perceived relevance. Based on the complete sample, reliability, in terms of getting a charging space whenever the user needs one, was the most important evaluation criterion, followed by the dual use of time and routes and the location's accessibility. Interestingly, the dual use of time was more important to non-users than actual users. This might indicate that the adopters already have integrated the charging process and related waiting times into their daily routine and, therefore, the longer time needed to charge compared to normal fueling processes is considered as less critical. Also, reliability and dual use were the only criteria that were significantly affected by gender. The dual use of time and routes was more important to men than to women, whereas women perceived reliability as the most important evaluation criterion. Regardless of age and gender, the connection to the public transportation network as well as the safety of drivers, passengers, and vehicles is only of minor importance.

Based on the limitations of the ranking method, it was possible to reveal the relative weighting of the evaluation criteria, but it is still uncertain whether the criteria with low average ranks, such as connection to the public transportation network, are completely irrelevant for the evaluation process or just less relevant relative to the most important criteria, like dual use or reliability. Previous works give hints that all mentioned criteria are relevant during the assessment process of concrete charging locations (Philipsen et al., 2015), but further work is necessary to quantify this, in particular with regard to context, e.g., the type of trip. External factors like charging times or charging prices could influence the weighting and absolute ranking of the evaluation criteria as well. The effects of movement patterns and the purpose of travel should be further investigated, too, by using conjoint analyses.

Regarding preferred locations for fast-charging infrastructure, it could be shown that nearly all presented sites are important to the users. No location was classified as completely unimportant and thus rejected. However, motorway service stations were regarded as the most important sites. This is consistent with previous findings since long-distance traveling is a major use case of fast-charging technology and there is a lack of willingness to accept long detours in terms of leaving the motorway to recharge (or refuel). This results in the necessity to equip motorway service stations with charging stations to enable electric vehicles to cope with long-distance routes. Next to motorway service stations, shopping facilities got high importance ratings. This is consistent with previous focus group studies that revealed that especially supermarkets and businesses of daily needs are preferable locations for fast-charging infrastructure (Philipsen et al., 2015).

Remarkably, gas stations got high importance values, too, by both users and non-user of electric vehicles. This contradicts the intended double use of charging time and route, because gas stations do not usually offer parallel activities to fill the charging time. However, this finding seems to hint that charging is still strongly associated with conventional fueling processes that are activities on their own and do not coincide with other tasks of daily routine. Further research is needed to reveal whether this shifts to a more parallel activity concept in the long run. Currently, experience with electromobility is limited to an early adopter group and there might be a change regarding the way the charging process is integrated into the daily routine after long-term use. At present, the importance of gas stations as possible charging locations can qualitatively be explained by the awareness and familiarity of existing gas stations (Philipsen et al., 2015) and the general wish for the charging network's spread to be similar to the current gas station network (Halbey et al., 2015).

Comparable considerations can be applied to the workplace as a possible location for charging stations. Normally, the length of stay at the workplace exceeds the time necessary for fast charging. Therefore, charging at normal speed would be sufficient here. Nevertheless, the workplace as fast-charging location got high importance ratings by the participants, although there was no willingness to move the vehicle after the battery is recharged as the participants are unwilling to interrupt ongoing activities, like work, just to relocate their cars and free a charging connection. It seems that the concept of fast charging and the need to vacate the parking places after completing the charging process are not yet fully adopted in the current sample, especially by the participants who are interested in electromobility but still non-users. In contrast, the rather neutral evaluation of workplaces as potential fast-charging locations by BEV users seems to take into account the mismatch between charging and working time.

4.1. Experience with BEVs

Overall, it was shown that prior experience with BEVs affects the evaluation of charging locations significantly in several ways, in accordance with previous studies that revealed the influence of e-vehicle use on range anxiety and the general attitude towards electromobility (Bühler et al., 2014; Rauh et al.; Franke et al., 2012). The different evaluation of possible charging sites by users and non-users can be problematic for the technology spread. That is, the infrastructure planning has to adapt to the users' concrete requirements and needs and, therefore, should be primarily based on e-vehicle users' demands. However, as long as the charging network's expansion level is still an impediment to adoption, the requirements of potential future users, e.g., the requests for fast-charging stations at workplaces or educational institutions, should not be ignored and have to be addressed by suitable communication strategies, as recommended by Zaunbrecher, Beul-Leusmann, and Ziefle (2015). Accordingly, the reasons behind the differences between users and potential users regarding their requirements on charging locations should be explored in greater depth. The present paper uses driving experience in terms of vehicle use as the independent variable, because it is easy to measure. However, it cannot be stated with certainty which aspect of experience contributes to the differing evaluation of charging locations. As already mentioned, experience with BEVs results in a reduction of range anxiety which might be the main explanatory variable. Furthermore, increasing trust in the technology and integration of the charging process into everyday life that differs from the conventional fueling procedure, both caused by long-term use of electric vehicles, might contribute, too. Therefore, BEV experience with regard to charging location choice have to be further explored. Also in this context, the requirements of e-vehicle users have to be re-investigated once the user group exceeds the current early adopters. It is likely that user requirements could change if the user group becomes more heterogeneous in terms of demography, education, or income.

4.2. Age and gender

Furthermore, significant effects of gender were found regarding both the preferred locations for charging infrastructure and the requirements for the charging sites. However, there were no completely contrary opinions between men and women found in this study. The significant differences were limited to differences in the strength of the respective agreement or disagreement. Items that were important to men were also important to women and vice versa. However, the related effect sizes were prevalently small. The same applies to the age effects found. This could indicate universal relations between the items, which would simplify at least the rough-cut planning phase during the establishment of a fast-charging network. However, this finding is currently limited to the demographic factors considered in this work and has to be proven by exploring additional user characteristics in future studies. Furthermore, the effects of age and gender should be explored in greater depth, because there might be underlying factors mediating the revealed effects. Although possible factors, like technical affinity or driving behavior, are hard to integrate into infrastructure planning processes due to a limited data basis, further research should be done to gather a more profound understanding of the decision making processes during the assessment of charging locations.

5. Conclusion and outlook

In conclusion, the present findings can only be the starting point to explain users' evaluation of fast-charging stations. Preferred locations for charging infrastructure and concrete arrangement requirements with respect to user diversity have been revealed here. However, a more complex set of user characteristics is necessary to explain the small but existing variance and to model human factors into traffic simulations and planning tools for a (fast-)charging infrastructure. Therefore, further work is needed to cope with user diversity beyond the factors experience, age, and gender considered in the present work. In particular, potential effects of movement patterns, occupation, the residential situation (e.g., rural vs. urban or regional differences), or charging possibilities at work and at home should be explored to get a more complete picture of user requirements, needs, and willingness to accept drawbacks and trade-offs.

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