Well Worth a Detour?—Users' Preferences Regarding the Attributes of Fast-Charging Infrastructure for Electromobility

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Abstract The spread of electric vehicles can be a partial solution for reducing greenhouse gas emissions, which are a major challenge of modern industrial nations. However, the limited ranges and the fragmentary charging infrastructure are currently impediments to adoption. To develop a need-based fast-charging network users' requirements on preferred charging locations have to be factored in. Therefore, the present study aimed at quantifying users' preferences regarding the fast-charging infrastructure and identifying possible trade-offs by using conjoint-analysis. Both current and potential battery electric vehicle users were addressed through an online questionnaire (N = 283). It was revealed that the waiting time for an available charging station, the necessary detour and the charging costs are the most important attributes for the selection of charging locations, whereas possible on-site activities to bridge the charging time were less important. While the attributes' importance was largely independent from trip length, participants' BEV experience contributed significantly to found variance.

Keywords Fast charging · Electromobility · Battery electric vehicles · Infrastructure planning · Evaluation criteria · User requirements · Conjoint analysis

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1 Introduction

Global warming as part of the climate change is one of the major challenges mankind is facing today. Amongst others, the man-made emission of greenhouse gases, in particular CO_2, caused by the burning of fossil fuels is one of the most important factors contributing to the warming of the atmosphere [1]. Therefore, a major aim of modern societies and especially of industrial nations should be to reduce those emissions.

Besides industrial production, the transport sector, especially the motorized private transport, is one of the domains that is heavily responsible for the emission of greenhouse gases [2]. New technologies in this area might initiate a change leading to a more efficient and sustainable mobility. Specifically, a switch of drive technology, i.e., from internal combustion engines to electric drives, should help to reduce emissions and reduce the dependence on fossil, and thereby limited, resources.

Consequently, the German Federal Government formulated the objective to increase the number of vehicles with electric drives in Germany to 1 million by 2020 in its "National Electromobility Development Plan" in 2009 [3]. However, at the present time, only a little more than 25,000 battery electric vehicles (BEVs) are registered in Germany [4]. Although the public perception of electric vehicles is predominantly positive, particularly with regard to the perceived environmental benefits [5, 6], there are still major impediments to adoption that prevent a widespread dissemination of this technology. In addition to the high costs of BEVs and their integrated batteries [7], especially the limited range and the long charging times of electric vehicles as well as the lack of a comprehensive charging network are perceived as major barriers [8, 9].

Therefore, fast-charging technology that enables recharging of a vehicle's battery up to 80 % of its capacity in 20–30 min could alleviate these problems and enable new motion patterns with BEVs, e.g., long-haul travelling. However, the fast-charging infrastructure in Germany is still in the very early planning and build-up phase and predominantly dependent on public funding programs. A major and yet not fully answered question is, where to place the fast-charging stations to establish a both comprehensive and needs-oriented charging network.

2 Related Work and Question Addressed

Implementing a more user-focused design is an important consideration to achieve the aforementioned goals [10]. Therefore, it is necessary to understand both the users' requirements for charging locations and their individual charging behavior. In response to this last point, there has been already a lot of fundamental research done focusing on driving in critical range situations and the psychological concept of range anxiety [11, 12], perceived range comfort zones [13], and the driver's charging behavior in general [14, 15]. The results of these research approaches might be incorporated into recommendations for charging grid densities and the required absolute numbers of charging stations, but the selection of concrete locations for charging stations needs further research.

Indeed, there are already some approaches to factor the user in during the planning and development of charging infrastructure. However, current methods are mostly limited to activity-based [16, 17] or discrete-choice [18] models that are based on users' activity and movement profiles and try to cope with the increasing number of electric vehicles by simulating the regional technology spread [19]. The resulting information about optimal placement is normally limited to local district level; exact locations, for example, on the street level, cannot be proposed or evaluated. Therefore, a further integration of user factors and information about how users assess and select charging locations into the planning models is needed.

In previous focus group discussions, several requirements on charging locations and eight corresponding evaluation criteria have been identified: *dual use of time and route*, *habit compatibility*, *accessibility*, *visibility*, *reliability* in terms of an adequate number of functional and free charging points, *safety*, *connection to the public transportation network*, and *necessity* [20]. It was revealed that users' willingness to spend extra time for detours, waiting for an available charging point and the charging process itself is rather limited. Consequently, users requested to use the charging time meaningfully by parallel on-site activities.

However, the weighting of these evaluation criteria during the selection of charging stations is yet unknown. In real-world scenarios, charging locations rarely can fulfill all the users' requirements in an ideal way. Therefore, the selection process is always a trade-off between possibly conflicting objectives that presumably depend on type and length of the trip. Additionally, the prior experience with BEVs could influence the trade-off decisions, as it affects the handling of range limits [11, 12] and the general evaluation of electromobility [21].

The present work aimed at identifying possible trade-offs by quantifying the preferences of both early adopters and potential future users regarding the attributes of fast-charging infrastructure in different trip scenarios.

3 Method

A questionnaire utilizing conjoint analysis was used to address the research question. In the following, the development of the questionnaire and the design of the conjoint analysis will be presented in detail. Subsequently, a short summary of data acquisition, preparation, and statistical analysis will we reported. Last, the gathered sample will be introduced.

3.1 Questionnaire

Based on the aforementioned findings from focus group discussions [20], a questionnaire was developed. It aimed at quantifying the trade-offs between different attributes of charging stations that are considered during the driver's decision making process. Therefore, the questionnaire consisted of two parts. The first part dealt with personal information of the participants, especially demographic data like age, gender, occupation, and income. Additionally, (e-)mobility-related behavior in terms of general attitude toward electromobility, car use, annual mileage, charging possibilities at home or at work, and, if appropriate, range and connector types of the used BEV were queried. To gain an impression of the participants' technical affinity, Beier's inventory to gauge technical self-efficacy [22] was used. The second part of the questionnaire used a conjoint measurement to research the participants' selection of charging locations.

3.2 Conjoint Study

To explore participants' preferences regarding the selection of charging locations, a choice-based conjoint (CBC) design was used. This method addresses the problem that trade-offs between user requirements can hardly be measured by conventional question designs in terms of an isolated rating of charging station attributes.

To take different trip lengths into consideration, a scenario-based approach was used. One scenario dealt with long-haul trips, mainly on highways, and the other broached the issue of short-haul trips in terms of everyday urban driving. The trip scenario was designed as within-group factor; thus, every participant had to answer two separated sets of conjoint-related questions. To address possible knowledge gaps and to create a more uniform basis of decision-making, participants were told that they would need 25 min to recharge their BEV and their battery's capacity was sufficient for a 100 km drive which complies with current BEV's typical performance characteristics.

The selection of attributes and their levels (see Table 1) was based on focus group findings. The first two attributes were derived from criteria of *dual use of time and route*. Consequently, possible on-site activities to spend the charging time constitute the first attribute. Its levels distinguish between a productive use of time, activities just to keep busy, and no parallel activities at all. The second attribute dealt with the detours that are necessary to reach the charging location. Concrete distances between 0 and 15 km were used to specify no, small, medium, and large detours. The distances varied between the short- and the long-haul scenario to be more adequate. The third attribute was deduced from the *reliability* criteria. Users in focus groups requested an immediate charging possibility after arriving; therefore, the waiting time for an available charging station was the next used attribute. The levels varied between no waiting time at all and 30 min. The last attribute was not

Table 1 Attributes and associated levels used in conjoint analysis

Attributes	Possible parallel activities to spend charging time …	Charging costs	Necessary detour	Waiting time for an available charging station
Levels	… productively	100 % of fuel costs	15 km [a]	30 min
	… keeping busy	75 % of fuel costs	10 km	15 min
	None	50 % of fuel costs	5 km	5 min
		Free charging	2 km [b]	None
			None	

[a]used only in long-haul scenario
[b]used only in short-haul scenario

based on focus group findings but should help to research whether financial incentives influence the charging location selection. Due to the current confusing and very heterogeneous market situation, it was expected that concrete prices are not assessable for non-users. Therefore, more abstract levels were used, matching charging costs to conventional fuel costs needed to achieve the same range. All levels were introduced to the participants before the actual questions and illustrated with additional graphics. Especially the levels of the parallel activities attribute were described in detail, e.g., activities to spend the charging time keeping busy meant activities the participants might enjoy but would not do without charging, like getting a coffee to keep boredom at bay.

For both scenarios, participants had to carry out ten tasks each. A task consisted of a selection of the preferred charging location out of four randomly composed alternatives based on the predefined attributes and levels. There was no possibility to skip tasks or use a "none of these"—option.

3.3 Data Acquisition, Data Preparation and Analysis

The survey was conducted via online-channels. It was spread in the social environment of the authors and at the university as well as by using social networks and expert forums dealing with (e-)mobility. The aim was to acquire both early adopters, in terms of current BEV users, and potential users, i.e., participants who are strongly interested in electromobility but have no purchase intention yet due to the already introduced barriers. Although a total of 326 participants completed the survey, 43 who stated that they are absolutely not interested in electromobility were removed to focus on the aforementioned user groups.

Hierarchical Bayes (HB) estimation was used to analyze the CBC-data by computing the attributes' relative importance scores as well as the corresponding part-worth utility values for each participant. In addition, non-parametric methods were used for scenario and user group comparisons. The level of significance was set to $\alpha = 0.05$ and two-tailed tests were used for the statistical analysis.

3.4 Sample

A total of 283 (N) participants have been included in the analysis. 214 (78.1 %) were male, 60 (21.9 %) female. The age ranged from 19 to 82 years with a mean of 42.40 years (SD = 14.80). The educational level was rather high; in particular, 183 participants, and thus nearly two-thirds of the sample (64.6 %), stated that they had achieved a university degree. 16.2 % (n = 46) of them were even graduated. The second most frequent educational attainment was graduation from high school (n = 59, 20.8 %), followed by completed vocational trainings (n = 27, 9.5 %) and secondary school (n = 14, 5.0 %). Most participants were employed (n = 169, 59.7 %), whereas 62 (22.0 %) were still in training or education and 25 (8.8 %) were retired. The technical self-efficacy in the sample was rather high with M = 3.71 (SD = 1.01, scale min = 0, scale max = 5).

Mobility Behavior and Charging Possibilities. 63.0 % of the participants (n = 178) reported that they drive more than 10,000 km per year. 199 participants (70.8 %) stated they would be able to charge a BEV at home with no or little effort, whereas 74 (27.1 %) could charge at work. Concerning prior experience, 55 participants (19.4 %) indicated that they already use a BEV as private or company car. 92.7 % of these (n = 51) used it on a daily base and 29.1 % (n = 16) used BEVs with fast-charging compatible plugs like CCS or CHAdeMO. The most frequent ranges achievable with one battery charge were 100–150 km (n = 27, 49.1 %) and 50–100 km (n = 12, 21.8 %).

4 Results

Hereinafter, the results of the survey will be presented in detail. First, the relative importance of the charging stations' attributes as well as the part-worth utilities will be introduced for the complete sample. Second, the effects of BEV experience on the attributes' relative importance will be presented.

4.1 Model Fit and Relative Importance Scores

The HB model's goodness of fit was determined by the root likelihood (RLH) that could vary between 1 (best) and 0.25 (worst) under the present CBC design with

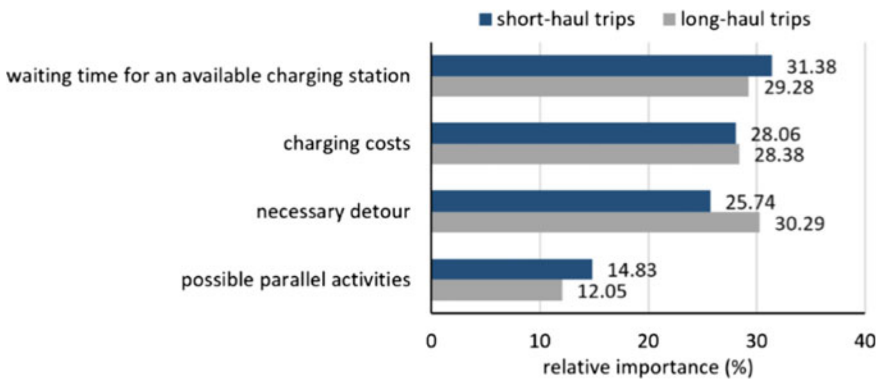

Fig. 1 Average importance of charging stations' attributes for short-haul and long-haul trips

four choices. The calculated RLH was 0.61 for the short-haul and 0.64 for the long-haul scenario.

Average importance scores for all attributes were calculated to quantify how they contribute to the participants' decision making. A full overview about the scores for both short-haul and long-haul trips can be found in Fig. 1.

Concerning short-haul trips, the necessary waiting time for an available charging station was most important, followed by charging costs and the detour necessary to reach the charging location. These three most relevant attributes had a relative importance of roughly 30 %. In contrast, the lowest importance value deviated clearly and was the possibility to bridge the charging time with parallel activities.

In comparison to short-haul trips, the order of importance changed in the long-haul scenario. In particular, necessary detours got the highest average importance value. The most important attribute for short-haul trips, i.e. the needed waiting time for an available charging station, was only the second most important factor regarding the selection of charging stations on long-haul trips. However, the importance of the latter two as well as of the third most important attribute, i.e. the costs for charging, again were approximately the same with values approximately 30 %. Likewise, the on-site possibility for parallel activities had the lowest relative importance value by a clear margin.

The comparison of short-haul and long-haul trips revealed several differences. Both the waiting time for an available charging station and possible parallel activities are significantly more important for short-haul than long-haul trips ($Z_{waiting\_time} = -3.809$, $p < 0.001$ and $Z_{activities} = -4.982$, $p < 0.001$). In contrast, the necessary detour was more important for long-haul trips with $Z_{detour} = -6.424$, $p < 0.001$. The relevance of charging costs for the selection of charging locations did not differ depending on trip length.

4.2 Part-Worth Utilities

Looking at the part-worth utility values of the attribute levels (see Fig. 2), it can be shown that the order of preferences mirrored the designed order of precedence. Accordingly, participants' average preferences decreased from no waiting time for available charging stations at all to the longest waiting time of 30 min. However, the part-worth utility values for no waiting time and a period of 5 min lay close together, whereas the distances between the other attribute levels were considerably higher.

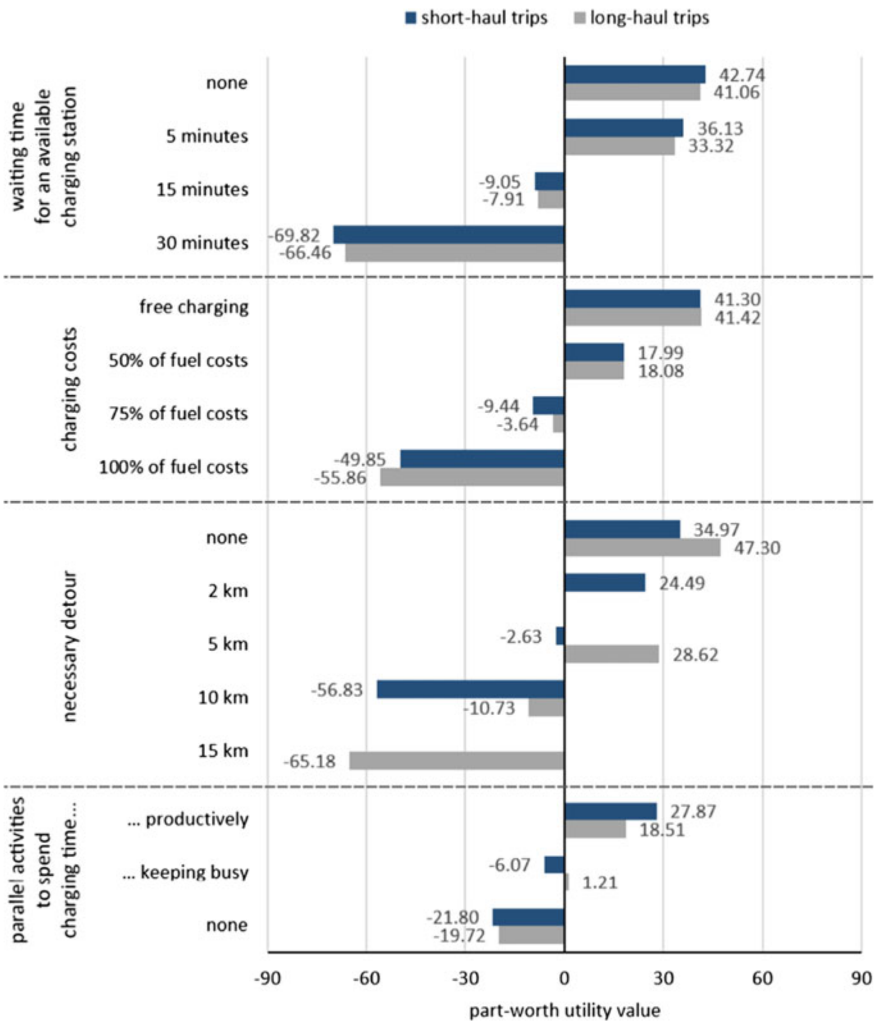

Fig. 2 Part-worth utility values (zero-centered diffs) for charging station attributes distinguished by trip length

Concerning charging costs, it becomes obvious that there is a strict best to worst order. As expected, free charging is preferred most, followed by charging costs about half as expensive as conventional fuel. The other two cost levels, i.e., charging costs of 75 and 100 % of the amount of fuel costs, were considerably less preferred.

A comparable picture has also been obtained for the detour attribute; that is, preferences decreased from no detour at all to the presented maximum detour. Concerning the possible activities to pursue during charging, activities to spend time productively had clear priority over activities to spend time keeping busy. Absence of on-site possibilities for activities parallel to charging got the lowest utility values and was thereby the least preferred level.

Although most part-worth utility values differed between the short- and long-haul scenario to a small extent, there were no differences with regard to the relative order of preferences for all attribute levels. Relating to the detour attribute, the absolute differences of part-worth utilities between the scenarios were bigger in comparison to the other attributes, but due to the different parametrization of this attribute, they were only partially comparable.

4.3 Effects of Prior Experience with BEVs

Taking prior experience with BEVs into account, several differences between the user groups were revealed in both trip scenarios. First, the effects of BEV use in the short-haul scenario will be described (see Fig. 3).

The importance of two charging station attributes differed significantly between BEV users and interested non-users with regard to short-haul trips. The waiting time for an available charging station was more important to BEV users than non-users ($U = 4247$, $p < 0.001$, $r = -0.22$), whereas the necessary detour was

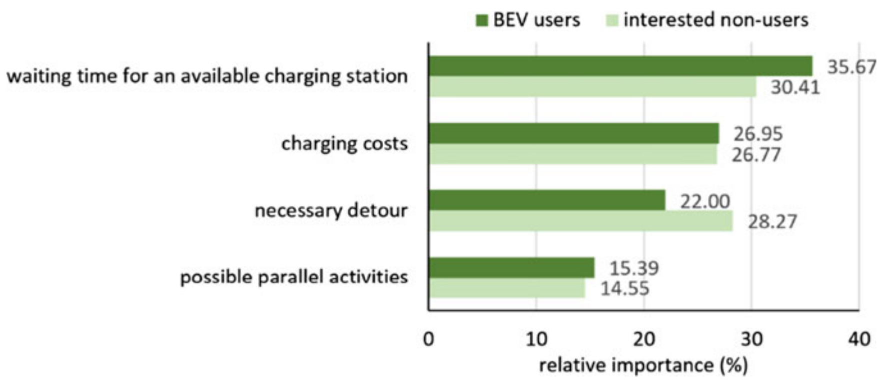

Fig. 3 Average importance of charging stations' attributes for **short-haul trips** distinguished by user groups

more important to participants without BEV experience (U = 4536, $p = 0.002$, $r = -0.19$). In contrast, the importance values of both charging costs and possible parallel activities did not differ significantly depending on the user groups in this scenario.

The mentioned attributes' differences result in different orders of importance, too. Both BEV users and non-users matched concerning the most and least important attribute, whilst detours were more important to BEV users than charging costs, this order reversed for non-users.

Concerning long-haul trips, a comparable picture emerged (see Fig. 4). The attributes' order of importance for BEV users matched the short-haul scenario and the waiting time for an available charging station is more important to users than non-users (U = 3907, $p < 0.001$, $r = -0.26$), whereas the necessary detours were more important to non-users (U = 4725, $p = 0.005$, $r = -0.17$). Once more, there was no significant difference between user groups regarding the charging costs. However, the importance of possible parallel activities was influenced by BEV use in the long-haul context. These activities were more important to non-users than users (U = 4951, $p = 0.015$, $r = 0.14$).

Therefore, the attributes' order of importance concerning non-users changed in comparison to short-haul trips. The necessary detours were the most important attribute for non-users during the selection of charging locations, whereas charging costs and the waiting time for an available charging station followed jointly in second place (n.s. differences between attributes). Accordingly, possible parallel activities at charging locations played by far the least important role.

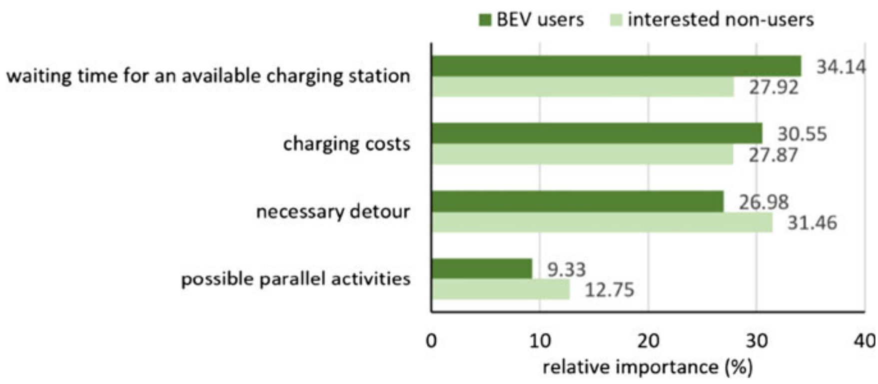

Fig. 4 Average importance of charging stations' attributes for **long-haul trips** distinguished by user groups

5 Discussion

The present study aimed at quantifying users' preferred attributes of fast-charging stations for electromobility to factor them in during planning and development processes. To know users' preferences is necessary for establishing a comprehensive charging network that is need-based and no longer perceived as barrier to adoption.

It was revealed that the waiting time for an available charging station, the charging costs, and the necessary detour to reach a charging location are the most important attributes considered during the user's selection process. All three attributes shared nearly the same importance level, i.e. accounting for about 30 % of the user's decision. Following the 'time is money' principle, monetary incentives in terms of low charging costs theoretically can almost equally compensate high waiting times or long detours. However, the nearly equal importance of waiting times and detours was not expected, because while both attributes imply a loss of time, detours additionally cause a range reduction and extra charging costs. This finding might be caused by different possible uses of time; in particular, activities during detours are limited to driving, whereas more varied actions are possible in or around parked vehicles during the wait for an available charging station. Furthermore, detours are predictable for familiar charging locations, whereas the occupancy rate at a station can be a factor of uncertainty, if not retrievable in advance, for example, by web-based services. Therefore, further studies should address the effects of underlying factors, e.g., contrasting loss of time and loss of range as well as uncertainty and calculability. Surprisingly, in contrast to expectations after the focus group discussions [20], the fourth researched attribute in terms of possible activities at a charging site was identified as least important for a user's selection process. Although locations that enable activities to bridge the charging time productively were preferred to locations that only enable to kill time or offer no activities at all, this characteristic might be disregarded, if the other location attributes offer enough perceived benefits. As a consequence, charging stations at shopping or recreation facilities as requested in [20] can be a good choice of location, but stations will only gain market share there, if waiting times, charging costs, and necessary detours will not contradict this locational advantage.

Further, the meaningfulness of revealed part-worth utilities is somehow limited, because, due to the measurement scale that is limited to relative preferences, it was not possible to identify absolute deal breakers that would prevent the selection of a certain charging station completely. It is still unclear what the turning points of attribute levels are, for example, which amount of detour, waiting times, or charging costs would lead to a complete dismissal of a charging location. Currently, it can be only stated that, for example, waiting times of 0 or 5 min seem to be rated nearly equal, whereas delays beyond 15 min are considerably less preferred. To identify crucial criteria for location selection, further studies with a more adaptive conjoint analysis design flanked by isolated ratings will be necessary.

Concerning trip scenarios, the current study could not reveal major differences. Although, detours were more important on long-haul trips, which might also be influenced by deviating parameterization of distance levels, the trip length had no decisive influence on the attributes' order of importance. However, the current study used only two abstract scenarios to utilize short- and long-haul trips. The next step will be to use more precise distance information to contrast trip length and maximum BEV range, especially with regard to the number of necessary charging stops. Furthermore, the types of trips, e.g., business trips, trips for shopping or leisure activities, or holiday journeys, should be taken into consideration.

Finally, the effects of BEV experience were analyzed. It was shown that users and non-users currently differ regarding the importance of waiting times and detours, whereas there basically is consensus regarding charging costs and parallel activities. Although the emerged picture was not completely uniform, the revealed commonalities should be helpful for establishing a charging infrastructure that can cope with the requirements of both the current early adopter group and potential future users who, as of yet, perceive the status of the charging network expansion as impediment to purchase.

However, the effects of prior BEV experience were only small and therefore can explain only a small amount of the identified variance. Consequently, further user factors should be taken into consideration in future studies. To start with, emphasis should be placed on demographic factors, e.g., gender, age, or residential information, that can usually be acquired from public authorities at street or at least district level. Although a deeper understanding of the charging location selection, that might also include further human factors, should be aspired, the consideration in simulation tools for infrastructure planning is limited to the available data base.

In conclusion, the present work is one of the first steps to measure user requirements on concrete charging station placement. The obtained findings could be implemented in concepts and simulations for charging location evaluation that aim to predict how specific site characteristics contribute to the acceptance and use of fast-charging infrastructure to be built. Based on the relative weights of individual importance levels, information about the planned location, and with respect to underlying business models, it can be assessed, for example, whether the site offers the opportunity for parallel activities and, thereby, allows a positive utilization forecast, or whether a location is well worth a detour.

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