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Booking Public Charging: User Preferences and Behavior towards Public Charging Infrastructure with a Reservation Option

Michael Hardinghaus [1,*], John Erik Anderson [1], Claudia Nobis [1], Kerstin Stark [1] and Galya Vladova [2]

[1] German Aerospace Center (DLR), Institute of Transport Research, Rudower Chaussee 7, 12489 Berlin, Germany
[2] hySOLUTIONS GmbH, Burchardstraße 21, 20095 Hamburg, Germany
* Correspondence: michael.hardinghaus@dlr.de

Abstract: Electric vehicles offer a means to reduce greenhouse gas emissions in passenger transport. The availability of reliable charging infrastructure is crucial for the successful uptake of electric vehicles in dense urban areas. In a pilot project in the city of Hamburg, Germany, public charging infrastructure was equipped with a reservation option providing exclusive access for local residents and businesses. The present paper combines quantitative and qualitative methods to investigate the effects of the newly introduced neighborhood charging concept. We use a methodology combining a quantitative questionnaire survey and qualitative focus group discussions as well as analyses of charging infrastructure utilization data. Results show that inner-city charging and parking options are of key importance for (potential) users of electric vehicles. Hence, the neighborhood concept is rated very positively. Providing guaranteed charging and parking facilities is therefore likely to increase the stock of EVs. On the other hand, this could to a large extent lead to additional cars with consequential disadvantages. The study shows that openly accessible infrastructure is presently utilized much more intensely than the exclusive option. Consequentially, the concept evaluated should be part of an integrated approach managing parking and supporting efficient concepts like car sharing.

Keywords: electric vehicles; public charging infrastructure; neighborhood charging; reservation system; urban; city; Hamburg

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1. Introduction

Electric vehicles (EVs) offer one effective solution to reduce greenhouse gas emissions in passenger transport when using electricity from renewable sources [1–3]. However, a major challenge remains for electric vehicles: adequate public charging infrastructure must be provided. The lack of a comprehensive public charging infrastructure network is still one of the main challenges facing the uptake of electric vehicles [4,5].

In a review paper, Hardman et al. examined consumer preferences and consumer interactions with charging infrastructure to gain insights into improving this infrastructure [6]. The authors conclude that easier access to infrastructure is required. Hardman et al. also state that home charging is the most important location followed by work and then public locations [6]. In another paper, Lopez-Behar et al. identify the "chicken-and-egg" problem with public charging infrastructure: consumers will not purchase EVs until there is sufficient infrastructure, but infrastructure providers require a sufficient number of EVs in the market to supply charging stations [1]. Thus, the research shows that adequate public charging infrastructure is required for the successful uptake of EVs.

The identification of public charging infrastructure as key to the success of electric vehicles has led to numerous efforts to quantify and locate public charging stations. Grote et al.

developed a methodology to select locations for public charging stations using geographical information system (GIS) analysis of census and parking data [2]. Their methodology provides recommended locations for public on-street infrastructure. In another paper, Funke et al. examined the very fundamental question of how much charging infrastructure is required for electric vehicles [3]. In a similar paper, Gnann et al. looked at current and future demand for charging infrastructure, but limited their analysis to fast-charging stations [7]. Schulz and Rode conducted a general survey of the national uptake of electric vehicles and the buildup of infrastructure in Norway, which is seen as a leader in the uptake of EVs [8]. At a more local scale, Hardinghaus et al. presented the approach of implementing public charging infrastructure in Berlin, Germany [9,10]. Subsequently, the authors analyzed real-world charging derived from this infrastructure to provide recommendations for future locations of charging stations [11]. The authors also examined the role of carsharing vehicles on demand for public infrastructure. In another paper, the authors estimated charging demand, accounting for different user groups, technical developments, infrastructure availability, and carsharing development [10].

Numerous other researchers have analyzed electric vehicles and charging infrastructure in detail. Lee et al. examined charging behavior of real-world users and identified factors influencing charging location (i.e., gender and age, vehicle attributes, commute, and workplace infrastructure) [12]. Metais et al. conducted a review of all models available for charging infrastructure planning and provided insights for improvements based on real-world conditions [13]. In another paper, Chen et al. reviewed the overall landscape of electric vehicles and charging infrastructure for the national case study of the United Kingdom [14]. Regarding charging infrastructure, they identified three factors critical to site selection: design, location, and cost. Pagani et al. used an agent-based model to simulate the impact of individual behavior on charging infrastructure [15]. Wolbertus et al. used stated- and revealed-choice experiments to estimate the effects of policy measures on EV adoption and charging behavior [16]. Li et al. estimated charging demand to plan charging infrastructure requirements based on usage data in Beijing, China [17]. Zhou et al. used charging behavior and access to infrastructure to determine optimal range for electric vehicles [18]. Pagany et al. conducted a review of location methodologies for infrastructure, and identified a lack of empirical data from electric vehicles [19].

In another article, Chakraborty et al. identified the factors driving charging demand as cost, driver characteristics, infrastructure access, and vehicle attributes [20]. Fang et al. used an evolutionary game model to consider policies and user behavior to promote charging infrastructure [21]. Tao et al. optimized real-world data for the spatial layout of charging stations [22]. Chen et al. investigated the sociodemographic, behavioral, economic, and technical factors of electric vehicles [23]. Zhang et al. estimated infrastructure demand for shared autonomous electric vehicles utilizing an agent-based simulation model [24]. Ou et al. assessed the impact of charging infrastructure on electric vehicle ownership [25]. Gnann et al. simulated the impact of charging infrastructure use on electrical vehicle sales, with a particular focus on public slow infrastructure [26]. Schmidt et al. evaluated the impact of user behavior on the use of charging infrastructure at public destination locations [27]. Philipsen et al. used qualitative interviews and a quantitative comparison to analyze user charging behavior compared to refueling with fossil fuels in traditional vehicles [28]. Teoh examined charging strategies for urban freight via a two-level charging strategy [29]. However, despite this breadth of research on public charging infrastructure a key question remains: what kind of charging infrastructure is suitable for the needs of urban residents in densely populated urban areas and how shall this infrastructure be provided?

Lopez-Behar et al. state that an overwhelming majority of charging events occur at home [1]. The authors find that densely populated residential areas, however, present a particularly challenging context for the adoption and use of private electromobility due to the lack of off-street parking spaces [1]. This in turn requires that users charge at on-street charging stations and share them with several EV drivers. In another paper exploring how much charging infrastructure is required for EVs, Funke et al. also indicate the particular challenge of public infrastructure [3]. They state that home charging must be supplemented with public charging infrastructure in densely populated areas [3]. In examining user preferences for charging infrastructure, Globisch et al. found that most users are not willing to pay a basic fee for public charging; however, specific groups will value public charging more [30]. These groups could likely include residents in dense urban areas without private charging options at home or work.

Creating adequate charging opportunities in dense urban areas is required for the successful uptake of EVs. However, providing this infrastructure is generally more complex than providing private infrastructure [1]. Complicating factors are manifold and include financial, technical, institutional, and administrative (resistance from stakeholders) barriers; public acceptability, legal or regulatory (regulatory and policy gaps, potential legal challenges, and planning restrictions) factors; and physical (spatial constraints for infrastructure installation and availability) issues [1].

Thus, while significant research has been conducted on electric vehicles and charging infrastructure, there is a research gap on how to successfully provide public charging infrastructure in dense urban areas with a focus on operational design. To address this research gap, we selected Hamburg as a real-world case study to investigate public charging infrastructure in dense urban environments. Hamburg is an interesting case study for several reasons. Firstly, Hamburg leads in the share of EVs [31] and public charging infrastructure [32] in Germany. In addition, there are numerous government initiatives to promote the uptake of electric vehicles and the buildup of charging infrastructure in the city. Finally, Hamburg also has a notorious shortage of parking spaces in residential urban areas. The detailed information about the Hamburg case study is presented in the following section.

We research an innovative new concept called "neighborhood charging" deployed in Hamburg, Germany. The concept aims to create attractive framework conditions for EVs in densely populated areas, thus fostering EV adoption. The objective of the present research is to evaluate the effects of this new concept. The main features of the concept include charging stations in public spaces limited to registered users (i.e., residents and residing businesses in the area). An app provides users with authorization to charge at this charging infrastructure with an option to reserve. The app also provides an overview of reservation slots (reservation conditions, weekly coupons) and is supported by technical features (i.e., parking barriers), which restrict access to the infrastructure for unauthorized users. This neighborhood charging concept is developed within the framework of project ELBE (Electrify Buildings for EVs) with the financial support of the German Federal Ministry for Economic Affairs and Climate Action. It is currently being tested in two pilot areas in Hamburg. The pilot phase started in June 2021 and is planned to end in September 2022.

This paper offers lessons learned from quantitative and qualitative analysis of the neighborhood charging concept as well as a study of the infrastructure use. The current research was conducted from July 2021 to February 2022. The initial pilot phase was followed by adoption of the concept and the release of the adjusted concept in March 2022. The findings provide lessons to address the challenge of providing public infrastructure in dense urban areas. The paper is organized as follows: in the following section we outline the methodology of the research project and provide specific information for the case study. This is followed by the results section, where the findings from the analysis are presented and summarized. We then present a detailed discussion of the findings and their implications for public charging infrastructure. Finally, the conclusions and limitations of the research project are summarized.

2. Materials and Methods

The study follows a mixed-methods approach and combines methods from qualitative and quantitative research paradigms [33]. The section is structured as follows: first, we describe the case study of Hamburg to provide insight into the relevant framework conditions that are present in the study area. In addition, we describe the features and rules for the concept of neighborhood charging allowing residents and local businesses to book an exclusive public charging stations in advance. Second, we describe the user survey researching potential users of the neighborhood charging infrastructure. This module combines a quantitative questionnaire survey as well as qualitative focus group discussions. The objective was to investigate basic data of the potential users as well as motives, drivers, and odds of adopting the concept of neighborhood charging. For both methods, conceptualization and procedure are described in detail. Third, we present the analytical framework and the evaluation criteria/indicators applied for the utilization data analysis. In addition, we conduct a spatial comparison between the concept of neighborhood charging and openly accessible infrastructure in a defined control area and evaluate their temporal development.

2.1. Case Study in Hamburg

The city of Hamburg has seen a significant rise in the share of electric vehicles over the last decade. As of January 2022, 11.5% of all commercial vehicles and 1.7% of all privately owned vehicles in the city have been electric vehicles (BEV or PHEV) [34]. The market share of BEV and PHEV is rapidly increasing and accounted for 16.9% of all new vehicle registrations in 2021 [35].

The electrification of the transport sector has been a key priority and a main political goal for the city of Hamburg for years. The city targets and policy objectives are set in the Climate Plan [36] and the Air Quality Plan [37]. Both strategic documents foresee a comprehensive package of local rules, incentives, and measures that foster the uptake of electromobility in the city. These include binding requirements for the electrification of public transportation and the vehicle fleet of the city administration, the introduction of regulations and privileges for EVs, as well as cooperation with vehicle manufacturers and carsharing companies. A central pillar in the electromobility strategy of Hamburg is the provision of publicly accessible charging infrastructure.

The basis for the development of a needs-based charging infrastructure in Hamburg was laid with the master plan for publicly accessible charging infrastructure approved in August 2014 and revised in 2019 [38,39]. The city presently has over 1,600 publicly accessible charging points, most of them operated by the grid operator Stromnetz Hamburg [40]. The number of charging points is planned to increase to over 2,000 by 2,025.

The publicly accessible charging points are systematically mapped in an online platform, which provides real-time information about the occupation status of all charging stations. New development sites are evaluated against a number of predefined assessment criteria. The locations are assessed both from a provider perspective (e.g., attractiveness of the location, visibility to the public) and from a user perspective (e.g., accessibility, centrality or proximity to specific user needs, links to public transportation).

While expanding its network of public charging stations, the city also invests in innovative ideas for shared use of resources. In the pilot project for neighborhood charging, Hamburg looks to create attractive framework conditions for EVs in densely populated areas with limited parking spaces. The reservable neighborhood charging stations are to provide residents and local businesses without their own parking space with guaranteed access to charging infrastructure.

Reservations are made through a web-based booking system that is accessible to users after registration and account validation. The booking process builds on a personalized coupon system. Each registered user receives three coupons a week and can redeem them in three time slots: daytime (8 a.m.–5 p.m.), evening (5 p.m.–8 p.m.), and night (8 p.m.–8 a.m.). During the day the charging infrastructure can be reserved for up to three hours. The night slot, on the contrary, can be booked as a complete block. Drivers can reserve a charging slot up to two weeks in advance or use the ad-hoc charging option. Cancellations can be made up to 30 min before the charging session starts. Users manage their personal profile information and check their available coupons, and past and upcoming bookings in a user dashboard. The integrated timer function in the dashboard displays the time left until the next reservation is due.

Access to the charging area is regulated by automatic parking barriers, which keep the charging spots free for registered users. The parking barriers are equipped with a replaceable battery and sensors, which report the availability of each charging spot to the system. Those who book the charging spot can open the parking barrier via the website in the selected time window. The floor locks close automatically as soon as the driver has left the parking area.

The reservation system exchanges real-time information with the parking barriers. The sensors in the barriers report on the availability of the charging stations and transmit commands to the floor locks, which open or close according to the booking status. At its core, the booking system manages the reservation requests, the check-ins and check-outs of the users, and the online payment for the charging process. Users do not need to pay a reservation fee for booking the charging stations. They can select between several payment methods and use either a charge card (an existing contract with a charging operator) or ad-hoc charging. The reservation system also controls the coupon generation and redemption process.

To perform its tasks, the reservation system, managed by the company MSU Solutions, is connected to the backend of the charging station operator Stromnetz Hamburg as well to the platform Book-n-Park of the company Green Mobility Solutions (the producer and maintainer of the parking barriers). In the future, the systems should automatically exchange information about the booking process and information for timely updates.

An automated communication process guides the users through their booking and charging activities. The users receive automatic notifications and instant updates of their booking status, such as confirmation of reservation, reminders for check-in, and information about missed timeslots. The stored data files allow for detailed analyses of the users' charging patterns and for tracking technical problems in the system. In addition to this one-way communication channel, the users can also seek direct customer support. This service provides them with fast help in the event of questions about the system or malfunction of the reservation system. Malfunctions of the charging station are reported to the charging station operator. Problems with the parking barriers or the online reservation system are reported to the technical support team of MSU Solutions.

The concept of neighborhood charging is currently being field tested in two densely populated urban quarters. The pilot quarters of Hoheluft-Ost and Goldbek are characterized by high parking demand, a high number of registered electric vehicles, and a high level of utilization of public charging stations. The pilot installation consists of four charging stations (eight charging points with a capacity of 22 kW) and technically equipped parking slots. The reassignment of the parking spots required a special use permit provided by the district administration. The first electric vehicles were able to charge in Hoheluft-Ost as early as July 2021. The neighborhood charging stations in Goldbek commenced operation in September 2021.

2.2. User Survey with Qualitative and Quantitative Methods

The empirical survey design consisted of a questionnaire survey and focus group discussions. These two elements pursued different goals and addressed different target groups. Since very few households in the two pilot areas currently have an electric vehicle, only a few can use the exclusive charging option. For this reason, a holistic approach was chosen in order to address all households from the pilot areas and to investigate both their general acceptance of electric mobility and their acceptance of the new charging concept in their own neighborhood. In addition, focus groups were conducted with selected residents who have a strong interest in electromobility in order to obtain information about potential future users. Early adopters of new technologies generally have specific sociodemographic characteristics and attitudes. For example, middle-aged, tech-savvy males are overrepresented in the group of early adopters of electric vehicles [41]. Later user groups may have different daily routines and different requirements for charging systems. The latter group of users is of great importance for the uptake of electromobility and is therefore central to the current research.

2.2.1. Questionnaire Survey (Quantitative)

In order to identify people with a high interest in electromobility and gain an overall picture of the residents with regard to their mobility and their acceptance of electromobility, a letter from the City of Hamburg and a questionnaire were distributed to all households as a first step. The letter also contained a flyer with information about the exclusive charging option in the neighborhood. In this way, all residents of the neighborhood were informed about the new offer in their area.

The survey topics were:

- general mobility behavior;
- vehicle ownership, ownership of a public transport pass;
- attitudes towards electromobility;
- willingness to buy electric vehicles;
- key decision factors and criteria to switch to electromobility (e.g., importance of charging options);
- attitudes towards electric vehicle charging and the new charging concept in the neighborhood;
- assessment of the traffic situation in the neighborhood;
- sociodemographic characteristics.

In addition, respondents were able to provide their contact details if they were interested in participating in a focus group. The collected information database served as a basis for building the focus groups.

To ensure the linkage to the data from the national household travel survey "Mobility in Germany" (MiD 2017), identical questions were asked [42]. In the city of Hamburg, almost 15,000 people took part in the MiD in 2017. They reported a total of 45,000 trips and answered general questions about mobility. Persons with a high interest in electromobility can thus be linked to the overall distribution in Hamburg.

This paper presents the survey results for the neighborhood Hoheluft-Ost. The survey material (2,230 letters) was distributed immediately after the charging stations were installed and put into operation in June 2021. Residents could either participate in the survey online or complete the attached questionnaire and return it to the City of Hamburg with a postage-paid envelope. With 377 completed questionnaires, a response rate of 17 percent was achieved. With a share of 81 percent, the questionnaire was filled out far more frequently in written form than online.

2.2.2. Focus Groups (Qualitative)

Three focus group discussions were held online using a video conference system. The participants were selected from the survey participants who had agreed to be contacted for further questioning. The two selection criteria were (a) vehicle ownership and regular usage as precondition, and (b) interest versus non-interest in electromobility. Interest was measured by interest in the topic and technology and/or willingness to purchase an electric vehicle. In the pilot quarter of Goldbek 20 volunteers met criteria a and b and were invited; in the pilot quarter of Hoheluft-Ost altogether 22 persons were contacted for the focus group discussions. Three focus groups were formed: two of them contained participants with interest in electromobility—one with seven, the other with four participants. The third focus group contained five participants that were selected because they had no or little interest in electromobility. None of the participants had ever used the new neighborhood charging service and most of them had no or little experience operating an electric vehicle.

Guiding questions addressed the following topics: electric vehicle purchase decisions, availability of parking space in the neighborhood, requirements for charging practice and charging infrastructure, and attitude towards/interest in/acceptance of the tested charging concept, which was illustrated and described during the discussion. The participants were encouraged to give suggestions for the concept's improvement as well as recommendations for the promotion of electromobility in Hamburg in general.

The video recordings (the participants were asked beforehand and all agreed with the recording of the discussion) were transcribed completely word-for-word and analyzed in MAXqda following the method of content analysis following Kuckartz [43].

2.3. Analyses of Utilization Data

The approach for analyzing the charging infrastructure utilization data compares the utilization of charging infrastructure with reservation option in the study area to those without reservation option in the same study area, as well as in a defined control area consisting of two districts. First, we describe the approach to comparing study areas and the control area as well as the process of selecting the control area for comparison. Second, we describe the analytical framework and define the evaluation criteria. Third, we compare and evaluate the defined criteria in the study and the control area. Prior to that we briefly describe the content of the dataset.

All charging stations (neighborhood charging and openly accessible) are operated by the local grid operator Stromnetz Hamburg. In the backend, comprehensive data on each charging process are recorded. The data cover information on the location of the charging station, date and time of start and end of the process, charging power, energy consumed, and user ID. The data are derived directly from Stromnetz Hamburg. Unrealistically short events with no transmitted energy as well as data resulting from service operations by the operator were removed. After validating and cleaning the data, a total of 18,811 charging events were included in the analyses. 863 events took place at eight neighborhood charging stations with a reservation option. 17,948 events were assigned to 50 openly accessible charging stations, both in the study area and in the control area. The period under observation was filtered from 1 October 2021 to 28 February 2022.

To evaluate utilization of the infrastructure, we draw two comparisons. On one hand, we compared the utilization of charging stations with a reservation option to the utilization of nearby charging stations in the same study area (the districts of Goldbek and Hoheluft-Ost). On the other hand, we evaluated the utilization in the control area, which has no implementation of additional charging stations with a reservation option but is of a similar structure than the study area. To define the control area, we used the statistic units as smallest common administrative division. Selecting the control area was based on data in several categories regarding location, size, inhabitants, number of vehicles, number of EVs, vehicles and EVs per 1,000 inhabitants, number of public charging stations, utilization rate of public parking spaces, and ratio between EV and charging stations.

Subsequently, we defined quantitative criteria for evaluating the utilization of the charging stations We identified two categories with various criteria of interest. These are presented in Table 1.

Table 1. Evaluation criteria for the utilization of public charging infrastructure.

Category	Criterium	Unit
Efficiency	Number of charging events per day and charging station	Charging events
	Delivered energy per day and charging station	kWh
	Delivered energy per event	kWh
Utilization	Utilization rate: ratio between all hours and connected hours per charging station	%
	Estimated charging power	kW

Finally, we calculated the values of the defined criteria for all charging stations in the study area and the control area. In addition, we evaluated the values and drew comparisons between the study area and the control area.

3. Results

In this section, the results of the study are presented. The results are structured according to the methods. In the first section of the user survey, results of the questionnaire survey and the focus groups are presented. Subsequently, results of the utilization analyses are described.

3.1. User Survey with Qualitative and Quantitative Methods

3.1.1. Results of the Questionnaire Survey (Quantitative)

The presentation of the results starts with a comparison of the sample with the official statistical data for Hoheluft-Ost to show how close official statistical data and the sample distribution are. Subsequently, the presentation of the results is structured along the following three topics: first, the general attitudes towards electromobility are described. Second, the willingness to purchase electric vehicles and the according role of various factors is evaluated. Third, the evaluation of the concept of neighborhood charging by the residents is presented.

Comparison of the Sample with Statistical Data

Compared to the official statistics of the district (i.e., data of the statistical office for Hamburg and Schleswig-Holstein 2020), the survey sample is characterized by a disproportionate participation of men and persons aged 45 to under 65 years (Table 2). Another noticeable aspect is the high participation of people with a university degree. There is no official benchmark for the neighborhood itself. According to MiD 2017 [42], the figure for the city of Hamburg is 35%. Even though this value will be higher in inner-city neighborhoods, the proportion of 75% with a college or university degree in the survey sample indicates a clearly disproportionate participation of people with a high level of education.

Table 2. District of Hoheluft-Ost: sample characteristics compared to official statistical data.

		Own Survey	Official Statistical Data *
Age	21 to <45 years	42%	47%
	45 to <65 years	40%	34%
	65 years and above	18%	20%
Sex	Women	46%	53%
	Men	54%	47%
Education	College or university degree	75%	/
Household size	Single-person households	36%	63%
	Multi-person households	64%	37%
Vehicles per 1,000 inhabitants		416	335
Average number of vehicles per household		0.8	0.5

* Data of the statistical office for Hamburg and Schleswig-Holstein 2020.

The proportion of multi-person households is also noticeable. According to official statistics, the share of multi-person households in Hoheluft-Ost is 37%, while it reaches 64% in the survey sample. This is accompanied by a very high vehicle ownership rate, which is also significantly higher than the official values for the neighborhood. In summary, men with a high level of education from multi-person households that own at least one vehicle are represented in the sample with above-average frequency. Given the subject matter and the experience of the MiD that, for example, households with cars are more likely to participate in mobility surveys, this is in line with expectations.

General Attitudes toward Electromobility

Although only a handful of respondents have an electric vehicle in their household (6 of the 377 respondents reported owning an electric vehicle and 14 reported owning a hybrid vehicle), respondents' attitudes toward electric vehicles are to a high extent based on personal experience with electric vehicle use: 39% have already driven an electric vehicle themselves, and a further 17% have used them as passengers. It is not possible to say whether this includes charging experience.

Carsharing fleets are an important access point to electric vehicles in the quarter of Hoheluft-Ost and in Hamburg in general, as many of the fleets are at least partly electrified. Slightly more than half of the respondents have a membership in a carsharing platform. While 63% of carsharing members have already driven an electric car themselves, only 13% of non-members reported the same. When the use of car sharing as a passenger is also included, it is seen that three-quarters of carsharing members have experience of using electric cars. Among people without carsharing membership, this applies to only a third.

In terms of attitudes toward electromobility and transportation in general—measured by assessing items on a 5-point scale—the picture is as follows: half of those surveyed are personally interested in electromobility. They consider special privileges for electric cars, such as reserved parking spaces with charging options, to be very good. The technology itself, on the other hand, is viewed quite critically: 45% do not have confidence in the range of electric cars. They are reluctant to rely on public charging stations. For a good half of those surveyed, the purchase of an electric car only makes sense if they have their own parking space with charging facilities. One reason for the cautious assessment of the technology is the very high demands placed on cars: 77% state that a car must be usable for all driving purposes, both in everyday life and for longer trips (Figure 1).

Electromobility is only partially seen as a solution to the environmental problems caused by transportation: 40% see electrification as the future of the car, and for 39% electric cars are an important contribution to environmental protection. However, the larger proportion of respondents selected the answer category "partly" or described the statement as not applicable.

When comparing the different means of transportation, bicycles and public transport perform better than cars: three-quarters of the respondents consider the bicycle to be a good way to get around in town. A good half say that they can make better use of their time by public transport than by car and that public transport is simply superior to the car in the city. This goes along with the view that the car is not a natural part of mobility: 48% of respondents do not believe that the car nowadays is simply a part of life. However, 41% agree (compared to 33% who disagree) that they can save a lot of time by car. Most respondents thus have an ambivalent relationship to the car but own a car despite the location of their home close to the city center and a good connection to public transportation.

Willingness to Purchase Electric Vehicles

Asked about their intentions to buy an EV in the upcoming years, 30% of the respondents considered a purchase to be (very) likely, 44% to be (very) unlikely, and 26% are sure that they will not buy one. In the next step, those interested in buying an EV were asked whether the EV would replace a current car. This is the case for 60% of the potential EV buyers. However, 33% currently do not own a car, so the EV would be the first car in the household. Another 7% indicated that they would purchase an EV as an additional car. The purchase of EVs is therefore by no means just a matter of replacing less-environmentally friendly passenger cars.

The survey also examined the factors that play a role in the purchase of EVs. To this end, respondents were given 12 options that could provide an incentive for purchase. Respondents could indicate on a 5-point scale how important they considered each of the options. The answers give a very clear picture: all options related to charging and driving range are in first place, ahead of all other options such as low purchase prices, purchase premiums, or special lanes for electric vehicles. With 88% and 84% agreement, guaranteed charging options en route and the guarantee of finding a charging option close to home when needed were given the highest importance.

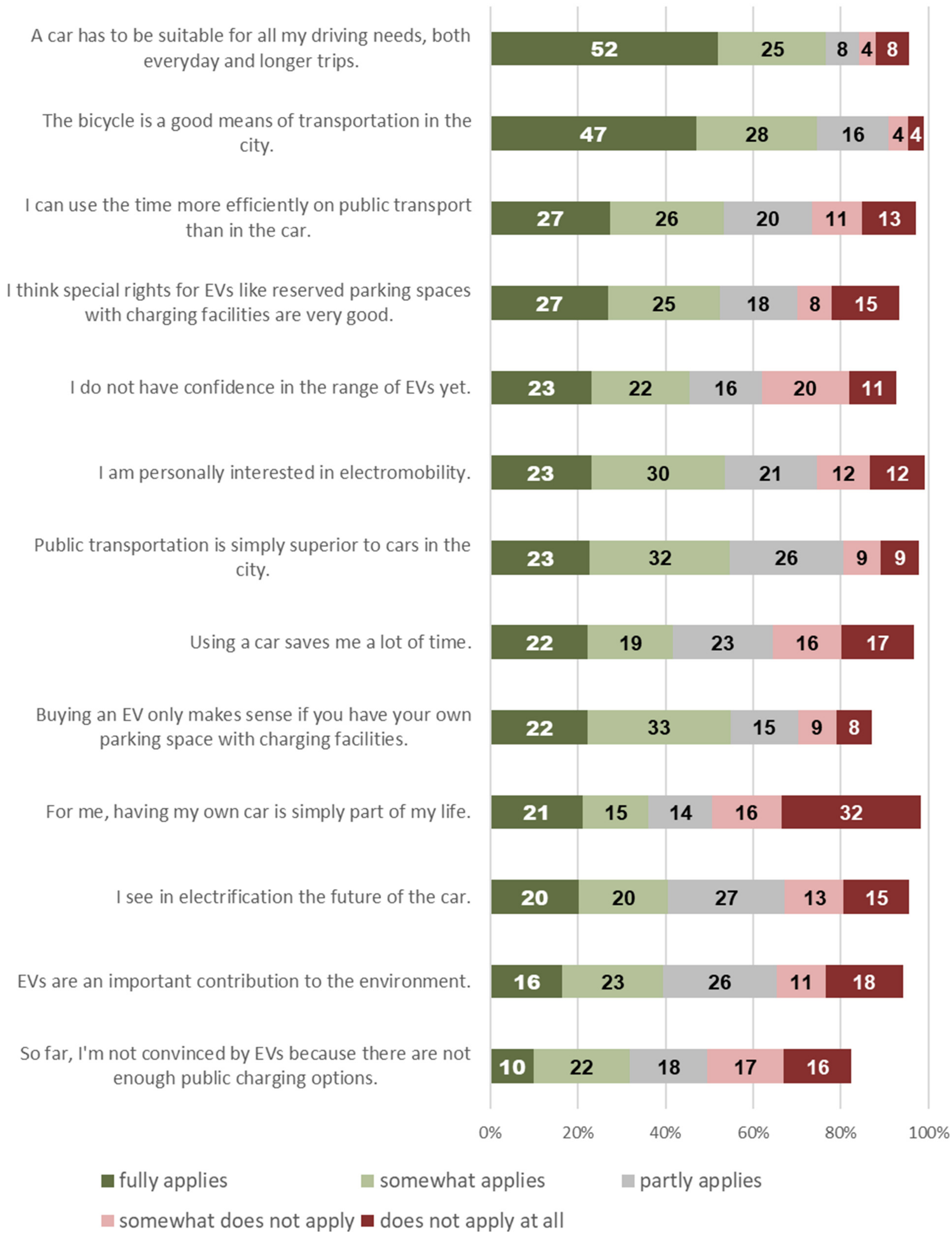

Figure 1. Attitudes towards electromobility and different means of transportation. The values missing to create 100% in each row represent "cannot judge".

Evaluation of the Concept of Neighborhood Charging by Residents

The concept of neighborhood charging was very positively assessed by the respondents. 82% assume that they would use the exclusive/reservable charging stations if they had an EV; 69% consider the exclusive charging option to be a good idea for promoting electromobility. Concerns were shared with regard to the need to park the vehicle after the reserved charging period has expired. Slightly less than one-third would be willing to accept having to look for a parking space after the reserved charging time. One reason for this is the very high parking pressure in the neighborhood. In terms of the city of Hamburg, two-thirds of respondents report that it is difficult to find parking spaces (18% describe it as very difficult, 47% as difficult). For their own neighborhood, the respondents report even more problems: here, 87% find parking difficult (66% very difficult, 21% difficult). The advantage of the guaranteed parking space with charging possibility is considerably diminished by this concern.

The responses from the car-free households show how widespread the parking problem is in the neighborhood. When asked about the reasons for not having a car, the most common answer (80%) was "it is difficult to find parking", followed by environmental reasons (66%) and the answer that no car is needed (62%).

3.1.2. Results of the Focus Groups (Qualitative)

While the survey covered a broader spectrum of questions related to the aim of car use, electromobility, or willingness to purchase an electric vehicle, the focus group discussions aimed to shed more light on the acceptance requirements for charging and the evaluation of the tested neighborhood charging concept.

The results provide insight into the key question of how the concept of neighborhood charging is perceived and accepted, what the expected barriers and benefits are for potential users, and whether the reservation option is a pull factor motivating residents/drivers from the pilot areas to switch from their combustion-engine car to an EV. In the following, we present the three key requirements that we drew from the focus groups.

Key Requirements for Electric Car Use in Densely Populated Urban Areas

In addition to range, we identified the availability and accessibility of charging options as well as the ease of integrating charging and related operations into everyday life as key requirements for switching to an electric vehicle. Given the tight parking situation, another common requirement is that charging options should either improve or at least not worsen access to parking.

In terms of availability, participants assume or have experience with a lack of available public charging stations. This leads to an even larger issue that came up clearly in all focus groups: parking is scarce in both neighborhoods and it is difficult to find a parking space, especially during peak hours (afternoons and evenings). Few have their own parking spaces; for one thing, rental parking spaces are scarce and for another, they are considered (too) expensive. Since the pandemic, the parking situation is partly perceived as aggravated, as more residents work from home and do not move their cars regularly during the day.

As is typical for German inner cities, all participants live in apartment buildings. Those wishing to use an EV therefore tend to rely on public charging facilities as they could not install their own wallbox. There is a preference for exclusive/private charging options either at home or at work, which is also cited as a pull factor for purchasing an EV. However, this option only exists to some extent and only some see a chance that the landlord or workplace could provide charging options in the near future.

Regarding access to charging options, in Hamburg, public parking spaces with charging stations are limited to two hours of parking during the week, so the need to move the car and find another parking space is considered a problem by participants. In addition, access to charging options for electric cars is limited due to irregular parking of vehicles that occupy charging facilities without charging.

Considering the third requirement to easily integrate charging into everyday life, the charging process should not require additional planning or time. Since the entire charging process depends on parking and charging in public spaces, it should be as quick and easy as filling up with gasoline. Alternatively, charging on the go is also considered an option. Stations should be available wherever people spend longer periods of time anyway, such as at work, at home, or while shopping.

Neighborhood Charging Concept

In terms of the key requirements described above, benefits of the neighborhood charging concept are expected to come mainly in the form of improved individual access to charging facilities and also additional availability in general, should the concept be extended to other parts of the city.

One issue raised is that dedicated charging spaces for electric cars are often occupied by electric cars that are not charging or even by non-electric cars. The reservation and booking system combined with access control and protection against unauthorized parking (parking bars) is seen as beneficial in solving this problem. In addition, the booking system is expected to provide reliable information on whether the charging space is occupied or not. Exclusive access for residents is also seen as beneficial. This is expected to ease the parking situation and increase the number of accessible parking spaces, at least for those with an electric car. The reservation option and different time slots as key elements of the concept are generally welcomed and seen as an improvement over the general public charging infrastructure system. However, the fixed time slots are also seen as too strict and more flexible or demand-oriented time slots are desired—for which willingness to accept additional fees is also expressed.

In contrast to the advantages, barriers and disadvantages of the charging concept are expected, mainly in view of the already challenging everyday integration of car use in general, i.e., regardless of whether it is an electric vehicle or not. Due to the charging requirement, the use of an EV, it is assumed, would only further increase this challenge. From the respondents' point of view, an improvement in the integrability of car use in everyday life would be desirable and additional or exclusively accessible parking facilities would be an improvement in this respect. Reduced parking or access restrictions, on the other hand, would represent a deterioration.

In this context, the expected additional time needed for parking and recharging, due to the need to park the car again after recharging or after the booked time has expired, is considered a significant barrier. In a similar vein, the offered time slots are considered to be not long enough and not flexible enough. In addition, it is questioned whether the 3-h time window would be sufficient to fully recharge EVs with larger batteries (and longer range). Finally, the flip side of the described benefits for EV owners is the overall increase in parking pressure. With more and more EV owners, the benefits are likely to diminish or neutralize as charging stations take up more from the already scarce space in urban areas. With this in mind, ideas for alternative technical solutions were expressed, such as charging options integrated into streetlights.

3.2. Utilization of Public Charging Infrastructure

In this section we describe the results of the analyses of the utilization data for public charging infrastructure. First, we describe the basic data used to select the control area, which is comparable to the study area. Second, we present the results of the calculated indicators described in Section 2.3.

Table 3 shows all relevant basic data in the study area and the selected quarters of the control area. As seen, regarding location, basic data, vehicles, and infrastructure, the two quarters in the study area and the two quarters in the control area appear similar.

In Table 4 the results of utilization of the public charging infrastructure are presented. In the table, the two left columns refer to the eight charging stations with a reservation option. The two middle columns refer to 30 charging stations in the same study area without a reservation option. The two right columns refer to 20 charging stations in the defined control area. For each quarter, relevant evaluation criteria are presented. The rows titled *trend* show the percentage change between October 2021 and February 2022. As seen, across all indicators calculated, the charging stations without a reservation option in the study area and the control area appear rather similar.

Table 3. Relevant basic data in study area and control area (2021).

	Study Area		Control Area	
Location				
Quarter	Hoheluft-Ost	Goldbek	Hoheluft-West	Uhlenhorst Central
District	Nord	Nord	Eimsbüttel	Nord
Location in context of city	Edge of inner city	Edge of inner city	Edge of inner city	South of Goldbek
Basic data				
Area [km^2]	0.134	0.153	0.163	0.146
Inhabitants	3,400	3,081	3,621	2,475
Inhabitants per km^2	25,373	20,137	22,215	16,952
Vehicles				
Number of passenger cars	1,138	999	1,135	894
Number of EVs	3	8	4	11
Share of EVs	0.26%	0.80%	0.35%	1.23%
Vehicles per 1,000 inhabitants	335	324	313	361
EVs per 1,000 inhabitants	0.88	2.60	1.10	4.44
Infrastructure				
Number of public charging stations	4	8	2	2
Number of public charging stations in proximity	12	18	10	10
Vehicles and infrastructure				
Parking pressure	5.78	4.38	4.52	3.1
Utilization of charging infrastructure [%]	13	12	24	18
EV-infrastructure ratio	1	1.3	1	3.7

Table 4. Utilization of public charging infrastructure.

	Neighborhood Charging		Study Area		Control Area	
Location						
Quarter	Hoheluft-Ost	Goldbek	Hoheluft-Ost	Goldbek	Hoheluft-West	Uhlenhorst Central
Efficiency						
Events/day	0.7	0.6	2.5	2.5	1.9	2.4
kWh/day	13.6	10.2	35.1	37.8	33.0	42.4
Trend	−33%	+4%	+40%	+40%	+45%	+36%
Utilization						
Mean kW	4.4	4.4	4.9	5.3	5.1	5
% utilization	26%	18%	55%	51%	51%	65%
Trend	−21%	+70%	+23%	+27%	+25%	+25%

The trend rows describe the change between October 2021 and February 2022. Gray values appear affected by random effects due to small sample size per month and charging station.

Figure 2 visualizes the efficiency of public charging infrastructure in different concepts. The left axis and the columns refer to the total energy delivered per day. The right axis and the horizontal lines refer to the number of charging events per day. It can be seen that the publicly available charging stations without a reservation option (study area and control area) in mean deliver between 33 and 42.4 kWh at on average 1.9 to 2.5 events per day. In contrast, the charging stations with a reservation option (neighborhood charging) account for 0.7 and 0.6 charging events with a total of 13.6 and 10.2 kWh delivered per day.

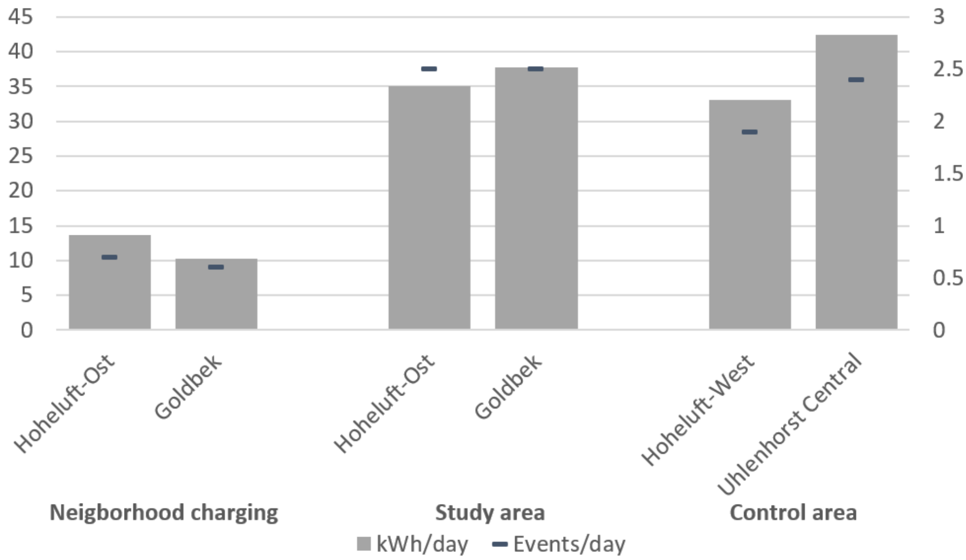

Figure 2. Efficiency of public charging infrastructure in different concepts.

Figure 3 shows the efficiency of the charging infrastructure. The left axis and the columns refer to the percentage utilization rate. The right axis and the horizontal lines refer to the mean charging power. For the unreserved charging stations (study area and control area), the calculated average charging power for the whole connection duration lies between 4.9 and 5.3 kW. The utilization ranges between 51 and 65 percent. The average charging power for the charging stations in the concept of neighborhood charging is 4.4 and the utilization rate 26 percent and 18 percent, respectively.

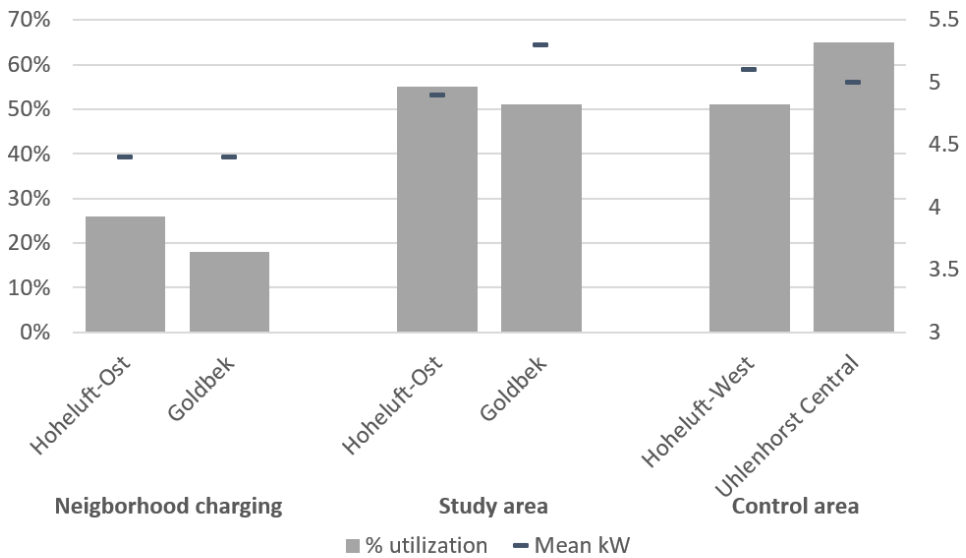

Figure 3. Utilization of public charging infrastructure in different concepts.

4. Discussion

The present paper evaluates the pilot project of neighborhood charging implementing a public charging infrastructure with reservation in inner-city neighborhoods in the city of Hamburg, Germany using various methods. In the following, the main findings are discussed with regard to the methods used.

The empirical research shows that residents have an ambiguous relation to the car. Despite owning cars, many of them see disadvantages in terms of shortage of parking and environmental issues. Electric vehicles may apply to some of the environmental factors but do not solve the issue of space consumption for parking.

As most respondents do not use only the car as a mode of transport, they show an urban mobility culture valuing public transport and active mobility as also seen in the MiD 2017 [42].

Nevertheless, a substantial share of the inhabitants showed interest in purchasing an electric vehicle in the near future. For many of them, it is through carsharing that they had their first experiences with electric vehicles. This may therefore help to dismantle barriers [10]. The concept of neighborhood charging itself was rated very positively by the potential users. Both methodological parts of the user survey revealed the key importance of parking for the use of cars—either electric or with combustion engine—as was seen earlier by Lopez-Behar et al. [1].

The parking situation is considered very problematic. Accordingly, guaranteed parking and charging facilities are very attractive to the residents, which is in accordance with previous research [11]. Hence, in inner-city neighborhoods where many vehicles are parked in public spaces, concepts such as neighborhood charging can be of great importance for the acceptance of EVs. A main advantage of the concept as evaluated from the user's perspective is the longer duration of charging slots compared to openly accessible infrastructure. Searching for a new parking space after this duration expires is seen as a major disadvantage of using electric vehicles. Thus, the afternoon time slot in the concept (5 p.m.–8 p.m.) was criticized as it requires re-parking during peak hours. Based on initial feedback from the users, the time slots were adapted and simplified. Since March 2022, there are only two time slots, one for daytime, one for nighttime. In addition, the detection mechanism for occupation was improved and parking management was introduced. This resulted in more accurate data and irregular parking behavior is penalized.

In general, however, new routines need to be developed. A change in thinking is required, as charging is not the same as fueling. Due to limited public space, especially in city centers, the use of a public parking lot for charging will always be limited in time, and the car will have to be moved afterwards. Since charging takes longer than fueling, it needs to be integrated into people's daily routines as best as possible. Therefore, further research is needed to learn more about the charging needs of e-drivers and to tailor the offers to their needs.

It has to be noted that in 40% of the households that are interested in buying an EV, the new EV would not replace an existing car. This additional motorization appears very problematic, especially in dense urban areas. Earlier research finds car-free households to be especially sensitive to measures increasing the attractiveness of EVs by subsidies or organizational advantages [44]. The finding of potential rebound effects due to additional cars caused by improved framework conditions is in line with earlier research [45,46].

The analyses of charging infrastructure utilization data reveal large differences between charging stations with a reservation option and such without. As seen, across both area types, openly available charging stations show roughly three times more events and energy delivered per day than the charging stations with a reservation option. At the same time, utilization rate and mean charging power is higher at charging stations without a reservation option. The latter indicates shorter periods of vehicles being connected after the charging process is completed. The user group of the neighborhood charging stations is restricted to a limited number of registered neighbors. This allows for planning but at the same time causes a new entry barrier. Hence a lower utilization compared to infrastructure that is potentially usable by all drivers of EVs is not surprising. In addition, the concept is still rather new and should be evaluated further in the coming months.

Since electric vehicles are getting more and more popular and as demand for charging in public space increases, concepts such as neighborhood charging allowing for planning may gain more importance in the near future. Therefore, providing a share of charging stations with a reservation option can be beneficial.

The limitations of the present research are as follows: first, we still lack a thorough analysis of the perspective of current users of the new charging system. They can best describe the use of the new charging concept, its advantages and disadvantages as well as their reasons for purchasing and using EVs. Future research by the authors will include this perspective.

As described, many participants in the questionnaire survey have experiences with electric vehicles. On the contrary, most participants in the focus group discussions had no experience with operating an electric car and had difficulty assessing how often the car would need to be charged, how long it would take, and how to smoothly integrate charging into daily life. However, some had experience with electric car sharing or already drove a hybrid. Some had also already thought about buying an electric car and weighed the pros and cons in their particular situation. In addition, in the questionnaire survey, results were only based on one of the two districts in the study area.

Regarding the charging infrastructure utilization data, we can only analyze the charging events at public charging stations. Due to the structure of the data, it is not possible to identify individual users with multiple charging events. Given the comparatively low number of events at charging stations with a reservation option, the percentage trend development appears affected by random effects.

5. Conclusions

The present research provides insights into the role of electric vehicle charging in dense urban areas by evaluating the concept of neighborhood charging implementing a reservation option. The main findings are as follows: parking is the main concern of car ownership in the study area. Car users report a problematic parking situation while non-users mention the parking pressure as the main reason for not owning a car. As a consequence, according to the participants, using an electric vehicle should improve or at least not worsen the access to parking. Given the importance of the topic, it can be assumed that a concept such as neighborhood charging which allows for guaranteed parking and charging could be a driver for more electric vehicles in a dense urban environment like the study area. On the other hand, openly accessible charging stations are utilized about three times more than the charging stations with a reservation option. Hence, the effects of the new concept appear diverse. Considering the public funds needed for the implementation of public charging infrastructure and the limited number of benefiting users in the exclusive concept, future investment decisions should be based on careful considerations. Rebound effects of additional (electric) cars due to attractive framework conditions are likely. At the same time, the high number of car-sharing memberships represent an important anchor point for the spread of the use of EVs, at the same time lowering the total number of cars. Therefore, an overall concept is needed in which neighborhood charging systems can be one of several components. These concepts should be continuously evaluated and adapted to the respective circumstances.

Future research should evaluate the number of individual users per charging station in both charging schemes. Furthermore, future research by the authors will include the experiences current users have with the new concept and the effect on their long-term decisions. In addition, we will evaluate effects of the changes made to the concept.

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