Analysis of the charging behavior of BEVs in a free-floating carsharing fleet

Maximilian Schussler, Klaus Bogenberger
Department of Traffic Engineering, University of Federal Armed Forces Munich
Heisenberg-Weg 39, 85577 Neubiberg, Germany
maximilian.schuessler@unibw.de, klaus.bogenberger@unibw.de

***Abstract*—Although in the last years many models of Battery Electric Vehicles (BEV) were launched into the market, electric mobility in the car sector is still no mass market. Beside other reasons one problem is the small range of BEVs. To overcome this fear of customers a sufficiently sized public charging infrastructure is necessary. Unfortunately, operating charging stations is not profitable at the moment because of the small number of existing BEVs and the high investment costs. This problem is called the "chicken-egg-problem" of electric mobility. An often mentioned sector which could guarantee at least a basic utilization of charging stations to a public charging infrastructure provider is the electric free-floating carsharing. In this paper booking data of BEVs in a free-floating carsharing fleet is evaluated to analyze to which extent free-floating carsharing BEVs are relevant for the utilization of public charging stations. Furthermore charging behavior of different user groups charging a BEV of a free-floating carsharing fleet is analyzed. Also areas are identified which are preferred for the installation of public charging stations based on electric free-floating carsharing. Due to these results the requirements on a public charging infrastructure in terms of size, type and layout are identified from the perspective of a free-floating carsharing provider as well as from the perspective of a public charging infrastructure provider.**

I. Introduction

In the last years Battery Electric Vehicles (BEV) came more and more to the focus of the general public. Also many countries set up programs to promote electric mobility. For example, the Federal Government of Germany set up a research program "Modellregionen Elektromobilität" to identify existing barriers for the diffusion of BEVs [2].

One reason why many countries promote electric mobility is that BEVs are locally emission free. This fact is especially important for megacities with a lot of car traffic. These cities have serious problems with air pollution partly caused by traditional Internal Combustion Engine Vehicles (ICEVs). To make living in these cities more comfortable the shift from ICEVs to BEVs is preferable. But also in Germany there are ecological problems, especially when it comes to particular matter pollution (PM 10 and PM 2.5). As BEVs are also more quiet than ICEVs, when driving with lower speed, living in cities could become more comfortable. Another reason in favor of BEVs is the fact that the stock of worldwide crude oil is finite. To diminish the dependency on oil, it is necessary to substitute ICEVs by vehicles with alternative powertrains. This makes only sense when the electricity is generated by renewable energies. The higher the share of renewable energies of the total energy mix is, the better is also the overall ecological advantage of BEVs.

But there are also some disadvantages of BEVs compared to ICEVs. Firstly, BEVs are more expensive than ICEVs. For example, the electric VW Golf costs about 16 % more than the comparable conventional VW Golf because of the high cost of the used lithium ion battery [10]. The battery is also a problem considering range and charging. Whereas ICEVs are able to drive up to a thousand kilometer without refueling, most of the BEVs have to be recharged after at most two hundred kilometers. This leads to "range anxiety" of potential buyers of electric cars. Additionally, the refueling takes at most ten minutes whereas the charging takes from 30 minutes up to 8 hours depending on the type of charging.

One often mentioned solution to reduce the range anxiety is to built up a sufficiently sized charging infrastructure. The European Union suggests a proportion of 10 BEVs per charging point [5]. The main reason why the installation of more charging station is proceeding slowly, is that there exist no profitable business model for the operation of most of the public charging stations at the moment [4]. The chief cause for this issue are the few existing BEVs in Germany and, as a consequence, the low degree of capacity utilization of existing charging stations. This problem is also called the "chicken-egg-problem" of the charging infrastructure [14]. To solve this problem charging infrastructure providers would need at least a guaranteed basic utilization to limit losses at the beginning. In bigger cities carsharing could fill this gap.

The overall idea behind carsharing is that you don't own the car, you just use it. There exist different types like station-based or free-floating carsharing for example. At the station-based approach a user rents a car at one station and has to return it at this station when he finishes his trip. On the other hand free-floating carsharing enables users to conduct one-way trips. The only restriction is that you have to end your trip inside the operating area which is defined by the service operator. Both types are seen as potential drivers of the electrification of the automobile sector [14] as a high share of the new cars in the business are expected to be BEVs [9]. Additionally carsharing will grow further in the future [8].

There are different reasons why carsharing is more likely to have a high share of BEVs in their fleet. Firstly, many trips done by carsharing are short enough to be satisfied by the range constraints of BEVs. According to a study about a stations-based carsharing in Vienna about two thirds of all trips could be made by BEVs [11]. Also a survey of carsharing users proves this argument for free-floating carsharing where about 80% evaluated the range generally as positive [17]. Secondly, BEVs in carsharing are also a marketing possibility for automobile manufacturer. So users are able to test BEVs in practice before buying them. Furthermore BEVs are more present in the public especially at free-floating carsharing ([3], [13]).

As explained carsharing could be a potential driver of electric mobility. The focus of this paper is to analyze the impact of carsharing on the public charging infrastructure and vice versa. Station-based carsharing has almost no impact on the public charging infrastructure as the cars can be charged at non-public charging points at the different stations (see [11]). So only free-floating carsharing is considered in the following.

BEVs are already part of different free-floating carsharing fleets. Car2go, a company of the Daimler AG and Europcar, operates only with BEVs in Stuttgart, San Diego and Amsterdam. It also exist an electric free-floating carsharing called Multicity in Berlin. Furthermore BEVs are also part of the fleet of DriveNow, the free-floating carsharing company of BMW and Sixt, in Berlin and Munich. Unfortunately, BEVs are probably more cost intensive for service providers [6]. One reason is that conventional cars are refueled by users in general. In return they get a reward in bonus minutes. This is only possible as refueling takes normally less than ten minutes at a petrol station. Compared to that recharging at charging stations takes from 20 minutes to 4 hours depending on the type of charging [1], so recharging during the trip is not feasible for the most use-cases. Consequently, either a service assistant has to drive a BEV to a public or private charging station to recharge or an user ends his trip at a public charging station. Of course, the user would only end his trip at the charging station if his original destination is near that point. So the denser the charging infrastructure is, the less service costs occur for the free-floating carsharing operator.

On the other hand, if there exist many charging stations in a city, free-floating carsharing can be an important business group for charging station operators. These BEVs have a high daily mileage and are highly dependent on the public charging infrastructure. This is a big difference to private early adopters of BEVs who, in general, have the possibility to charge at home [19] and therefore don't often charge at public charging stations [18]. So charging station providers could expect a basic utilization for their stations depending on the number of electric free-floating BEVs in the city.

In this paper booking data of BEVs of a freefloating carsharing system is analyzed to answer the following research questions relevant for the carsharing as well as the charging infrastructure provider: How many public charging events are generated per charsharing vehicle per day? How long block carsharing vehicles the charging point? How often has to charge a service assistant an BEV based on an existing charging infrastructure? Which charging stations are preferred?

In the next section the data set on which the analysis is based is introduced. In section III data analysis based on the data set is conducted. Afterwards consequences based on the evaluated results are drawn from the point of view of a free-floating carsharing as well as of a charging infrastructure provider. At the end a conclusion is drawn how to bring the different perspectives together.

TABLE I. AVAILABLE INFORMATION BOOKING DATA

- Start charging state ch_{st}
- End charging state ch_{en}
- Start time t_{st}
- End time t_{en}
- Start km k_{st}
- End km k_{en}
- Longitude Start lon_{st}
- Latitude Start lat_{st}
- Longitude End lon_{en}
- Latitude End lat_{en}
- User group u

II. CARSHARING BOOKING DATA

This section describes the raw data used to investigate the charging behavior of BEVs of a free-floating carsharing fleet in Munich. Furthermore also data problems are mentioned and how these affect the following analysis.

The analyzed carsharing booking data was made available by a free-floating carsharing provider. The data is based on booking events of BEVs in the city of Munich from January 2014 to December 2014. 20 BEVs are part of the fleet. Depending on personal driving style as well as on other factors the used BEVs have a range up to 160 km.

For each booking event there are different information available (see table I). Based on these information it is possible to identify charging events. Normally, a charging event can be detected when the charging state of a BEV rises between two booking events ($ch^i_{st} > ch^{i-1}_{en}$). Furthermore the charging event can be assigned easily to public charging stations based on the longitude and latitude information (lon^i_{st}, lat^i_{st}, lon^{i-1}_{en} and lat^{i-1}_{en}). Also the parking time at the charging station can be analyzed using t^{i-1}_{en} and t^i_{st} as well as the user group (Customer or service assistant) using u^{i-1} . Unfortunately, because of data errors and data inconsistency not every charging event could be identified on such a high level of detail. Especially, when service assistants recharge, problems occasionally occur. The main reason for this issue is that some trips of service assistants were not correctly recorded. For example, it can be observed that the charging state rises during a booking event ($ch^i_{st} < ch^i_{en}$). This means that is not possible to determine the correct the starting time of the charging event. Also the starting point of a trip differing from the end point of the former trip causes difficulties analyzing these charging events correctly. Then it is not possible to determine the correct charging stations as well as the parking duration in the most cases. Another data error happens when users drive until the battery is empty and they can't drive any further. Then this BEV has to be charged by a mobile charging vehicle. This event is hard to identify and could lead to misinterpretation of the results.

III. EVALUATION

This section presents the results of analyzing the data described above. The evaluation is divided into three subsections. At first an overall booking analysis is conducted over the whole analysis period, followed by a more detailed investigation over time like changing charging behavior over day or month. Afterwards the spatial distribution of the charging events over

Munich is described as well as the potential correlation between charging station coverage and service assistant charging.

A. Overall booking Analysis

During the period January to December 2015 the booking data of 20 BEVs were analyzed. An overview of the total charging events is given in table II. Altogether 4773 charging occurrences could be detected. From these it was not possible to identify 316 occurrences because of the mentioned data errors. As the share of the unidentified charging operation is small (only about 6.6%), it is expected that the remaining charging events can represent the charging behavior of BEVs in free-floating carsharing systems. So the unidentified ones were omitted.

About 45% of the identified charging occurrences were initialized by customers of the free-floating system who ended their trip at a charging station. The others were executed by service assistants of the carsharing provider. This is a comparatively high share of charging events. A potential reason for this issue is examined in more detail in subsection IV-A.

From the other charging events 3374 could be detected perfectly. Based on these, the charging stations were occupied for 1.503.482 minutes. Consequently, the BEVs occupy the charging stations for about 446 minutes per charging event.

The distribution of the duration of the occupying times is given in figure 2. It can be seen that most of the allocations last less than 10 hours. At the figure two peaks can be identified. The first one are duration of about one hour, so BEVs are moved quickly after the start of the charging. The second one lies between about 5 and 6 hours, this is about the time how long it takes to recharge completely the deployed vehicles from a low charging state. These observations are supported by analyzing the increase of the battery level per charging event. There the first peak was at about 10% increase of battery level, the second one at about 90% (see figure 1). So BEVs are mainly recharged for only a short time or these are recharged almost completely. These two peaks are analyzed in more detail based on the two different groups charging a BEV. Only 18% of the charging events lasting less than 2 hours were executed by service assistants compared to 58% when only considering charging events with a duration between 5 and 7 hours. Probably the main reason lies in the fact that BEVs, recharged by a service assistant, are blocked by the service operator. This is to avoid usage of BEVs with a low current range by users which would cause a new recharging instruction for a service assistant.

The time of the charging start t_{st} as well as the charging state at the begin of charging ch_{st} could not be generated for 1083 occurrences because of mentioned data inconsistency (see subsection II). It can be observed that most of these charging events were executed by service assistants. So when differences between service and users are examined only based on the perfectly identified operations, this issue should be kept in mind.

TABLE II. OVERVIEW TOTAL CHARGING EVENTS BASED ON BOOKING DATA

Battery electric vehicles	20
Overall identified charging events	4773
Perfectly identified charging events	3374
Partly identified charging events	1083
Unidentified charging events	316
Customer charging events	1994
Service assistant charging events	2463
Total occupying time (in minutes)	1.503.482

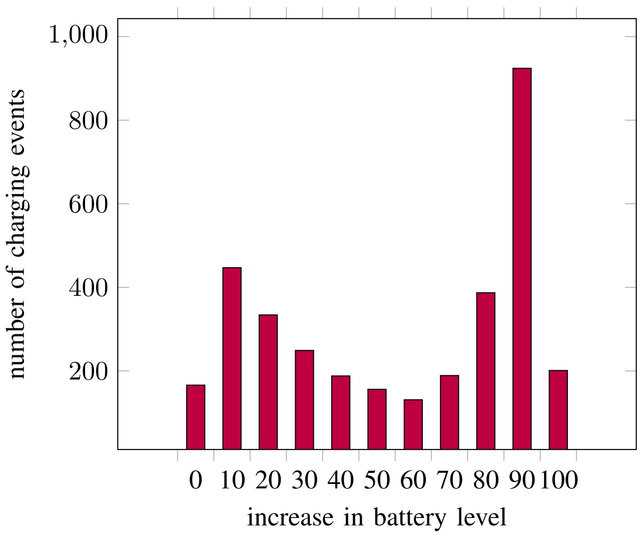

Fig. 1. Bar plot of the distribution of the increase in battery level per charging event

B. Temporal booking Analysis

In this subsection the carsharing events are examined about changes over time. Appear differences of the charging behavior over one day? Can be a different amount of charging events detected in different seasons?

In figure 3 the distribution of the charging starts over one day is depicted. These diurnal curves are created by splitting each day into 24 one-hour parts and counting the number of charging events that started in the different time intervals. Additionally it is distinguished between users and service assistants. It can be seen that during the day the charging starts are almost evenly distributed except of the nightly hours from 0 a.m to 5 a.m where less charging events begin. This observation is preferably for a charging infrastructure provider as it would ensure a high degree of capacity utilization over the day. When you look at the typical charging starts of the two different groups, then differences can be observed. The high share of charging starts in the morning hours almost only result from the service assistants beginning a charging event. Probably the reason for this is that the service assistants start their work in the morning. Then their first task is to recharge BEVs which only have a low charging status. As mentioned in subsection II most of the only partly identified carsharing events were executed by service assistants. So

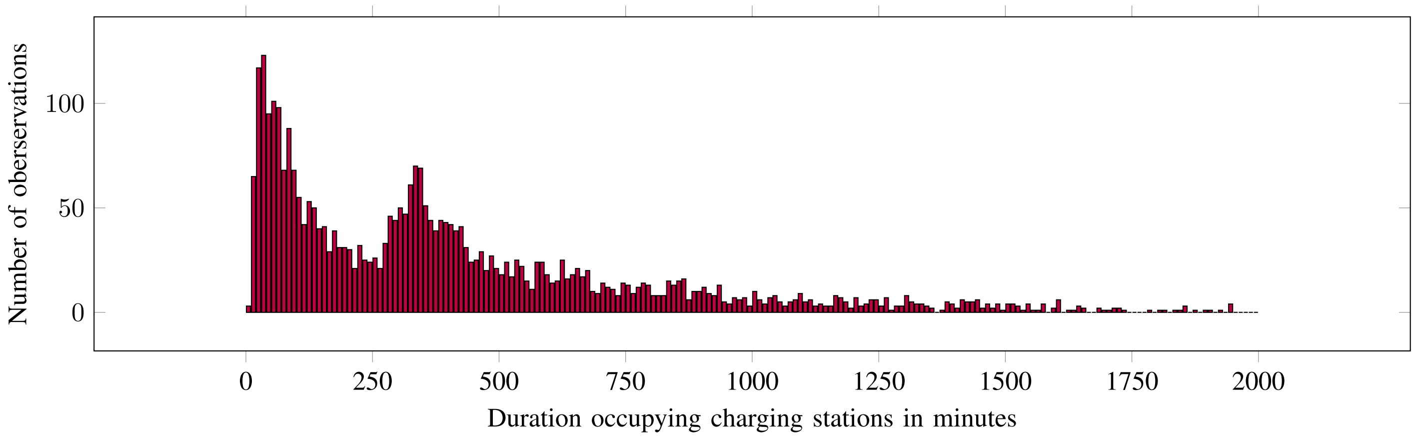

Fig. 2. Bar plot of the distribution of the observed occupying times for every minute

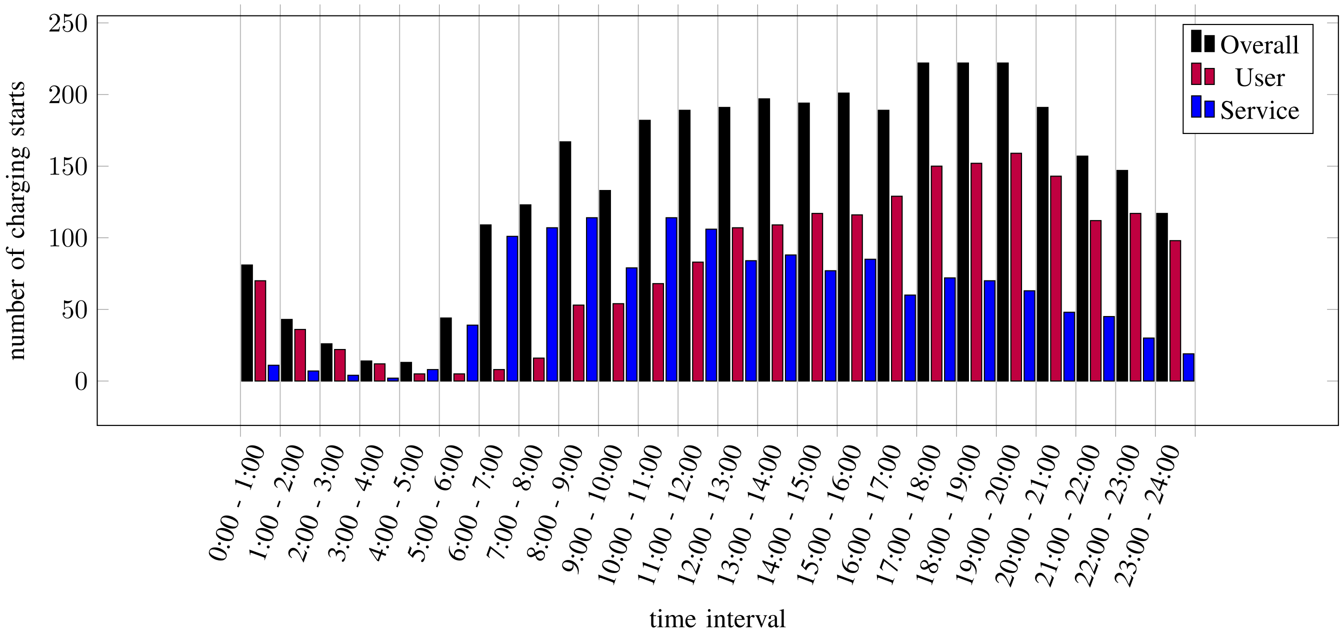

Fig. 3. Bar plot of the distribution of charging starts over one day in one-hour intervals

probably even more charging occurences happened during the morning hours. On the other hand carsharing users mostly charge in the evening hours. This agrees with the typical diurnal usage distribution of carsharing users overall. There for workdays as well as for weekends a high afternoon peak can be seen between 5 p.m. and 8 p.m. [16] (see figure 4).

Beside analyzing the charging behavior over time during one day, it can also be analyzed per month to identify changes during the year. The whole research period is examined by calculating the number of charging events per car and day for each month. The result is depicted in figure 5. In July a BEV was recharged slightly more than 0.7 times per day whereas in January less than 0.6 charging events per BEV and day occurred. All in all there are no major shifts of charging events per car and day over the year. The minor differences can have several reasons. July was the hottest month in 2014, so users could have turned on the air condition more often compared to other months which decreases the range of a BEV. Whereas in December where you would expect that more charging events occur because users turn on the heater, the lowest number were derived. Another reason for the differences could be a development in overall utilization of the carsharing system. If the BEVs are used more often then, of course, these have to be charged more often. Also service times of BEVs could have an impact. When two or three BEVs have to be repaired or checked for more days it also has an effect on the number charging events per car and day. Altogether no obvious differences could be detected of charging behavior over the year.

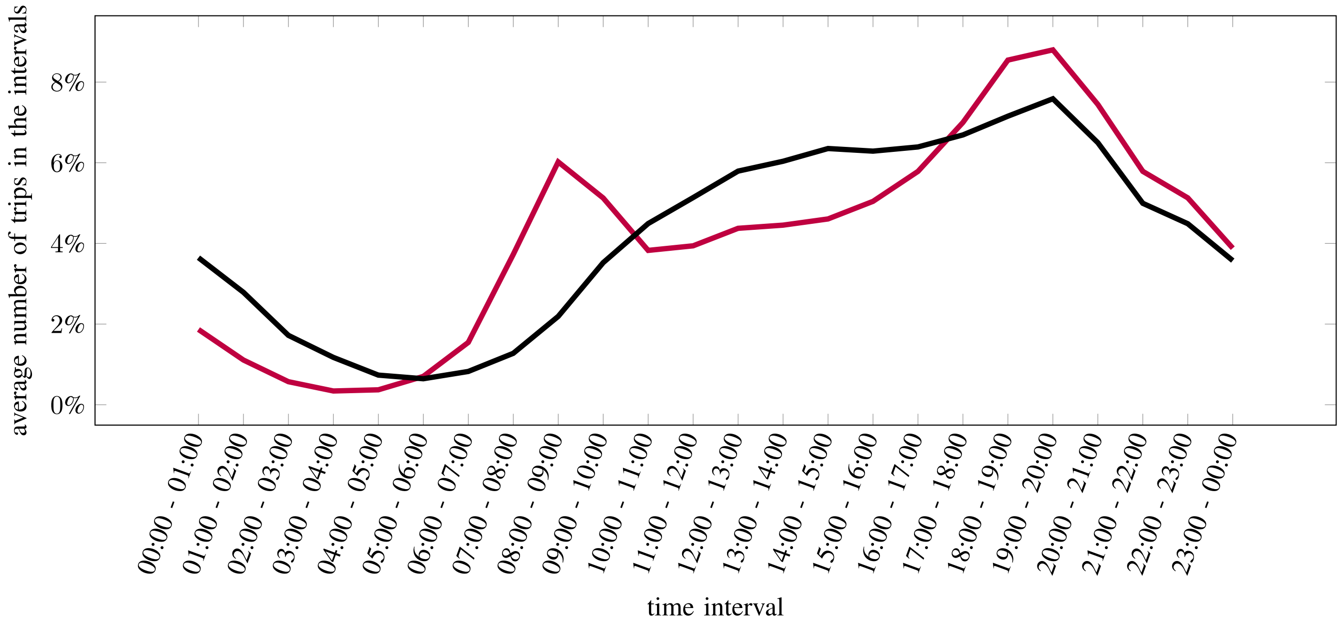

Fig. 4. Diurnal usage curves of workdays (purple) and weekends (black) - from [16]

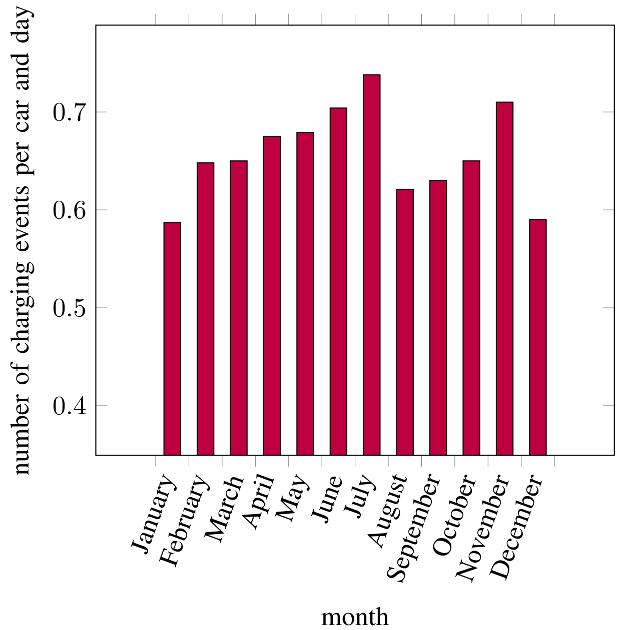

Fig. 5. Bar plot of the distribution of the observed charging events per car and day over one year per month

C. Spatial booking Analysis

This subsection deals with the spatial distribution of the identified charging events. The evaluation is only based on the perfectly identified charging events (see subsection II). Figure 6 shows the number of charging processes occurring at different public and private charging spots. Each dot in the figure symbolizes a charging station/point. Additionally, these are also differentiated in color. Black marked dots indicate public charging stations which are suggested to users by the service provider. For example, these are shown in the on-board unit of the BEV or at the general map view of their homepage. Green marked dots illustrate other public charging stations where charging events occurred. Finally, blue dots symbolize private charging points of the carsharing provider where only service staff is allowed to charge the BEVs. The colored background grid represents the spatial distribution of carsharing bookings (end of trips) of all carsharing cars in Munich. Green colored cells indicated few observed booking endings whereas the more red a cell is the more bookings ended in this zone. This figure only shows the number of charging events inside of the operation area of Munich. In addition most of the charging occurrences (in total 660) were identified at the airport where it is also possible to return a BEV. All of these except of one were executed by service assistants mainly because this charging station is not suggested to the user by the carsharing provider.

Firstly, it can be seen that most of the charging events were executed at public charging stations. Only 2.5 % occurred at private charging stations of the carsharing provider. So the BEVs of the carsharing fleet result in a sufficiently higher usage utilization of the public charging infrastructure as users (98 %) as well as service assistants (70 %) prefer to charge there.

Secondly, charging stations at which nearby comparatively many general bookings ended, seem to be more used for carsharing charging events. This observation is analyzed in

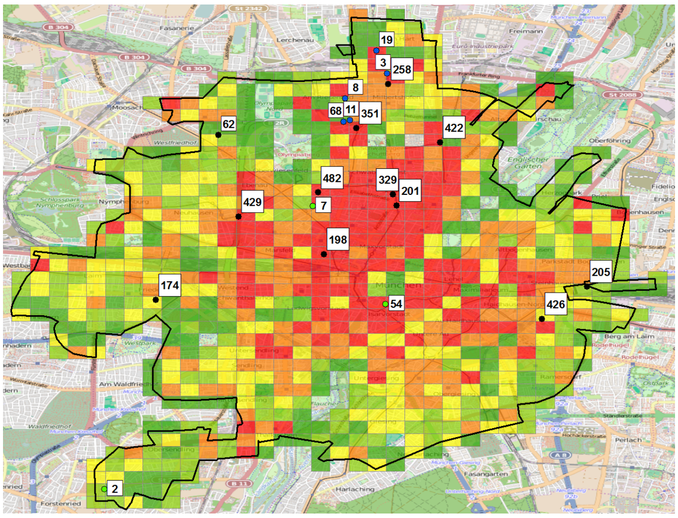

Fig. 6. Number of charging events occurring at different charging stations in Munich; black dots indicate suggested public charging stations by the service provider to the users; blue dots indicate other public charging stations; green dots indicate private charging stations used only by service assistants

more detail.
As service assistants get instructions by the service provider the location of charging events depend mainly on management decisions and therefore don't depend directly on general booking endings. So charging events as well as booking endings executed by service assistants are omitted for the analysis.
It is assumed that users only charges the BEV when their original destination is near a public charging station. Studies about perfect distances between public transport stations found out that people are willing to walk about 500 meters to the next section without any problem. So the number of booking endings inside of a circle with 500 m radius were calculated for every charging stations. Afterwards a correlation coefficient of 0.65 could be derived. So the number of general bookings near a public charging station is positive correlated with the number of observed charging occurrences.

IV. Interpretation

The goal of this section is to interpret the evaluated observations of the last section. Two different views are considered. On the one hand the view of a carsharing provider and on the other hand the view of a charging infrastructure provider. Both have deviant opinions on the outlay and capacity utilization of a perfect charging infrastructure.

A. Free-floating carsharing provider

On the one hand BEVs cause less costs compared to conventional cars when you only look at fuel costs. In general costs per 100 kilometer are about 2-4 € less for BEVs in comparison to a similar conventional car [15]. On the other hand there are higher operating costs of BEVs in free-floating carsharing fleets. About one in two charging events has to be executed by service assistants (see subsection III-A). In [20] hourly wages for service assistants were estimated with 15 € per hour. In combination with the about 0.65 daily charging times (see subsection 6) and about 55% service assistant charging possibility (see subsection III-A) this leads to approximate additional 5.36 € operating costs per day per BEV. In contrast these costs don't occur for conventional cars operating in free-floating carsharing fleets as the refueling is mainly conducted by the users.
Consequently, the goal of a carsharing provider is to decrease these additional operation costs. If BEVs would have a higher range the duration between charging events would be higher. So these costs depend also on future development of battery capacity of a BEV. Another important factor of these costs is the share of charging events conducted by users. As users only end their trip at a charging station when their destination is nearby, a high concentration of public charging stations inside the operation area would increase this share.
The current coverage of circles with 500 m radius around public charging stations (see figure 7) is about 13% of the operating area. The share booking endings inside this coverage is about 19%. As it can be seen there is a significant difference between users who charge a BEV (45%) and users ending there trip near a charging station (19%). So users execute more often a charging event as you would expect it.
One reason could be that you also get 20 bonus minutes if you recharge the BEV when the remaining range is smaller than 30 km. With this incentive a user could be encouraged to make an even longer detour from his original destination. When you enlarge the radius around public carsharing stations to 800 m, about 32% of all booking endings lie inside the operation area. This doesn't explain the whole deviations between share of charging events executed by users and share of booking endings near public charging stations. Additionally, you have to keep in mind that users have more than one possibility to recharge the BEV. If there are 4 bookings between two charging events, there are also 4 possibilities for users to have a destination near a charging stations. If you assume that these 4 bookings are independent from each other the possibility that at least one destination is in 500 m radius around a public charging station is 55%. These two reasons can be an explanation why a poor coverage of charging stations lead to a comparatively high share of user charging occurrences. But to make BEVs in carsharing fleets more profitable a highly deployed charging infrastructure is necessary.
Another problem of BEVs in free-floating carsharing fleets are the potential opportunity costs during a charging process. It takes about 200 minutes (see subsection III-A) per charging event compared to only about five minutes for a conventional car. In this time the BEV can't gain new sales for the carsharing provider. So a fast charging infrastructure would be preferred by a carsharing provider.
To sum up for a carsharing provider a highly concentrated fast charging infrastructure would be perfect to make BEVs more competitive to conventional cars in free-floating carsharing fleets. Probably at least a minimum requirement of a charging infrastructure should exist in a city, to be a possibility for operating an electric free-floating carsharing. If this is not the

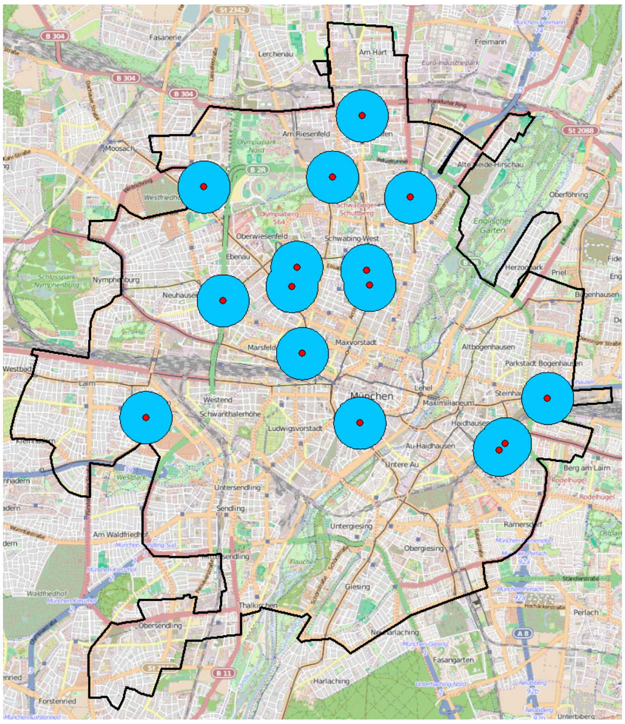

Fig. 7. Assumed catchment area of each charging station inside the operation area - radius of catchment area: 500 m

case only conventional free-floating carsharing will be offered.

B. *Charging infrastructure provider*

The charging infrastructure provider also wants to be profitable by operating the public charging infrastructure. So the utilization of the charging infrastructure has to be as high as possible. As seen in subsection III-A a BEV of a free-floating carsharing fleet is charged sufficiently more often at a public charging point compared to a private user with the possibility to charge at home (0.65 charges/day (see subsection III-B) compared to 0.03 charges/day (see [12])). Private users with home charging possibility are to be expected to be one of the first groups who adopt BEVs [7]. So free-floating carsharing is of high interest for charging infrastructure providers especially at the beginning of the electric mobility. In this time the "chicken-egg-problem" is given and with a known number of free-floating carsharing BEVs, the charging infrastructure provider at least could plan with a certain basic utilization for his operated charging stations.

A problem which occurs for the charging infrastructure provider is the evening peak of the charging event starts by users. If more charging infrastructure is set up by the provider more users will have the possibility to end their trip at a charging station. So less service assistants will charge in the morning hours where only few charging events were conducted by users. This leads to a smaller overall utilization of the charging infrastructure.

To sum up, a charging infrastructure provider prefers to built up enough charging stations to meet the demand of the free-floating fleet. Especially areas which have a high booking ratio by users are interesting as sites for a charging station.

V. Conclusion

There are congruent as well as deviant goals regarding the set up of a public charging infrastructure between a carsharing and a charging infrastructure provider. For both their own business goals are in the foreground but they also supplement each other to reach these. To support BEVs both providers should negotiate with each other about the size, the type and the layout of the charging infrastructure.

The biggest deviation is the question about the amount of charging stations needed. The carsharing provider prefers a highly dense charging infrastructure inside the operation area to enable as many users as possible to end their trip at a charging station. Whereas the charging infrastructure provider needs a sufficient high utilization of his charging stations to cut losses at the beginning of the electric mobility. The key issue is the question how much basic utilization should free-floating carsharing contribute to overall utilization of the charging infrastructure. If this point is negotiated successfully between the two, the charging infrastructure provider could built up the amount of charging station which correspond to the planned number of BEVs operating in the city in the future. When negotiating this issue the carsharing provider should keep in mind the preferred charging start time of charsharing users (see subsection III-B). For example if a basic utilization of 2 charging events per public charging point should be reached, this is no problem if you just look at the typical charging duration. But if you want that both charging events should be executed by users these users also have to find a free public charging spot. As most of the users start charging in the evening hours, users often won't be able to charge even if they have the intention to do that. Especially when you incorporate private users charging on public charging spots in the evening hours. This leads to a higher share of service assistants executing public charging events. On the other hand this issued is preferred by a charging infrastructure provider as this would lead to well-balanced utilization of the charging stations of the day.

The type of charging stations highly depends on the weighting of the goal to built up a dense charging infrastructure on versus the goal to built up fast charging stations. When a basic utilization is negotiated with the charging infrastructure provider, more daily charging events for fast charging stations are needed compared to normal charging stations as fast charging stations are more expensive than normal charging stations. So if you built up a fast charging station then less other charging stations are needed by the charging infrastructure provider to ensure the negotiated basic utilization. So the grid of charging stations would be less dense. Which goal is preferred by the free-floating provider depends on the expected share of service assistants charging (see subsection III-A), the typical duration of a charging event (see subsection III-B) and on the difference of pricing charging events depending on the type of charging by the charging infrastructure provider.

A consensus is given about the question of the layout of the public charging infrastructure. The charging stations should be built up in free-floating carsharing booking hot spots. This leads to a higher possibility that a charging event is executed by a user which is the wanted by carsharing providers.
To sum up the results of the analysis of the booking data, it can be seen that the free-floating carsharing would contribute to the utilization of a public charging infrastructure. Nevertheless, a free-floating carsharing provider at least needs a sufficiently dense charging infrastructure to run the operation profitable. To reach this goal he should negotiate with the local charging infrastructure provider about the installation of more public charging stations. In return he can promise a basic utilization to the charging infrastructure provider depending on the number a BEVs operating in the free-floating carsharing fleet.

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