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Article

Perceived Usage Potential of Fast-Charging Locations

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Abstract: Fast-charging infrastructure with charging time of 20–30 min can help minimizing current perceived limitations of electric vehicles, especially considering the unbalanced and incomprehensive distribution of charging options combined with a long perceived charging time. Positioned on optimal location from user and business perspective, the technology is assumed to help increasing the usage of an electric vehicle (EV). Considering the user perspectives, current and potential EV users were interviewed in two different surveys about optimal fast-charging locations depending on travel purposes and relevant location criteria. The obtained results show that customers prefer to rather charge at origins and destinations than during the trip. For longer distances, charging locations on axes with attractive points of interest are also considered as optimal. From the business model point of view, fast-charging stations at destinations are controversial. The expensive infrastructure and the therefore needed large number of charging sessions are in conflict with the comparatively time consuming stay.

Keywords: fast charge; infrastructure; electric vehicle; user behavior; business model

1. Introduction

The aim of the German Government is having 1 million electric vehicles (EV) licensed in Germany by 2020 [1]. However, the current number of licensed battery electric vehicle is 34,022, while the number of hybrid vehicles in Germany 165,405 [2]. This leads to the conclusion that the anticipated number seems difficult to realize. An inevitable and arising question is what reasons prevent potential users from deciding against an EV. Currently, long perceived recharging time and the unbalanced distribution of charging infrastructure have been found to be among the biggest challenges for the broader acceptance of the vehicles [3,4]. To approach this issue, a feasible measure to increase the number of EV in Germany might be the optimal distribution of public charging opportunities, enabling a higher perceived usage potential of an EV [5]. This in turn leads to the question, whether a novel technology with shorter charging time can help to increase the acceptance and perceived usefulness of electric mobility. A technology exhibiting a potential of this kind might be the fast-charging technology with charging time varying between 20 and 30 min [6] and therefore decreasing the necessary time waiting during recharge. Regular charging options need up to 16 h to recharge the battery to 100% state of charge (SOC), depending on performance and capacity of the battery. In contrast, fast-charging technology enables recharging the EV up to 80% SOC within 20 to 30 min. Having had its onset in early 2014, the research project SLAM (Schnellladenetz für Achsen und Metropolen) therefore focuses on this technology as potential future charging option by building up and completing a comprehensive and demand-oriented fast-charging grid in Germany [7]. It is planned to set up 600 combined charging system (CCS) fast-charging stations in Germany [8]. Furthermore, a web based simulation tool with open access has already been developed, helping future investors of fast-charging stations in optimal positioning of their planned charging infrastructure. The tool is based on different layers such as urban planning, mobility and user level. The user level, which is focused on in the next section, considers optimal charging locations from user perspective.

To gain deeper insight into the potential of fast-charging technology, the present paper focuses on examining an increased perceived usefulness induced by optimal positioning scenarios of fast-charging infrastructure. Furthermore, it examines the impact on business models and their fit to the scenarios found to be most effective from a user's perspective. In preliminary research, it could be found that optimal fast-charging options en route are perceived as beneficial from user perspective, depending on travel purpose [9]. However, this benefit may not necessarily exist from business point of view due to higher installation costs compared to regular charging options (cf. [10]). Both perspectives shall therefore be compared in the present paper.

2. Perceived Usefulness of Fast-Charging Infrastructure from User Perspective

To identify user-relevant fast-charging scenarios, an online user survey was conducted. During the study, relevant scenarios, differing in the amount and position of fast-charging stations, were combined with daily travel purposes to "use cases". For each use case, (potential) EV users should quantify the usage potential of an EV. In addition, relevant location criteria were collected. The method as well as the results of the studies are presented in the following sections.

2.1. Perceived EV Usage Potential of Relevant Fast-Charging Use Cases

To examine and quantify the usage potential of electric vehicles, depending on the fast-charging location, an online survey was conducted. This online survey included 12 charging scenarios. The charging scenarios were derived from two expert workshops, which took place in advance of the survey.

2.1.1. Methods

The expert workshop should help identifying a first set of relevant charging scenarios from expert's view. The first workshop intended to define relevant fast-charging scenarios, depending on the travel purpose. Thirteen experts took part in the workshop and were divided into four groups. Each group independently from the other groups had to identify relevant charging scenarios. The workshop's result was six charging scenarios. The charging scenarios differed in the kind of travel route (direct distance from home to destination or trip chain from home to destination with interim destinations) as well as in the number and position of fast-charging stations (e.g., just at route, just at destination, or both), and were post-hoc combined with five travel purposes taken from the MiD 2008 [11], resulting in a total of 30 combinations which are called use cases. The five travel purposes selected were work, business, shopping, private errands and leisure because of relevance issues for fast-charging.

The revealed 30 use cases of the first workshop were prioritized in a second expert workshop. The prioritization was based on frequency and the relevance rated. The prioritization process revealed 12 use cases, which in turn served as basis for the subsequent online studies. For easier orientation in the online questionnaire, the original six charging scenarios were re-categorized into the following three different charging scenarios:

1. Direct short distance: Direct distance from home to destination without interim stops and with exceeding half of the maximum EV driving range.
2. Direct long distance: Direct distance from home to destination without interim stops and with exceeding the maximum EV driving range.

3. Travel chain: Route from home to destination with several interim stops and with exceeding the maximum EV driving range until reaching the final destination.

The scenarios direct short distance and travel chain were again combined with all five travel purposes, in accordance to the expert workshops. The third charging scenario was only combined with the travel purposes private errands and leisure, because of prioritization in the second expert workshop. A list of the final use cases is presented in Table 1.

Table 1. List of the 12 use cases which were presented in the online questionnaires; A indicates the use cases that are presented in Version A of the questionnaire, while B indicates the use cases that are presented in Version B.

Travel Purpose	Fast-Charging Scenario		
	Direct Short Distance	Travel Chain	Travel Chain
Work	A	B	-
Business	B	A	-
Shopping	A	B	-
Private errands	B	A	A
Leisure	A	B	B

Furthermore, the charging scenario direct short distance included the rating of the usage potential considering three different charging station location options:

- Charging station just located at route;
- Charging station just located at destination;
- Charging station located at route and at destination.

The location of charging options for the scenario travel chain was always "at several positions of interim destinations and at final destination". For the scenario direct long distance, the EV usage potential had to be rated considering the following four options:

- One charging station just located at route;
- One charging station located at route and one at destination;
- Several charging stations just located at route;
- Several charging stations located at route and one at destination.

The online questionnaire was presented to a total sample of N = 70 EV users (two of them were female; mean age of participants M = 48 years, SD = 9.40) via online platform from December 2016 to January 2017. The questionnaire was divided into two versions, each with 6 of the 12 charging scenarios presented. This was necessary to not overwhelm the participants by a too long questionnaire. About half of the sample (n = 31) filled in Version A of the questionnaire and n = 39 filled in Version B. The selection of the questionnaire Version A or B was randomized for each participant. The sample was asked per use case which EV usage potential they subjectively perceive to be appropriate. They were also asked to estimate the rate of occurrence per use case in their personally daily routine. For that, a weighting factor of each use case, depending on its occurrence rate, was calculated afterwards. The results per use case are presented in the next section.

2.1.2. Results

Regarding the absolute perceived EV usage potential per use case and travel purpose, overall potentials are assumed to be at least 80%, showing no relation to charging scenario or travel purpose. These rates do not indicate variations in the perceived EV usage potential and therefore do not help identifying relevant scenarios for EV usage. To identify significant differences in the perceived usage potential, depending on charging scenario and travel purpose, and to increase the importance of the use case's occurrence rate as well as the travel purpose's occurrence rate, each EV usage potential therefore was post-hoc weighted by these two occurrence rates. The following equation exemplarily describes this approach on a basic level:

$$UR_{WUC_j} = UR_{UCj} * \gamma_j \beta_i \quad (1)$$

With

UR_{WUC_j} = weighted usage potential rate, depending on use case j; range: 0–100%;
UR_{UCj} = usage potential rate, depending on use case j; range: 0–100%;
γ_j = weighting factor 1, derived from the occurrence rate (in%) of use case j; estimated by the survey participant; γj = scenario occurrence rate/100;
β_i = weighting factor 2, derived from the occurrence rate of the travel purpose; source: MiD report 2008 [9]; βi = travel purpose occurrence rate/100.

The weighted EV usage potentials highly depend on the occurrence rate of the use case. In addition, the usage potentials are now highly diverting, depending on the travel purpose considered in the use case.

The weighted EV usage potential for all use cases regarding the scenario direct short distance varies from 1.2% to 2.6%, depending on travel purpose and the location of a charging opportunity (see Figure 1). Regardless of the charging location, the estimated (partial) EV usage potential is significantly lower for use cases with the travel purpose private errands (priv.err.), compared to use cases with other travel purposes ($t_{work\_priv.err.}$ = 6.44–12.20, $p < 0.001$; $t_{business\_priv.err.}$ = 11.24–11.80, $p < 0.001$; $t_{shopping\_priv.err.}$ = 6.75–13.50, $p < 0.001$; $t_{leisure\_priv.err.}$ = 9.98–23.16, $p < 0.001$). Furthermore, with charging stations located at the destination, the perceived usage potential is significantly higher for shopping use cases compared to use cases regarding the travel purposes work ($t = -4.32$, $p < 0.001$), business ($t = 3.08$, $p < 0.01$) and leisure ($t = 3.92$, $p < 0.01$). Therefore, a charging station at a public shopping location seems to have a substantial benefit regarding the EV usage.

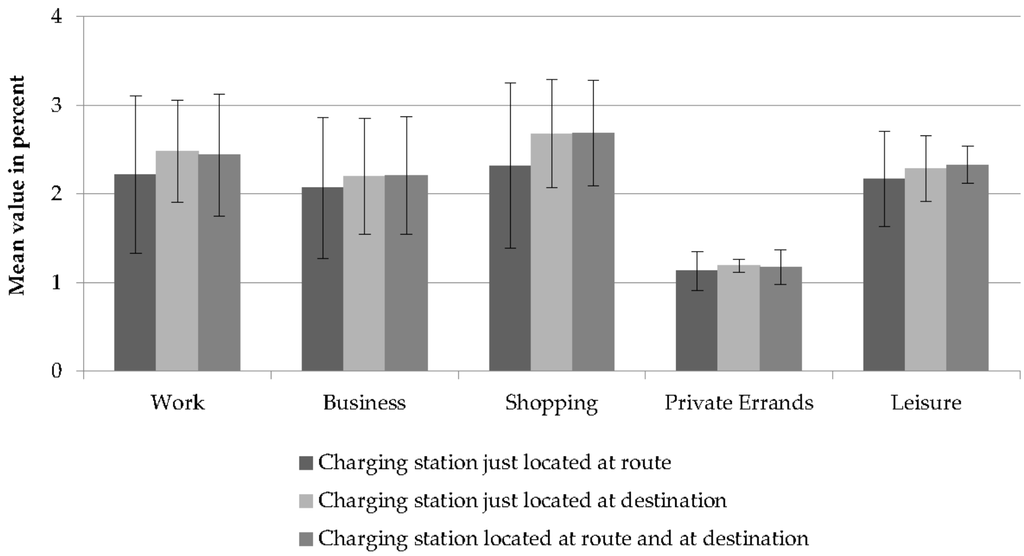

Figure 1. Estimated mean (partial) EV usage potential for use cases regarding the scenario direct short distance, depending on travel purpose and position of fast-charging stations (with standard deviation).

Considering the scenario travel chain, the weighted (partial) EV usage potential, again, showed a high dependence of travel purpose and estimated EV usage potentials varying between 2.0% and 4.1% (Figure 2). Compared to use cases with travel purpose business, shopping or leisure, use cases with work purpose or considering private errands are indicated with significantly lower usage potential ($t_{work\_business}$ = −8.19, $p < 0.001$; $t_{work\_shopping}$ = −23.66, $p < 0.001$; $t_{work\_leisure}$ = −72.55, $p < 0.001$; $t_{priv.err.\_business}$ = 7.21, $p < 0.001$; $t_{priv.err.\_shopping}$ = −28.32, $p < 0.001$; $t_{priv.err.\_leisure}$ = −45.44, $p < 0.001$). Compared to business cases, use cases with shopping or leisure purpose furthermore show a significantly higher perceived EV usage potential ($t_{shopping}$ = −16.96, $p < 0.001$; $t_{leisure}$ = −30.55, $p < 0.001$).

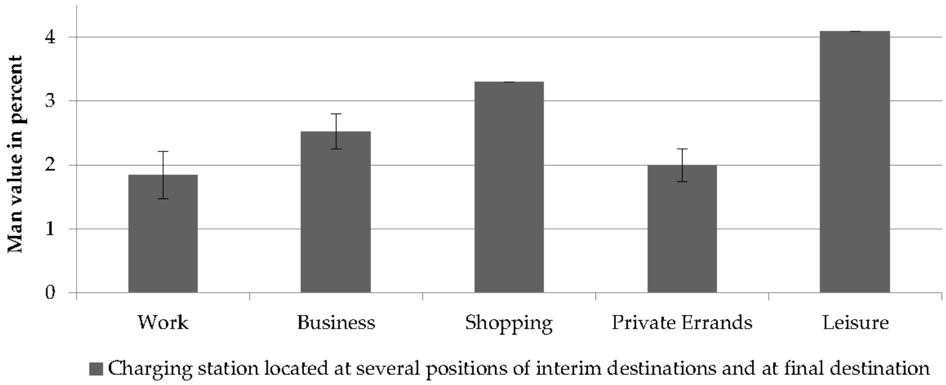

Figure 2. Estimated mean (partial) EV usage potential per travel purpose for fast-charging use cases regarding the scenario travel chain (with standard deviation).

Use cases with the charging scenario direct long distance generally show lower perceived (partial) usage potentials descriptive wise. This is because of low estimated occurrence rates of this scenario, which lead to lower weighting of the estimated EV usage potential. However, the weighted EV usage potential highly diverts between the two regarded travel purposes, going from 0.9% up to 2.2% (cf. Figure 3). Regardless of the charging station location, the perceived usage potential for leisure use cases is significantly higher than for use cases with purpose private errands (t_{single_exceed} = −7.46–−15.78, $p < 0.001$; $t_{several\_exceeds}$ = −10.17–−22.26, $p < 0.001$). Furthermore, the number and location of charging options influence the usage potential. If, for travel purpose leisure, there are several charging options at the route and one at final destination, the EV usage potential is significantly higher compared to just one charging location at the route (for both exceeds of driving range: $t = -2.11$, $p < 0.05$).

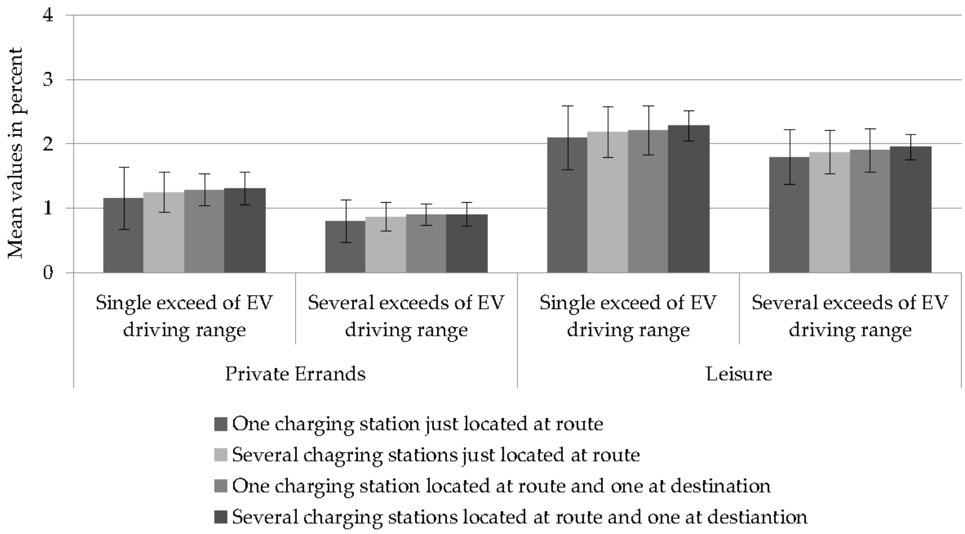

Figure 3. Estimated mean (partial) EV usage potential for use cases regarding the scenario direct long distance, depending on travel purpose and position of fast-charging stations (with standard deviation).

In summary, an increase in EV usage potential, caused by an optimal positioning of fast-charging infrastructure, is influenced by the travel purpose. Currently, optimal located charging stations for trips with shopping or leisure purpose seem to generate a perceived benefit regarding EV usage. Especially, the higher perceived EV usage potential regarding travel chains for shopping or leisure purpose, compared to business, results in the assumption that, for travel chains, charging locations close to shopping places and leisure spots seem to be likely favoring the decision for an EV.

Furthermore, the usage potential seems to be influenced by the number and location of charging options. Direct long distances with the necessity to recharge at route seem to be more comfortable when having several charging options that can be chosen from. Trips with leisure purpose also seem to be better manageable with an EV than trips for private errands, probably because of more perceived time flexibility that can be rearranged for a recharge. As a conclusion, fast-charging stations should primarily be placed at destinations, and further on axes close to leisure facilities.

However, participants in former studies mentioned that further location criteria such as necessary detour to the charging location or points of interest at charging locations also have an influence on the perceived usage potential of an EV from their perspective. In the next subsection, these further relevant location criteria are therefore discussed on an explorative basis.

2.2. Influence of Relevant Location Criteria

To examine the influence of relevant location criteria on the acceptance and usage of a fast-charging station, the approach of a conjoint modeling was used. In advance of this approach, an expert workshop was implemented to pre-identify relevant location criteria from expert's view.

2.2.1. Methods

First, an expert workshop was conducted to identify relevant location criteria of a fast-charging station from expert's view. Seven male research assistants with focus on electric mobility took part in the workshop. The mean age of the participants was 34 years (*SD* = 3.85). With the help of three different fictive use cases, derived from common use cases regarding driving a vehicle, the experts were asked to name relevant charging location criteria that they would consider when thinking of that use case. The use cases' content regarded the decision to buy an EV, considering one of three areas: urban, rural or highway area. Each use case was dealt with by two ro three experts. Finally, the as relevant defined criteria for each of the three use cases were discussed in the plenum. As a result, after post-hoc reduction, four relevant criteria, with three parameter values each, were defined for urban areas, and three relevant criteria, with three parameter values each, were defined for rural and highway areas. Because of the similarity of the location criteria for rural and highway areas, these two areas were combined to one region called "axes" afterwards. The urban area was post-hoc renamed to "metropolitan region".

The selected criteria for the metropolitan region were, with the parameter values in brackets:

- Necessary detour to the charging location (0.5 km, 2 km, 5 km);
- Kind of point of interest (POI) at charging location (shopping facility, sport facility, place to eat);
- Walking distance from charging station to POI (50 m, 300 m, 500 m);
- Number of charging options (1, 2, 3).

As relevant selected criteria for the region axes were, with parameter values in brackets:

- Necessary detour to the charging location (0.5 km, 2 km, 5 km);
- Kind of point of interest (POI) at charging location (shopping facility, place to eat, no point of interest);
- Number of charging options (1, 2, 3).

These criteria were implemented in an online questionnaire, presented to n = 66 EV users and n = 76 nonusers via an online survey platform. The mean age of the N = 142 participants was 37 years

(SD = 12.00). The participants were invited to rate the desirability of a charging location with a certain combination of location criteria. This rating gave a conclusion on the impact of each of these criteria. The method is called conjoint analysis [12,13]. With the help of this method, fictive charging locations with a randomly selected combination of several criteria parameters were created and presented to the participants. The participants have to rate the combination of the criteria—in this case, a fictive charging location. The method post-hoc concludes from an overall rating of the location to the rating of several criteria, which is possible because of the different combinations presented. For the metropolitan region, each fictive location consisted of one parameter regarding necessary detour, one regarding kind of POI, one regarding walking distance from charging station to POI and one regarding number of charging options, which makes in total 4 different criteria. A combination example for the metropolitan region is presented in Table 2. For axes, each location consisted of three criteria with a certain parameter, each referring to one of the three parameters available for selection per criterion.

Table 2. Example of a fictive charging location for the metropolitan region, consisting of four different parameters, each referring to one of the relevant criteria selected for this region in the expert workshop.

Criterion	Parameter Value
Necessary detour to the charging location:	2.0 km
Kind of point of interest (POI) at charging location	Place to eat
Walking distance from charging station to POI	50 m
Number of charging options	3

The participants had to rate 20 different fictive charging locations for the metropolitan region and 10 different fictive charging locations for axes. All of them were selected from a pool including all possible combinations of the 3 or 4 criteria × 3 parameters of each region and were randomly assigned to the participants, revealing n = 81 different combinations for the metropolitan and n = 27 different combinations for the region axes. Selected combinations were not put back to the pool. Once the pool was empty, all combinations were reactivated for a new selection process. This procedure ensured that all possible combinations were selected at least once during the study. The results of the rating are presented in the next section.

2.2.2. Results

First analyses of possible group differences did not show significant effects except for one significant difference in the perceived importance of the criteria necessary detour to the charging location. This one low significant difference can be disregarded due to little importance for further analysis and to increase the sample size for better interpretation of the study results. Therefore, ratings of non-users and users are summarized, resulting in a total of N = 142 participants. For the metropolitan region, all four criteria were rated by the EV users and nonusers as rather important or important. Therefore, all of them were included in the following examination.

Considering the necessary detour to a charging location, the likelihood of a good rating increases by more than 11 times, if the detour is not longer than 0.5 km, in comparison to a detour of 5 km (see Table 3). Furthermore, the walking distance from charging station to POI should not be longer than 50 m. Compared to other presented distances, the likelihood of a good rating increases about two times for such a location walking distance. Furthermore, it does not matter, if the POI at the charging location is a shopping facility or a place to eat. However, a sports facility would significantly decrease the likelihood of a good rating. Finally, the option of having three charging points at one location increases the likelihood of a good rating of this location by six times, compared to only one charging point available. In addition, the availability of two charging points still increases the likelihood of a good rating, compared to only one, but only by three times.

Table 3. Results for location criteria regarding the metropolitan region, with all parameters and reference parameters; displayed is the Odds Ratio (OR) for each comparison and significance; *** $p < 0.001$.

Location Criteria: Necessary Detour to the Charging Location	**Reference Parameters**	
Parameters	2 km	5 km
0.5 km	4.35 ***	11.53 ***
2 km	-	2.65 ***
Location Criteria: Kind of POI at Charging Location	**Reference Parameters**	
Parameters	Shopping facility	Sports facility
Shopping facility	-	2.13 ***
Place to eat	Not significant	2.00 ***
Location Criteria: Walking Distance from Charging Station to POI	**Reference Parameters**	
Parameters	300 m	500 m
50 m	2.01 ***	2.49 ***
300 m	-	Not significant
Location Criteria: Number of Charging Options	**Reference Parameters**	
Parameters	1	2
2	3.82 ***	-
3	6.02 ***	1.57 ***

For axes, again, all three criteria were rated as (rather) important, wherefore all of them were included in further examination. The importance of not more than 0.5 km detour to the charging location was even higher for this region compared to the metropolitan region (see Table 4). A necessary detour of just 0.5 km increased the likelihood of a good rating of the location by more than 27 times, in comparison to a detour of 5 km. In addition, a detour of 2 km would still increase the likelihood of a good rating by four times, compared to 5 km. The simple existence of any kind of POI, regardless if it is a place to eat or to shop, increases the likelihood of a good rating by about four times. Furthermore, the availability of three charging points, compared to only one, increases the likelihood of a good rating by eight times, and compared to two charging points, by two times. The availability of two charging points however still significantly increases the likelihood of a good rating, in comparison to just one charging point at the location.

Table 4. Results for location criteria regarding the region axes, with all parameters and reference parameters; displayed is the Odds Ratio (OR) for each comparison and significance; *** $p < 0.001$.

Location Criteria: Necessary Detour to the Charging Location	**Reference Parameters**	
Parameters	2 km	5 km
0.5 km	5.86 ***	27.63 ***
2 km	-	4.71 ***
Location Criteria: Kind of POI at Charging Location	**Reference Parameters**	
Parameters	Shopping facility	No POI
Shopping facility	-	5.21 ***
Place to eat	Not significant	4.25 ***
Location Criteria: Number of Charging Options	**Reference Parameters**	
Parameters	1	2
2	3.88 ***	-
3	8.61 ***	2.22 ***

In summary, necessary detours to a charging location in metropolitan regions should not be longer than 0.5 km and should have at least two charging points. Furthermore, a shopping facility or place to eat should be within direct walking distance (not more than 50 m) to the charging station. The results can be explained by the aim of current and future EV users to put little effort into the recharge of their vehicle, in line with the possibility to compensate the time effort during the recharge with pleasant activities. This way, the charging process is less perceived as an additional task with much effort. A charging location on axes should be reachable within a detour of not more than 2 km, but better within an extra distance of not more than 0.5 km. It should offer some kind of POI such as a shopping facility or place to eat. Furthermore, there should be at least two charging points available. Again, it is assumed that the participants of the conjoint study aim to have less as possible additional effort when having to recharge their vehicle. Additional effort probably would be perceived when having to manage long detours or not having any pastime activity available during recharge.

In conclusion, both the necessary detour to the charging location and the infrastructure around the charging location seem to have high influence on the evaluation of a charging location. It should be taken into consideration when calculating the optimal position of a charging station. Within the project SLAM, the multilayer simulation tool takes into account the amount and characteristic of POI around a potential location, the walking distance to these POIs as well as the radius of necessary detour to the possible charging location itself. This approach is set to help improving the fast-charging grid by considering the actual perceived benefit from a user's perspective.

3. Comparative Approach on the Analysis of Fast-Charging Infrastructure from Business Perspective

The following section gives an overview of results regarding fast-charging infrastructure from business perspective. In the present paper, the business perspective is rather evaluated in the form of a comparative approach, comparing business to user perspective.

3.1. Methods

In an open market approach, up to 200 out of these 600 charging stations were set up with the help of project external investors. To receive financial subsidies, investors had to fill an application form with detailed information about location, planned business model and calculated investment costs (CapEx). First, this information was used to decide on the suitability of a location and if an investor was capable of operating fast-charging stations for a longer period.

However, the main intention of gathering the data is to get insights on the business models market participants are operating on. Using the information of several investors combined with actual usage data directly received from the charging station, the project team also provides feedback to investors for them to be able to adjust their approaches. In this paper, several investors, location types and business models are distinguished. Primary results of the SLAM charging infrastructure network are presented in the following section.

3.2. Results in Comparison to User Perspective

Following the obtained survey results regarding the user perspective, destination charging seems to be prioritized by EV users, ideally with the possibility for fast-charging. As both fast-charging and slow-charging deliver the same products, namely an increased state-of charge, to the user, expectedly the option with faster energy delivery is preferred by the customer. Of course, a balance with the higher investment costs of fast chargers is needed. In case of fast-charging (or even high power charging with up to 350 kW DC) infrastructure, there is the question whether there is any opportunity of financial amortization.

Generally, the charging purpose can be distinguished into: (1) destination charging at trip ends; and (2) intermediate charging between trip ends. While intermediate charging is commonly found on motorway and off-motorway service areas, destination charging is often related with spots for leisure activities, shopping and private errands. Depending on the activities at the trip end, retention time can vary between five minutes at a service station and 8 h at the work place and therefore often exceeding the thirty minutes needed to charge at a fast charger. Figure 4 displays the actual usage patterns at five different locations. Even though "Urban area A" and "Urban area B" are located in medium-sized German cities, they clearly differ in position and surroundings. However, both locations, "Urban area A" and "Urban area B", are predestined for destination charging, whereas "Off-Motorway service station" as well as "Motorway service station" are basically used for intermediate charging. The "Suburban area" here is likely to be used for intermediate and destination charging, due to its peripheral position and potential use as alternative route to the motorway.

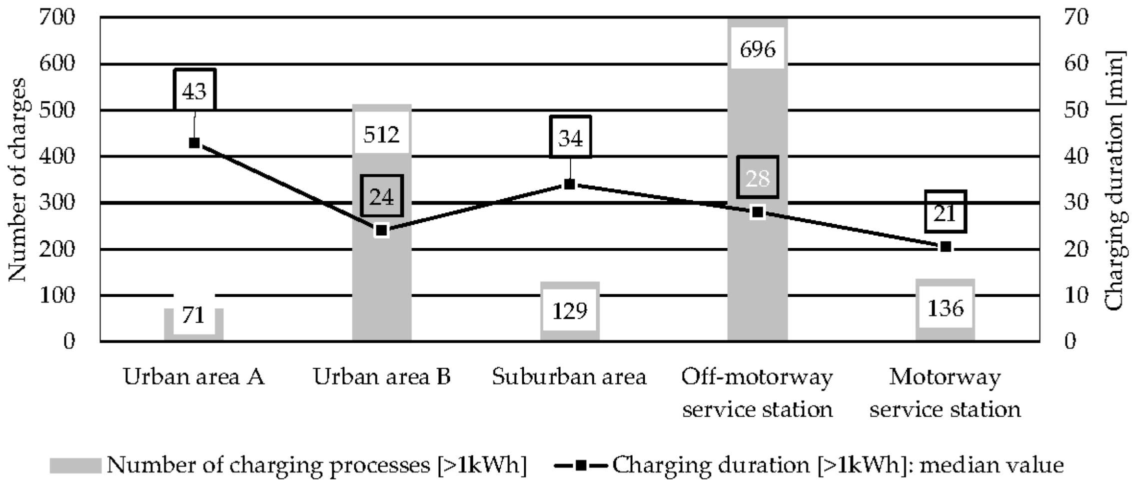

Figure 4. Median-charging duration at five different locations in the SLAM-Network. (Only DC-charging processes were considered. The operating period differs between 209 and 523 days. The number of chargers per location varies between 1 and 4; due to the currently small number of charging processes, no significant impact is expected.)

The most interesting fact is the difference in charging duration between "Urban area A" (43 min) and "Urban area B" (24 min). That difference might influence a potential business model significantly.

From a business perspective, fast-charging at destinations leads to several challenges:

First, charging capacity for fast-chargers are highly performant and therefore expensive. Somehow, the operator needs to refinance his investment. A classical approach is to sell the current or rather the charging time at a charging station. Four general types of tariffs can be distinguished: billing by energy consumption (kWh per charging session), time (minutes per charging session), paying a fixed session fee or a flat rate. Combinations of theses billing options are also offered by the market. At a location in central Germany, customers are paying a fixed session fee of 2 EUR plus 0.25 EUR per kWh [14].

Another business model is to utilize the fast-charging station as competitive factor to attract customers from competitors, consequently acting as a value-added service for the main business (e.g., at restaurants and shopping malls). In that case, the charging service is usually (as of today) offered at no or rather low costs. The German discounter ALDI for example has successfully introduced free fast-charging at many of its locations and the brand is also benefiting from the green image of electric vehicles [15]. Because of free charging, EV users are accustomed to use the charging lot during their whole stay at a destination, as there is no incentive to move the vehicle and free the charging point for the next vehicle. A further consequence is that a charging lot at a destination is often blocked for more than a considered period of twenty minutes, even though the charging process has reached 80% state of charge (SOC) already. As soon as operators need to amortize the fast-chargers with charging being the core business, customers need to change their charging behavior to allow for a constant flow of vehicles and therefore a high level of utilization. (This might happen when fast-chargers at destinations will not generate a competitive advantage anymore.) This effect is particularly high with time-based tariffs. One might think that, with the current number of vehicles, capacity of charging stations is not yet an issue—which is mostly true. First locations such as the Tesla charging station in front of the Gotthard Tunnel in Switzerland have seen massive shortages of capacity in the holiday periods with waiting times at the chargers of several hours. The well-known effect of waiting time at crowded gas stations is exponentially increased at electric charging stations as compared to the 5 min of refueling, the 20 min of time needed to fast-charge accumulates vehicles much faster and longer.

Tariffs can have a huge impact on the maximum capacity of a location, which can also be seen in the usage data. Figure 5 shows "Urban area A" where time-based tariffs were introduced on 1 January 2017. The effect was a drop of the median charging time from one hour to only 15–36 min, increasing the theoretical capacity by a factor of two to four. Introducing billing by energy consumption would not have solved the problem of excessively charging time, as the pareto principle can be applied to the charging process. (As a guideline, 0–80% SOC is achieved in 20–30 min, while 80–100% takes a lot longer, due to physical limitation.)

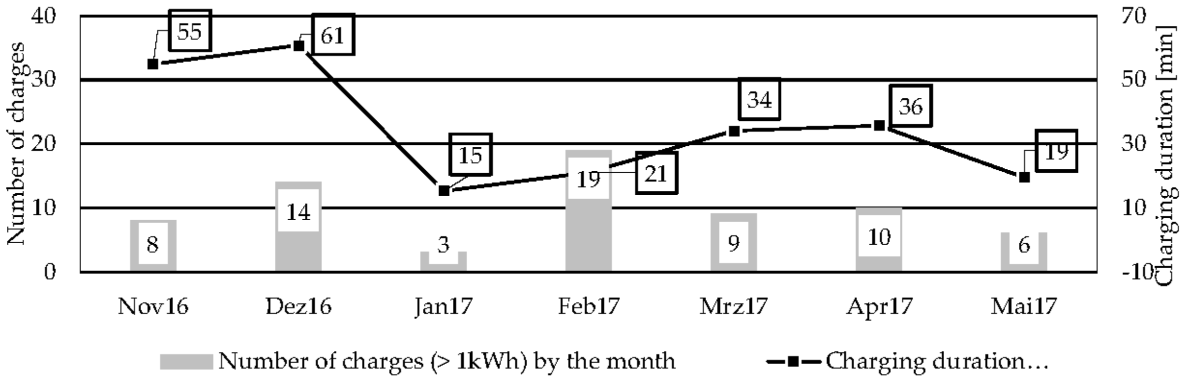

Figure 5. Change of charging behavior after introducing time-based tariffs at location "Urban area A".

Ideally, good utilization of DC fast-charging capacities is characterized by frequent charging processes with length of 15–30 min each [16].

The statements considering the user perspective are to an extent counterproductive with respect to viable business models. Although users prefer the top of the line, fast-chargers mostly exceed charging needs at destinations. Mostly, AC-charging (<22 KW) or lower DC-Charging (20–30 KW) fits perfect to the needs at destinations, as the retention time clearly exceeds the 15–30 min for a fast-charging process.

Data from the SLAM network illustrates that conflict. However, considering the different periods and that few data exist, general recommendations cannot be derived at the moment. Nevertheless, hints were found that an in-depth investigation of the preceding findings is strongly recommended.

4. Conclusions

The results of the studies regarding the user's perspective show that fast-charging options should be located near shopping or leisure areas to generate a perceived benefit by the user. Furthermore, charging locations en route seem to be less perceived as useful than charging options at a destination. However, the results are in contrast to current business model approaches which are not recommending the positioning of fast-charging stations (50 KW or more) at every single location. Factors, such as customers' duration of stay, tariffing as well as the strategic fit to the core business model should be taken into consideration by all means. A possibly perceived contradiction between both perspectives has to be solved in the future.

Furthermore, the evaluation of both perspectives should be linked to energy and urban planning perspectives in future research to enable an optimal solution that considers various current approaches in one model.

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