Abstract

Today’s cities endure major risks like global warming due to gas emissions. This is challenging for both humans and technical developments. E-mobility, however, raises the opportunities of enhancing a more sustainable mobility (structure) and providing healthier living in future cities. The paper identifies not only which locations of fast-charging stations in a city are preferred but also reveals how users evaluate them. With multiple empirical focus group studies, a user-centered evaluation could be carried out. This is important to identify possible trade-offs for infrastructural planning due to e-mobility use in the future. In total, eight main evaluation criteria for fast-charging locations regarding both position and concrete realization were derived in the subsequent discussions about the charging infrastructure. An overall accordance could be identified in the discussions, which indicates a step in the right direction for the long term goal of building a charging network with the help of user preferences.

Keywords: fast charging; electro mobility; battery electric vehicles; infrastructure planning; evaluation criteria; user requirements; mobility behavior

1. Introduction

Global warming as a pattern of the climatic change is one of the 21st century’s major risks, caused and accelerated by the emission of greenhouse gases like CO₂ [1]. Human mobility in terms of automobile traffic is responsible for a
large proportion of these gases, especially because combustion engines are still the most commonly used means of propulsion [2]. The federal government of Germany started its “National Electro Mobility Development Plan” in 2009 in order to reduce both the emission of greenhouse gases and the dependence on fossil fuels [3]. The central objective is the promotion of electro mobility to increase the number of electric cars used in Germany to 1 million vehicles by 2020. Therefore, several challenges have to be addressed by research: in addition to solving technical problems, the acceptance of the vehicle users plays a crucial role.

Supplementary to the limited battery capacity and range of current electric vehicles, especially the large amount of time required for charging is impeding on the technology adoption. One solution can be the building of a fast-charging infrastructure in a need-based manner and thus enable drivers to recharge the batteries of their electric cars up to 80% in less than 30 minutes [4]. However, there is only a very limited number of public fast-charging stations currently available in Germany. In order to establish a nationwide network of fast-charging stations, positioning concepts have to be developed to not only guarantee a basic provision but cope with the users’ needs and requirements to result in a positive public perception and acceptance of the novel technology.

2. Related work

Halbey et al. [5] identified four potential issues that have to be addressed to make the use of battery electric vehicles (BEVs) more attractive and increase public acceptance: battery capacity, charging time, location of the charging stations, and density of the charging grid. While battery capacity and charging time are determined by the state of the technical development, the other two factors can be actively shaped during the planning and implementation of a charging station grid.

There has been already a lot of fundamental work done dealing with the charging behavior of electric vehicle drivers that is expected to influence the users’ requirements related to charging infrastructure. For example, Franke et al. [6] showed that the charging behavior is related to users’ confidence in their mental model of range dynamics, the utilization of range, and to the accessibility of energy from renewable sources. They also were able to show the influence of stress-buffering personality traits and coping skills on range experience [7]. In addition, Bühler et al. [8] showed that the opportunity to charge at home has no effect on the attitude towards electric vehicles, which indicates that a fast-charging infrastructure should have no disadvantages regarding acceptance compared to charging at home. All of these studies have in common that fundamental attitudes and behavior models are identified and partially explained, but there is still a knowledge gap between those findings and the concrete user requirements related to the positioning and density of charging stations out of the perspective of potential electric vehicle users.

While already some research has been done dealing with the placement of slow charging stations and the corresponding use cases, the users’ perspective on fast charging is still insufficiently explored, especially as it enables e-vehicle users to implement new mobility patterns.

Bernardo et al. [9] showed that a planned fast-charging network is able to compete with networks that organically grow due to free market entry of commercial providers. Indeed, planned networks have a more uniform coverage instead of dense clustering in local areas. Bernardo et al. used a discrete-choice model as well as traffic models to simulate the implementation of charging networks. The user modeling is limited to the mapping of origin-destination commuting trips.

In contrast, González et al. [10] adopted an activity-based approach: They mapped the drivers’ daily activities to identify possible parking times. Within their simulation model of the Flanders region in Belgium the authors addressed both normal and fast charging as exemplary fields. According to findings charging activity is equally possible at home or work, but in case of missing charging opportunities at these places, most recharges can be done in the course of other activities, in particular during shopping. However, the simulation is based on behavioral patterns, (in this case users’ activity and movement profiles) but does not integrate users’ opinions on charging, perceived benefits and drawbacks. Another approach is utilized by Namdeo et al. [11] who take demographic data into account and specify three groups of early adopters to simulate the spread of electric vehicles in cities to adopt the planning of charging infrastructure to the diffusion process. Like Bernardo et al., they use an origin-destination model to simulate the movement patterns of the early adopters.

The mentioned studies have in common that they do factor the users in during the planning process of the charging networks. As user characteristics, mostly, demographic data (age, gender) and activity patterns and movement profiles
are captured. This seems sufficient to determine at least a rough positioning that is focused on basic mobility needs. As such it could be learnt from those data which age and gender group is travelling in which direction. Though, on this information base, only few information about the exact positioning, for example, on street level, can be derived. Still, little is known about the effects of the concrete siting referring to the users’ perspective (at which location users would expect and prefer charging stations) as well as the underlying individual evaluation standards (out of which reason), especially if the focus is not on ensuring basic requirements but on establishing a perceived comfort that can be important for user acceptance.

A major cornerstone in this context is thus the need to understand how users evaluate the locations of fast-charging stations, and which criteria are used for preferences. While many studies focus on the identification and description of the current e-vehicle users [12, 13, 14], namely the early adopters group, it makes sense to also include those persons for whom the current expansion of the infrastructure is still an impediment to the use of BEVs.

3. Methodology

To gain a better understanding of which specific criteria determine positioning decisions of fast-charging stations out of the perspective of potential BEV users, we conducted a qualitative study with the identification of user requirements at its focus. Hereafter, the planning and realization of the study will be presented, followed by a detailed description of the sample.

3.1. The focus group instruction

We carried out structured focus group discussions with different user typologies regarding vehicle use and habitats (urban and rural) to explore possible evaluation criteria and to gather concrete site proposals. The discussions were structured as follows: First, the actual state of the fast charging technology, particularly with regard to loading times and the current state of infrastructural development, was presented because the participants were expected to lack prior experience with this kind of charging process. To do so, a short film about the currently emerging fast-charging network along the A9 motorway was shown [15]. Second, the participants were asked to explain where they see themselves within the electro mobility context by having to place a marker on a scale between a positive and a negative extreme regarding their attitude towards the use of battery electric vehicles in general. Subsequently, the self-assessments were discussed in the group to identify perceived barriers and benefits of this technology. Last, the participants had to make specific location proposals for fast-charging stations based on their own daily routine and travel behavior. Afterwards, the chosen locations were individually discussed regarding criteria that would speak in favor or against the specific site in order to identify general assessment schemes.

The focus groups lasted between 45 and 75 minutes. The audio recordings were fully transcribed and analyzed, using qualitative content analysis according to Mayring [16]. The thereby created category system was used to derive general evaluation criteria for fast-charging locations.

3.2. Participants

There were two main acquisition requirements for participants. First, participants who are not fundamentally opposed to battery electric vehicles but are quite skeptical and therefore do not yet belong to the current adopter group had to be found. Second, participants had to drive a car quite frequently. The acquired participants were divided into three focus groups based on their place of residence and driving behavior. Hereinafter, the groups are referred to as the rural, the urban, and the commuter group.

The first group included six participants (n=6) who resided in rural areas. The average age was 45.8 years (SD=13.2) and ranged from 32 to 66 years. Gender was equally distributed in this group. With 50%, a university degree was the most frequently mentioned highest educational qualification. Five users were employed, one was retired. The average mileage per year was at 29,100 km (vehicles with internal combustion engines). All participants had the means to charge an electric vehicle at home, three participants could also charge at the workplace.

The next group consisted of five participants who lived in an urban area (n=5). Three of them were female, two male. The youngest participant was 25 years old, the oldest 27 years; the average age was 25.4 years (SD=0.9). Though
all participants were students (different field of studies), four of them owned a private conventional car and the average mileage per year was 19,700 km. One of the vehicle owners had his own parking space, but none had the opportunity to charge at home. One participant would have the option to charge an electric vehicle at the workplace.

The last group contained four participants who were commuters and frequent drivers (n=4). Two of them lived in a rural area while the others were residents of urban areas. The average age was 36.8 years (SD = 7.6, age range 28-48 years). Three participants were male, one female. All had a university degree and used their own private cars with combustion engines to get to work. The average mileage per year was at 20,000 km. While the rural dwellers had own parking spaces including the opportunity to charge at home, the urban participants were lacking this option. None of the attendees of this group had the means to charge an electric vehicle at the workplace.

4. Results

In the following, the results from the focus group discussions will be presented. First, the general attitudes towards electro mobility in the different groups will be shown briefly. Second, the derived criteria for site evaluation will be described in detail. Third, specific location proposals will be presented.

4.1. General attitude towards electro mobility

The participants of the rural group had, although not generally averse, the most skeptical view of electric mobility. In particular, the time that has to be spent on the charging process was considered critical. Additionally, the achievable ranges were considered inadequate for use in a rural area without a currently still missing, dense charging network. At the same time, the low operating costs compared to cars with internal combustion engines were highlighted as positive for high mileage.

According to the self-assessment at the beginning, the participants in the urban group had a slightly more positive attitude towards electro mobility. Benefits were seen particularly in urban traffic with short distances. However, the lack of infrastructure was a major point of criticism in this group, too, especially with regard to driving long distances. In addition, the environmental friendliness was critically evaluated, because not only the emissions of the vehicles but also the production of electricity and batteries was included in the assessment.

Neutral to skeptical positions were taken in the commuters group. Again, the missing, nationwide charging network as well as the current battery capacity were main points of criticism. In particular, the fluctuating battery capacity depending on outside temperatures was highlighted as critical since this implies an uncertainty factor for route planning. Similarly, the current government funding of electric vehicles was considered insufficient and mentioned as yet another reason for the slow increase of electric vehicle registrations.

All groups had in common that electro mobility was generally considered as useful, but a personal adoption of the technology would be realized in a few years at the earliest, and only if the charging infrastructure will be expanded, the battery capacities will increase, and the acquisition costs will decline.

4.2. Evaluation criteria

Eight main evaluation criteria for fast-charging locations regarding both position and concrete realization were derived based on the subsequent discussions about the charging infrastructure: (1) Dual use (2) Habit compatibility (3) Accessibility (4) Visibility (5) Reliability (6) Safety (7) Connection to the public transportation network (8) Necessity. There was broad consensus in all focus groups that the charging process should not be the sole purpose of a trip. Dual use in terms of combining the charging with everyday activities was referred to as a prerequisite for using battery electric vehicles. The saving of time and distances to be traveled was the main motivator.

“I think places where one has to stay on a regular basis anyway in everyday life are most important. It should not be a special trip. I don’t want to drive a detour and then wait half an hour for my charging.”

In particular, the commuters and participants from rural areas, who already have to spend a lot of time on everyday mobility, refused to invest additional time compared to a conventional fuelling process. Indeed, there was a critical
view on meeting the dual use requirements on long-distance routes because the limited driving range, in comparison to combustion engines, would lead to more time to fill during the charging process. The participants were rather skeptical of repeating artificial activities that do not result from everyday life:

“Or, as in this charming promotional film when they are happy because they drink their fabulous coffee at the motorway rest area. So, after the fourth, I would slowly ...
So one is ok.”

In conclusion, a preferably seamless integration in current daily routine was requested, which hints at the next evaluation criterion. Most of the participants were reluctant to significantly change their current route patterns. Although it was expressed that the presence of a charging station could have an impact on, for example, the choice of supermarket, there was a strong desire for habit compatibility in all groups. Participants stated that the better and less noticeable the charging opportunity would fit into the existing movement profile, the more likely they would accept and use it, because they expressed little willingness to familiarize themselves with completely new motion patterns without having major benefits compared to conventional refueling.

Another evaluation criterion is accessibility. This goes beyond the pure infrastructure density and refers to the actual, practical accessibility of the location by the user, which may vary depending on the time of day, the traffic volume, and personal route patterns. Two aspects played a role: First, detours should be avoided. Second, a time loss due to these additional ways or due to the risk of congestion is also not desirable. For example, charging sites in city centers were critically discussed:

“If I did not get there faster than if I'd run, it would be an exclusion criterion for me. So if I know I will surely get into a traffic jam because I need to drive into the city for charging, then that is already difficult for me.”

Conversely, locations outside city centers, for example, at motorways, can be problematic in terms of accessibility, too, if it is only necessary for charging to drive track parts that do not belong to the direct route:

“So, [a charging site at the] motorway would be bad, because I then would have to enter the motorway and drive in the wrong direction to the nearest service station or so, so I would have to accept a huge detour.”

Although accessibility is an evaluation criterion for a single location, participants mentioned that it would lose importance when there would be a choice due to a high number of available charging stations.

Visibility was another property of charging locations required by the participants. This refers not only to the design of the charging station in terms of an adequate signage and a display of free charging places but also to the location itself, which “should be visible and not hidden in backyards.”

Another frequently mentioned criterion was reliability. In this context, the participants used the term reliability not pertaining technical reliability of the stations but in terms of the expected availability. Participants requested the reliability that the charging station is open when they want to or have to charge their vehicles and that there are enough places available to park and charge in order to avoid long waiting times. In particular, locations with high parking pressure and few charging stations were considered critical in this context. Moreover, it should also be ensured by the location that vehicles are not parking any longer than necessary for charging. Reliability was also requested at a higher level in terms of knowing that particular facilities always offer charging options, like gas stations do for vehicles with combustion engines:

“Okay, if you are, for example, in a foreign city, you know, in any case, at gas stations there is always a recharge possible, but you do not know if there are any supermarkets, for example, that vary [and do not offer charging options in this city].”

In all groups, reliability was assessed against accessibility. Most of the participants were willing to take small detours if this would guarantee immediate charging without waiting:

“I would accept five kilometers. Yes, maybe ten minutes, or so.”

The next evaluation criterion has to be divided into two partial aspects. First, participants required safety for the vehicles while they are left behind to charge and the drivers pursue other activities. Second, safety for the driver and passengers has to be taken into account in the assessment of a site. Participants preferred public, visible and crowded
places for charging stations and considered especially dark and lonely places as risk factors. In particular in the rural group, there were concerns about charging stations along highways with little traffic in the evenings:

“Kind of scary then. Then I stand there for half an hour on the road in the dark,” and “during the day it may be safe, but what about later times of day?”

The need for security of some participants was even further reinforced by the opinion that charging times make criminal activities more projectable:

“I could well imagine that one or the other [criminal] person thinks that it is worth to make an extra visit there.”

The connection to the public transportation network has been identified as an additional evaluation criterion for a charging location. However, there was a considerable debate about this criterion in all focus groups, because in the case of a typical commuter, who drives to the station by car in the morning and then takes the train to work, even longer charging times and therefore normal charging stations would be sufficient. However, participants argued that they use the combination of car and train not only for working purposes but also for much shorter activities of one or two hours to avoid traffic jams and searching for parking spaces midtown. In this particular case, a fast-charging station could provide a fully charged battery in comparison to charging with normal speed.

Necessity, was mentioned by all participants as the most basic, because only fast charging would give a realistic opportunity to drive routes which exceed the normal battery range. In particular, long journeys on motorways and main roads played a role in the rural and commuter group:

“I, as a commuter who lives in a rural area, necessarily need charging stations along the highway or I'm not able to go away and will not come back.”

Therefore, participants distinguished clearly between two stages of necessity:

“There are places where a fast-charging station definitely must be and those where it might not be needed as much but is just convenient.”

These necessary locations are not preferred as a result of weighing of the preceding criteria but primarily due to avoiding limitations of the current movement profile.

4.3. Location proposals

In addition some concrete proposals have been developed in the focus groups. First and foremost, participants of all groups agreed that supermarkets and other businesses catering to daily needs would be the preferable locations for a fast-charging infrastructure for several reasons. First, purchases of daily needed products have to or may need to be done several times a week, each time with a duration that approximately matches the charging period. Therefore, the desired criteria of double use of time and track is met:

“Because you know for sure the vehicles are not standing there two or three hours, because such a purchase is usually done within half an hour and supermarkets usually have a high number of parking spaces, what otherwise, for example, is not a given in front of residential buildings or parking bays.”

In combination with a sufficient number of charging stations, the offered parking space at supermarkets and especially discount stores would meet the criterion of reliability, too. And if the supermarket would not have to be changed for the charging option, the habit compatibility would also be maintained.

Next to supermarkets, the participants also listed public authorities, medical centers, or recreational facilities like sports venues as possible locations for fast-charging stations because the length of a stay would be compatible with the charging time, too. Although the individual driver usually visits these facilities infrequently, a charging station there could still be utilized by constantly changing users. Participants mentioned that fetching and bringing people could possibly play a role, especially at sports facilities, since one could easily charge during the short waiting times:

“We cannot necessarily just focus on our age group but also on children, i.e., parents drive their children somewhere, deliver them, and when they are done, they come back
and pick them up again and no doubt wait a bit until the kids come out so that this time could also be used.”

Workplaces were generally not considered for fast charging because usually the parking durations are long enough for charging at normal speed. Additionally, there would be no opportunity to move the car after the battery is full during working hours to make the station available to other users. An exception was only seen at educational institutions where the timed breaks could allow staff and students to move their cars. However, there were strong doubts in all groups whether there exists a willingness to pause an unfinished activity to vacate a charging space.

Interestingly, gas stations have been proposed in all groups as possible locations, too. All participants agreed that a dual purpose in this case is not really possible, but participants still argued for gas stations. In particular, habit is the main argument. The drivers would know their usually frequented gas stations, they are accustomed to visit them and thus there would be a feeling of reliability and safety.

“I would maybe even link [the charging stations] to the fueling station network, because there I can remember it best, there I can go, I can refuel, and then I can just charge my car there.”

Finally, motorway service stations have been proposed as possible locations. Although the dual use is limited especially in repeated cases, these sites are required to complete long distances without leaving the motorway and therefore meet the criterion of necessity.

5. Discussion & outlook

The main aim of this study was to identify user criteria for the allocation of fast-charging stations. Additionally, specific site proposals should be worked out. Both objectives are necessary first steps to be able to choose and evaluate locations for fast-charging infrastructure and to reach the long-term goal of building a fast-charging network that can cope with the users’ needs and requirements.

Eight general evaluation criteria have been derived which seem to hint at two major issues. First, there was little willingness to spend extra time on both charging and detours. Anything beyond the timeframe of a conventional fueling process was perceived as an essential barrier. This finding is in accordance with results of several previous studies [5, 12, 17] and led to the requirement that it must be possible for the driver to use the time of charging meaningfully, referred to as the criterion of double use in this work. The targeted avoidance of waiting times led to the criterion of reliability, whereas the existing unwillingness to detours resulted in the accessibility criterion. The second major issue seems to be a lack of willingness to change existing driving behavior. Although fast charging could lead to new mobility patterns by combining charging with other activities to make rides only for the purpose of fueling superfluous, the participants wanted to remain within their current routes and patterns and, therefore, requested the compatibility with existing habits for the placement of charging locations.

Interestingly, there were no major distinctions across participants regarding both the general evaluation criteria and the concrete site proposals. Although the commuters and participants from rural areas were slightly more skeptical regarding long-distance driving with battery electric vehicles, all had, essentially, the same evaluation criteria for locations. Even though the arguments indicate that the selected site must conform to the respective movement patterns, the criteria themselves seem to be universal, which has to be validated in further quantitative studies. While the place of residence and personal mileage were the main distinctive user characteristics in this work, additional attributes like gender, age, educational level, or technical affinity will have to be taken into account in future works. Although only marginal relations between domain knowledge regarding e-mobility and acceptance were found [18], the influence of previous experience with BEV on site evaluation should be further investigated.

The same applies to the weighting of each criterion. Due to the qualitative nature of this study, preferences, like the stated importance of the double use of time and tracks in terms of a seamless integration of the charging process into everyday activities, can only be treated as hints and might serve as hypotheses for further work. Another important question is whether the weight of individual criteria changes when external incentives are given; for example, how the willingness to drive detours will change if there is a benefit in terms of lower charging costs at a secluded location. The charging time’s effect on criteria’s weightings should be further investigated, too.
In contrast to the comprehensive evaluation criteria, the scope of the concrete site proposals was quite limited. The supermarket was the central and most favored site which coincides with González et al.’s recommendation to combine charging with shopping [10]. In addition, there were only few other specific ideas. This could be due to the fact that the useful location options are indeed limited, but on the other hand, the hypothetical method used could also have framed the argumentation lines. Halbey et al. [5] made first steps to contextualize the topic by using maps in which focus group users might practically place charging stations at concrete locations on their own. It should be worthwhile to prospectively enhance this approach and implement it in a quantitative study.

The idea of using gas stations as possible locations for fast-charging stations - although they actually cannot meet the criterion of double use - shows that users still argued on the base of a classical gas station network. Charging still seems to be an activity on its own, like fueling currently is, instead of considering charging as a permanent, parallel activity to everyday routine. Because this study included only participants who did not reject electro mobility but did not use it either, it will be necessary to study if this mental model evolves by driving battery electric vehicles.

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References