Going on a Road-Trip with My Electric Car: Acceptance Criteria for Long-Distance-Use of Electric Vehicles

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Abstract. In this study we report on four focus group discussions to examine cognitions, attitudes of a broad variety of users with respect to battery electric vehicles (BEV). Specifically, we identified relevant criteria for the use of electric cars as a long distance vehicle and gathered first impressions of where users wish to locate such charging stations. Four main aspects were identified as acceptance relevant: The battery's capacity, given in the driving range in kilometers, the time it takes to regain this given range (*charging time*), the density of the charging stations grid and the attractiveness of the places where the charging stations are located, which could for example be a service area or a simple parking lot off the highway. Results of this study might provide detailed insights into conditions and technical specifications that have to be met beyond the possibility of quick charging to reach higher acceptance and a broad willingness to use BEVs for more than short-tracks in the city.

Keywords: Battery electric vehicles (BEV) · User acceptance · Quick charging · Infrastructure · Adoption of novel technologies

1 Introduction

In times of rising concerns about climate change and global warming, the automotive industry among many others is forced to find solutions for decreasing the massive exhaustion of carbon. To reach this aim, most automotive OEMs and governments all over the world consider battery electric vehicles (BEV) as the most reasonable drivetrain technology for the future. But despite high expectations as for example stated by the German government, still, the demand for electric vehicles is low. Except from the higher costs, this is assumed to be due to two main problems compared to fuel powered cars: The range is limited by the battery capacity, and recharging the battery lasts extremely long. That is why most of today's available BEVs are designed for short-track-use as a typical city car.

The possibility of quick charging might now provide a solution for the range and charging problem: With special charging stations suited with extremely high current, it is possible to regain 80 % of a battery's capacity in half an hour or less. Placed along

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highways and in cities, such stations might enable long-distance-use of electric vehicles. However, building such an infrastructure will be expensive and given the to date low demand for BEVs for short distances it is questionable whether a quick charging infrastructure will enhance acceptance and the intention to use BEVs. For this reason the current study investigated user requirements related to a quick charging infrastructure for long-distance-use.

1.1 Actual Use of Electric Vehicles

Surveys show that the public attitude towards sustainable mobility and electric cars in particular is mostly positive [1, 2]. Still, the demand for electric cars is low, though there are several models available and expectations are high. But in Germany, only 0.03 % of the entire registered cars are battery electric ones, which is a total of about 12000 cars [3]. However, this small group of current users of BEVs can be outlined quite consistently.

The great majority of BEV users in Germany are male (89 %) and about 50 years of age. They have an income slightly above the average but there are no significant differences in the educational level compared to users of conventional cars [4]. Furthermore, most of the BEV users live in rural areas or suburbs with their families and have their own detached houses. Reasons for the purchase of such cars are usually a great interest in technology and environmental awareness, as well as rather practical issues like the low energy costs per kilometer and even the driving pleasure due to the electric drive [5].

Not only can the group of the electrically mobile people be explained in such consistency but also the use cases for BEVs. Most important, few people (users as well as non-users of BEVs) can imagine using a BEV as the only means of transportation [1, 5]. As could be expected, problems occur especially when going on holiday. This attitude matches with the fact that most of the BEV users own a second car with a conventional combustion engine [5]. Thus, having an alternative as a kind of mobility reserve seems to play an important role in the decision to buy a BEV. Besides the limited battery capacity and therefore the small driving range, the long duration to recharge the battery is mentioned as another main reason for the lack of long distance suitability.

But despite these limitations, people perceive a lot of advantages in BEVs: Most of the daily ways can be and are indeed covered by BEVs [5]. This means for example to go to work, to the supermarket or from the rural home into nearby cities, which represents a typical use case for a second car. Still it is remarkable that the average range driven with BEVs is nearly the same as the overall German average of about 43 km per day [5, 6]. This is in the range of virtually all available BEVs. According to this, it is not surprising that more than 90 % of the BEV owners park and load their cars on their own premises [5]. On the contrary, this means that existing public (slow) charging stations are hardly used to date.

1.2 How to Deal with a Limited Driving Range

There has been a lot of research concerning the question how to fit the driving range of BEVs to the people's mobility needs [7, 8]. Since batteries are expensive and heavy, the idea is to make the battery not bigger than absolutely necessary, which means to know how far people go with their cars. The main results can be explained quickly: For most of the daily mobility needs, the existing BEVs are absolutely sufficient, as explained in the section above. But longer trips remain, that cannot be done with this range.

So why do only so little people buy BEVs even as a second car, though the range is sufficient for more than 80 % of the trips done in Germany daily? Of course the higher costs will play a role, but there seems to be a psychological factor concerning the range. When it comes to electric vehicles, people subliminally fear to remain lying on the street due to an empty battery. In transportation psychology research, this fear is called *range anxiety* [9, 10]. According to the concept, not only the effectively needed driving range is crucial, but people expect an additional reserve. Transferred to current users of BEVs, this means they only use up to 80 % of the available range [11]. So not only the technical capability should be considered when designing BEVs, but also the question of how to give the consumers a feeling of security, which occurs to be a crucial aspect. How this *range anxiety* can be overcome is not safely explored yet. Besides greater battery capacities, some researchers assume especially a good public charging infrastructure to be useful as a kind of *range safety buffer* [10, 12, 13].

1.3 Research Questions and Purpose of This Study

Based on the acceptance-related research so far, the aim of this study was firstly to explore all the relevant criteria that people apply to evaluate BEVs in comparison to conventional cars. Secondly, the study was supposed to investigate the influence of a quick charging infrastructure, since this technology presents a new part in the whole concept of electric mobility and could possibly have a great impact on feelings of security and acceptance, as has been shown in the previous section. Furthermore, ideas and criteria for possible locations for quick charging stations should be collected. Finally, we wanted to deal with the question what needs to be done to make BEVs comparable to conventional ones so that they one day could replace cars with combustion engines completely.

2 Methodology

In the following section, the methodological approach of this study is detailed. Focus groups were run because this method offers the most effective approach for exploring barriers and benefits of users regarding a technology that is at an early stage of market launch [14, 15]. Three focus groups with users of BEVs were conducted and one control group with users of conventional cars. Composition of the groups and their realization are explained in the following sections.

2.1 Procedure and Participants

The selection of participants was oriented on so-called "information-rich cases" [16], which can provide diverse and multifarious information to the given topic. Therefore, the approach of this study was to gather information from current users of BEVs as they are the only ones who can evaluate the existing cars and their range and charging time and thereby anticipate future effects of quick charging.

A control group was conducted to check whether the users really differ in their opinions from the great majority of drivers of conventional cars. Overall, four different groups were formed which are described in the following.

Group 1: With only 12000 owners of electric cars in Germany, getting private BEV users to join the focus groups was not easy. But in Aachen, Germany the local transportation operator has 50 *Smart Electric Drive* at use as part of a research field trial. So via this company, four frequent users of these electric cars could be selected for the first group, accordingly a very homogeneous group of colleagues with high domain knowledge. Three of them were female, one male (mean age of 39 years).

Group 2: The second group consisted of clients of a car sharing company who often use their electric cars. These are either *Smart Electric Drive* as well, *Renault Zoe* or *Mitsubishi EV/Citroen C-Zero.* All of these cars have driving ranges of about 100 to 150 km. In this second group, all were male (mean age of 39 years).

Group 3: The third group was a mixed group out of car sharing clients, research associates from the RWTH Aachen University (mostly technical disciplines), and a (completely enthusiastic) private owner of a Tesla Model S. Except from the latter, all of them do not own BEVs, but use them frequently and therefore have experiences with the range and driving performance. This group consisted of five male participants who were, on average, 40 years of age.

Group 4: For the control group, five drivers of conventional cars were recruited (two female, three male, mean age was 31 years).

2.2 Materials

A structured interview guideline was developed with the aim of maximizing the exploration of opinions and ideas to the research questions (see Fig. 1):

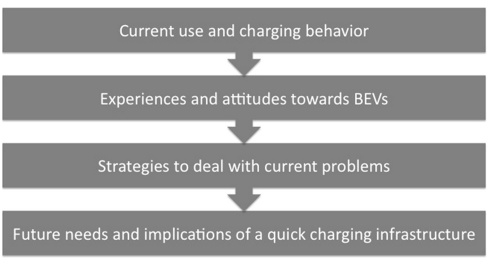

Fig. 1. Structure of the interview guideline

After a short introduction, the quick charging technology was explained briefly. Familiarizing participants with the topic, the first task of participants was to mark possible locations for quick charging stations on a city map of Aachen. Each participant was given three pins in an own color to pin on the map on a pin board.

Understanding the implicit rationale of positioning charging stations, participants were asked to explain their choices and even criticize other locations to get the discussion started. The next topic was to report about their usage behavior, especially with regard to the ways they drive with the BEVs and where they charge them so far. In this context participants were encouraged to perceived disadvantages and problems with the use of BEVs if present.

Resuming the discussion participants were asked how to deal with these existing problems and what – according to their view - needs to be done to make BEVs suitable for a wider use. Up to this point, the discussion did not explicitly refer to quick charging, but to the current state of technology and ideas for the future in general. At this point, participants were guided to include this new technique into their considerations: How could quick charging help solve the existing problems and overcome the disadvantages, related to the disadvantages they mentioned before? To put this idea even further, they were requested to report and discuss mobility needs in general and to reflect which part electric cars could take in this mobility behavior, given existing public quick charging infrastructure.

3 Results

The following section presents the results of the four focus group sessions. The findings are structured according to the expiry of topics in the interview guideline.

3.1 Current Use and Charging Behavior

Since most of the focus group participants did not own the electric cars they use, the use cases are mostly predetermined by the respective using context. For example the employees of the local transportation operator use the company's electric cars to get to work and back home or to do other business-related tours during their worktime. It is guaranteed that the employees can drive home and back to work without recharging. People who live farer away shall not use the cars. The cars are usually recharged on the company's site by 22 kW (quick-)charging stations to keep them available as much as possible. On the other hand, this means that the participants of this focus group did not have much experience with public charging stations or with longer trips.

This turned out to be quite different in the other two focus groups. Although it is intended that the car sharing cars are only recharged at the car sharing stations, some of the clients had already done longer trips where they had to recharge on the way. There were also participants who reported to have a lot of experience with electric cars and use public charging stations very frequently. Car-sharing clients declared they use the electric cars as often as possible and would drive them even more often if more of them would be available. The Tesla owner had even gone on holiday (about 800 km) with

his car. But there were also other BEV enthusiasts who like to have the risk and thus make it a bit of a challenge to try out how far they can go and try to use them for as much trips as possible. So the individual use cases of participants of these two groups differed widely. Some of the car sharing clients only do short trips in the city, others use them to get to work or for business, others use them as their first vehicle for everything. Besides the car sharing sites, some of them recharge the cars at home, at public charging stations or – in case of the research associates – at the institute's own charging stations.

3.2 Experiences and Attitudes of Current Users Towards BEVs

When asked about their first experiences and their attitudes towards BEVs, the overwhelming majority commented very positively. This is mainly due to two impressions:

First of all, the *driving pleasure due to the electric drive*. This experience was mentioned most often as first impressions in all focus groups with current BEV users. For many of the participants this fact was a bit surprising since electric cars are usually associated with economical driving and saving fuel – an approach that is basically contradictory to power and driving pleasure with fuel powered cars. So many of the users appeared inspired that with BEVs, it is possible to save fuel and have fun while driving at the same time.

Secondly, a lot of the users found that BEVs are *perfectly suited for cities* – the area where most of them use them. So the BEVs used by the focus group participants meet the mobility requirements they are intended for and perform quite well.

But there are also some limitations that shape the first experiences: There are lots of details that do not work very well yet. For example, some participants reported *public charging stations that do not work*, *different and complicated accounting systems for charging stations* as well as an *uncertainty regarding the range* as soon as the tracks get farer than the well-known inner-city ones. Furthermore, they check the battery status a lot more often than they check the fuel gauge in conventional cars. Though also differences in the opinions showed up. While few participants – most strongly the Tesla owner – find that BEVs can satisfy all the mobility needs, others even call it an "atypical car use" only for enthusiasts. Still most participants think BEVs have their advantages in cities, but *cannot compete with conventional cars on longer trips*.

In contrast to that the control group revealed a very different impression. Most often, BEV novices expressed concerns about the driving range. The higher costs (purchase, maintenance) was another important disadvantage. Without being well informed about electric cars (self-disclosure), they had the impression that driving an electric car needs much more effort as one would always be focused on the remaining range and would have to plan where the car can be recharged. So range and costs were the dominating factors in this discussion, even if two of the participants could imagine driving a BEV in nearer future.

Especially the reported disadvantages of current BEV users and their way of dealing with them will be analyzed and explained in more detail in the following sections.

3.3 Users' Strategies to Overcome Current Problems with BEV

Some disadvantages of BEVs were already mentioned (See Sect. 3.2). The argumentation lines of the main barriers, like restricted range and the corresponding infrastructure problems, are now analyzed in more detail to find out how users deal with them at the moment and further to derive solutions for the future.

In the control group as well as in the other three focus groups, the limited driving range has been mentioned as the main disadvantage of today's BEVs. BEV novices, for example, report that they would check the battery status every few minutes even on short tracks. This fact corresponds with the explained *range anxiety* [8]. However, with increasing familiarity and daily experience with the battery range, users get accustomed to undertake short tracks without anxiety. But even those report a different feeling while driving an electric car due to a battery in comparison to a fuel tank, even on short tracks. So in general, the majority of participants reported an perceived uncertainty which appears on different levels.

First of all, there is the *general uncertainty whether the driving range is sufficient* for the track planned as soon as it is not one of the usual tracks. This effect is even strengthened since most of the participants have experienced significant variations in the driving range depending on weather, track profile and style of driving. However, they have different ways to handle this disadvantage: Especially the less experienced participants usually *keep a range reserve*, which means they only use a part of the full battery capacity. Some of the real BEV enthusiasts instead rather *take it as a challenge* to explore how far they can go or to optimize their driving style. But of course, if they have really important dates, they take a safety reserve as well. So no matter how one handles the limited range and its variations, it always leads to a *higher planning effort* compared to conventional cars. For tracks which people drive the first time or at least not usually, they *first need to plan the route* and check out how far it is. Next, they have to consider whether the driving range of their car is sufficient. If not, they either *look for recharging possibilities* on the way or use an alternative vehicle. Although planning gets easier with increasing experience the fact itself remains the same. All of the participants agreed about this *higher planning effort* and the *limited range* as a restriction to electric mobility. Having chosen the first alternative (recharging on the way), soon another uncertainty arises: Is the planned charging station free or occupied when I get there? As mentioned before, some participants even experienced though free, but broken charging stations, which increases the uncertainty even more.

However, different participants have different ways to deal with this problem. For many of the car sharing clients and the local transportation operator employees, this planning effort and uncertainty about range and charging stations is a fact that discourages them from travelling longer distances. They evaluate BEVs as beneficial for short tracks in the city, but would usually not go on longer trips with today's technical and infrastructural state of the art. Nevertheless, there was a minority – one of which was the Tesla owner – who thought differently. For those participants, the advantages weigh out the disadvantages. For the benefit of driving pleasure and the environmental effects they report to accept the cost of a higher planning effort. Thus, on the one hand, there are the rather pragmatic BEV users who do not want to accept too much extra

effort or other disadvantages, on the other hand there are the electric car enthusiasts who accept some problems for the advantages they experience.

Besides range problems and connected aspects, other disadvantages – primarily mentioned in the control group - were the higher costs. Also in the control group, people wished more variety in the car models since most BEVs are small cars today. In the other groups instead, it was often mentioned that there are different accounting systems for public charging stations and that they sometimes do not work.

3.4 Future Needs and Implications of a Quick Charging Infrastructure

Based on the prior discussion, focus group participants were requested to consider potential issues to be changed to make BEVs more attractive in the future. Irrespective of this specific question, interestingly, the discussion focused on the fundamental question what an electric car can provide at all. Some participants argued that BEVs are generally only suited for short tracks and even in the future a mix of different transportation would be the only feasible solution – in line with the principle "The right car for the right purpose." Others were convinced that BEVs might completely replace fuel powered cars in the future. When asked what has to be changed in order to replace fuel powered cars in future, participants mentioned a lot of aspects that partially overlap with the stated disadvantages. Figure 2 gives an overview on the four most often mentioned aspects that have to be changed in order to enable the replacement of conventional (fuel power) cars through electric cars.

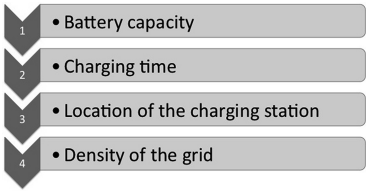

Fig. 2. The four most important aspects to enable a full usage of BEVs

First of all, all participants agreed that the **battery capacity** has to be increased, even though the vision of the future driving range varied widely across the groups. The desired range in the control group varied from 200 up to 800 km. In contrast, actual BEV users did not mention this great variety in range, they all agreed that at least medium-long tracks should be feasible. In order to use an electric car as means of transport most of the users wish at least a battery capacity that lasts for 300–500 km. As lower limit, 150 to 200 km would be barely acceptable, in order to avoid range anxiety. The desired range depended especially on the average mileage of the participants: Those who often travel longer distances considered higher ranges as necessary.

Charging time turned out to be another important factor. When the discussion came to charging, most of the participants in all groups did not find it acceptable to take any extra time to charge the car. Instead, recharging should happen while the car is

parking anyway. Also, for long distance tours most participants thought of recharging the car when they have a break, anyway. Again, there were great differences between the control- and the other groups. In the control group, the requirements on BEVs were even higher than on conventional cars. They argued on base of their current travel behavior and did only want to recharge the car while they would have a break anyway. The current users of BEVs instead were mostly willing to change their habits a bit and have extra breaks to recharge. But even though, the charging time should decrease since nobody seemed willing to wait for several hours. So especially in the group with the local transportation operator employees, different ideas came up, like stations to change empty batteries for new ones or redox-flow batteries from which the electrolyte liquid can be replaced, which is basically comparable to refueling a conventional car.

When guided towards the possibility of **quick charging** it turned out that some of the current user groups were aware of the concept before, some just got to know it during the focus groups. The participants agreed that quick charging stations placed along highways have a great potential to enable long-distance use of BEVs. But even though the cars can be charged a lot more quickly than to date, quick charging a BEV still lasts longer than refueling a conventional car. Therefore, in the following discussions the question arose how quick charging along highways should be arranged, implying the question what to do while the car is plugged in. In these discussions, the **location of the charging stations** turned out to be an important factor. Some of the participants had ideas to make charging more attractive like providing free Wi-Fi. But most of them considered service areas most appropriate so that the time can be used to eat and have a good break. So again, there seems to be low acceptance to spend extra time on charging, or at least the time needs to be used effectively for other things. Furthermore, the charging time itself was discussed again, since it was recognized that there still is room for development in this aspect as well even when considering quick charging stations. Again, the users had different ideas of how quick it should be. To sum it up, most of them considered half an hour as acceptable, given that a certain range can be recovered during that time. This range was, as explained earlier, dependent from the user and his using context. Some even thought of charging more than an hour or two in a city next to the highway and have a greater break during that time.

The fourth important point in the discussion about long-distance use of BEVs was the **density of the grid**. The participants did not state this aspect as often as the others, but the fact came up very often even during the discussions about planning effort. With conventional cars, one does not have to plan where to refuel the car, as there are more than enough stations available. This would be completely different if quick charging stations had the same distances in between. Due to the lower range of BEVs one would have to plan which charging stations to use. Thus, just to enable certain routes by placing few quick charging stations along these highways would not satisfy many of the focus group participants, but instead there should be a grid so dense that one would not have to plan so much in advance. However, this was a critical point and different opinions about it arose.

Concluding, four factors turned out to be most critical for long-distance use of electric cars, given that it shall be realized by a quick charging stations grid along highways: Driving range of the car itself, charging time to regain a certain range, the locations of charging stations and distances between the stations (i.e. grid's density).

4 Discussion

The aim of this study was to explore all the relevant criteria that people apply to evaluate BEVs in comparison to conventional cars. Furthermore, the study was supposed to investigate the influence of a quick charging infrastructure on acceptance of electric vehicles. Finally, we wanted to deal with the question what needs to be done to make BEVs comparable to conventional ones so that they one day could replace cars with combustion engines completely.

In general, all users, even most of the unexperienced control group, expressed a positive attitude towards electric cars. Nevertheless, some differences appeared between users and non-users of electric cars that give fruitful implications for development and further studies. The most important benefit for users respectively people with experience in driving BEVs was the driving pleasure an electric car offers as well as economical benefits in terms of fuel saving. In contrast to that the control group that never drove an electrical vehicle focused more on arguments against buying a BEV right now e.g. limited range and higher costs. Further results showed that users are more prepared for compromises than non-users especially when it comes to charging times and battery capacity. A reasonable explanation for this difference might be the perceived benefits that one experienced when driving a BEV some times.

Another argument in favor for this assumption might be the strategy to deal with restricted range. The possible range of electric cars was considered a major drawback in this study. Although field studies have shown that the average range of an electric car would meet the mobility demands of a large amount of people [16, 17], the wish for an extended range still persists. Nevertheless, further results in this study clearly showed that although range anxiety was a major topic in the user groups it turned out clearly that people get used to deal with this problem and develop a kind of routine in planning their trips.

The major point of these results is that although battery capacity and charging time are the most critical aspects that have to be improved for more acceptance, the perceived benefits of BEVs might outweigh a higher effort in being mobile with BEVs when these technical drawbacks will be improved in future, even if BEV technology can never achieve the flexibility benchmark conventional combustion engines offer. Therefore, expanding the infrastructure by quick charging stations might be one useful solution. Improvement of battery capacity and consideration of attractiveness of locations for charging stations as well as the density of grids are the other major aspects that might lead to higher acceptance and help to overcome the phenomenon *range anxiety*.

Because of the qualitative nature of the study, quantitative follow-up studies have to be conducted. For example a choice-based conjoint study would be helpful to examine the users' preferences and trade-offs of these criteria for a long-distance-use of

BEVs, similar to the approach in [19]. Conducting a conjoint study with different levels of each criteria could help to answer questions more in detail, e.g. what is an acceptable density of the grid, when the battery capacity is sufficient for 150 km, it takes 30 min to charge and quick charging stations are located on very attractive parking lots with entertainment and food – a charging station every 120 km, 100 km or still every 50 km? Results of these trade-offs could offer technical benchmarks for developing engineers that should be achieved in order to enhance adoption of BEVs.

Another important methodological aspect of this study is the discussion process in the focus group that revealed that people are not able to adequately differentiate between infrastructure and the technology itself. When asked to evaluate their acceptance of a quick charging infrastructure, participants mostly argued on aspects that apply to the car technology itself. Thus, the process of the discussion shows that people's acceptance largely depends on the fit of the technology, independently of car type or infrastructure, focusing on their mobility needs in general. This finding though is not specifically directed to electric mobility but reflects a typical discussion behavior of focus groups that can be found also in studies in other use contexts e.g. wireless medical context [20]. Thus, when studying acceptance of a new infra-structure technology the target in use, in this case the BEV, has to be evaluated or considered as well in order to give participants an appropriate framing.

Though this study revealed insightful argumentations about users' requirements in the context of electric mobility in general and BEV in particular, naturally, this study represents only a first approach in both, scope and methodology. One limitation refers to the specificity of the user group examined here. Focus group participants (even the control group) were well educated and had comparably high domain knowledge. Findings thus might not be representative to less elaborated argumentations prevailing in a less informed public majority, which though are important for the full understanding of perceived barriers in novel car technologies. In addition, user diversity in terms of age and generation, or, gender could be a valuable addendum in this context. Finally, it is also highly probable that country-specific and cultured attitudes are underlying acceptance for BEV usage that should be addressed in further research.

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