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Charging infrastructure implementation for EVs – the case of Berlin

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Abstract

In order to launch and facilitate the uptake of e-mobility, many major cities are facing the challenge of supporting the development of a cost-efficient and demand-meeting system of charging points. To tackle this task, the city of Berlin performed an innovative procedure. The approach included different working steps, beginning with planning the locations, followed by working out definitions of technical and contractual requirements to the actual implementation of charging infrastructure and its integration into the overall traffic system. The individual components of this overall process are described in this paper.

In the location concept, as a starting point of the overall concept, a methodology based on theoretical concern and stakeholder consultations was developed. Furthermore this approach uses empirical mobility data, traffic models, user groups and usage patterns to indicate a spatial distribution of charging points in the city that matches demand.

Subsequently, the construction of these charging points was tendered out Europe-wide. Seven bidders and consortia were chosen to participate in a 15-month-long competitive dialogue process. In this structured process a role-based model for operating the public charging infrastructure was developed. All technical details of the contract were developed in this dialog process as well.

Another important step towards successful implementation of an efficient charging infrastructure is the challenge of operator-independent user information. For this purpose real-time information about the location and occupation status of charging stations was integrated into Berlin's Traffic Information Center. In addition, an authentication platform was set up to ensure operator-independent and non-discriminatory access to the publicly funded charging stations.

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1. Introduction

Electromobility can be seen as one element to achieve a major shift towards a decarbonized and sustainable transportation system. Contrary to the German government's political objective of one million electric vehicles by 2020 (NPE 2010:12), the electric vehicle stock on 1.1.2015 of about 19,000 is far off meeting the expectations (KBA 2015). Regarding this, diverse obstacles have been identified (Hüttl et al. 2010; Steinhilber et al. 2013; Dijk et al. 2013). One major barrier is meant to be the deficiency of public charging infrastructure in combination with limited range (Zimmer et al. 2011:10; Dütschke et al. 2012: 15ff). Furthermore, a lack of confidence in using the existing public charging infrastructure is named as a main reason for their non-utilization (Ahrend et al. 2011: 68f). Charging infrastructure and vehicle sales mutually influence each other: without a certain stock of electric vehicles, investing in a charging infrastructure is uneconomic; without a public charging infrastructure, purchasing an electric vehicle may be unattractive for many users.

Against this background, many municipalities subsidise the establishment of a charging infrastructure. In doing so, a systematic way of proceeding is an essential condition. The development of a charging infrastructure is considered economically unfeasible (NPE 2012:48), public funding for initiatives and projects is common and justified by its support for electric mobility and the underlying aims. Thereby it is crucial to tackle the chicken-and-egg problem (infrastructure and vehicle stock) (Meister 2010:28) as well as finding a way to solve the conflicting aims of users (high availability) and suppliers (high utilization rate) and meet demand in order to spend public resources efficiently. Besides city-wide demand-based spatial distribution, non-discriminatory accessibility has to be ensured.

The complexity and heterogeneity of both Berlin's urban structure and its transport system reveal the necessity of demand-oriented planning towards a simple homogenous dispersion.

However, as Berlin was one of the first cities to strive for a comprehensive approach based on sound process, there were no scientific findings about detailed distribution of charging demand in cities. This leads to one major task: developing and applying a method to estimate the spatial characteristics of future charging demand. Due to the initial situation, theoretical concerns as well as usage of general findings on electric mobility from the literature play a decisive role in order to create a basis for quantitative research.

2. Location concept

For the near future, it was anticipated that operators of free-floating car sharing would use electric cars (Giesel et al. 2014; Mortsiefer 2013). In this specific usage context, the authors expect a comparatively large demand for public charging. The use of shared cars, which are parked on public streets, by a great number of individual users results in a high demand for public charging. By comparison, private or commercial use of electric cars results in lower demand for public charging (Peters, Dütschke 2010: 19ff; Krems 2011:60ff; Trommer et al. 2013: 54ff). Previous studies have shown that most private and commercial vehicle keepers tend to mainly charge their cars on private or commercial ground where cars are parked regularly (Frenzel et al. 2015; Trommer et al. 2013: 71). In this context, a strong psychological component of the electric mobility system becomes apparent: range anxiety (Tate et al. 2008:3; Kearney 2011: 14f). The availability of public charging infrastructure proves to be an important purchasing criterion for electric cars, but in everyday use, non-public charging is the preferred solution (Trommer et al. 2013: 71). This leads to the idea of a location concept based on the spatial distribution of the demand resulting from carsharing user requirements but which provides a basic supply generally accessible.

In terms of usability and in order to prevent path dependency, more challenges arose: many technical aspects were not standardized and had to be defined. The most important target was to define a user-friendly interface, including information, authentication and tariff, that is open to the customers of any mobility service providers. A further aim was to prevent the development and implementation of isolated services.

In the location concept the theoretical concerns described above are adopted and a methodology to locate charging stations in a model-based spatial distribution that meets demand is developed. The amount of charging points to be installed to ensure a basic supply was estimated on a policy level. The questions to answer were how to set up a location concept that distributes the objective target of about 300 charging points and where to locate those stations.

To answer these questions a charging station location concept was developed by VMZ Berlin and the Institute of Transport Research of the German Aerospace Center on behalf of the Senate Department for Urban Development and the Environment Berlin. Based on the theoretical concerns, in this initial phase of e-mobility the primary demand for charging points in public space was identified with respect to Berlin's carsharing providers and their customers. Resting upon data about the sources and destinations of carsharing trips, population parameters, and urban structure, a spatial simulation of vehicle-based trip chains was performed taking into account different scenarios with varying charging technologies, carsharing fleet sizes, energy consumption of the vehicles, range and charging duration.

The methodological framework of the location concept uses a combination of qualitative and quantitative research methods including modeling and simulation. The basis of the approach is consultations with key stakeholders. Using the results thereof, the authors set up a user-oriented quantitative method: Socio-demographic user profiles as result of the consultations and literature review form the core of the subsequent analysis of empirical mobility data. This involves analysis of mobility behavior of the corresponding person group in terms of travel issues, travelled distances, modal split and spatial localization of mobility behavior according to 195 statistical districts of Berlin.

Using a matrix of traffic relations from a 2008 Berlin traffic model, the results of the empirical analysis are optimized and fine-tuned from the statistical districts to 1224 traffic cells. This is followed by a simulation of vehicle movements to finally locate future charging demand.

2.1. Consultations with stakeholders

Consultations with several stakeholders were held, such as representatives of Berlin carsharing operators, automobile manufacturers, and energy suppliers. Framework conditions, supply and demand characteristics, current expectations, future trends, scenarios, and specific preferences concerning public charging infrastructure were discussed. Furthermore, the methodological approach of this concept was explained and the setting of priorities was discussed and agreed upon. The outcome of this process was an overview of suppliers' assessments, an analysis of the supply side as well as adjusted sociodemographic user profiles of carsharing users and private buyers of electric cars.

Regarding the results of stakeholder consultations, there are three carsharing providers with about 2,350 cars in the free-floating business model operating in Berlin. Thereof about 400 vehicles are electric-driven. Additional electric vehicles have been announced or are currently being added to the fleets, according to press releases (Mortsiefer 2013; Mortsiefer 2015).

As is obvious from the interviews, there are big differences regarding objectives and business models between the different operators. This applies especially to the business area served, operational concept, organization of charging process and the vehicles used. These differences arise in heterogeneous preferences concerning public charging infrastructure. It is obvious that, based on these differences in operator models, general objectives concerning the setting up of a public charging infrastructure cannot be generated directly. Therefore, the agreed user profiles form the basis for following analysis of empirical data and model applications. These user profiles contain specifications in sociodemographic parameters such as age, occupational activity, income, education, accessibility to private vehicles, and possession of a driving license. For future simulations, organizational parameters were adjusted in discussions, such as overall potential fleet size and operational guidelines regarding the charging process, as well as technical parameters including range and charging rate. These findings correspond with available references on carsharing users (Braun 2011; Knie et al. 2012).

2.2. Empirical analysis and modeling

For the quantitative analysis, the data collected in the cross-sectional travel survey System of Representative Traffic Surveys (SrV) has been used. Containing about 40,000 interviewed persons and 105,000 recorded journeys, the Berlin sample, drawn in 2008, forms a broad database for statistical analysis (Ahrens 2009).

Analyzing the mobility behavior in the previously defined user groups, the first findings clearly show that further modifications have to be made regarding the journeys to obtain a person- and journey-specific carsharing potential. In discussion with operators, the mobility behavior registered in the relevant user group was filtered to match the operators' insight into the form of demand. Therefore two restrictions were made in particular: Very short journeys were filtered out as they are mainly traveled by non-motorized private transport and operators do not see a high demand here. On the other hand, very frequently made regular journeys such as home-work, work-home or home-education, education-home (mainly commuting) were excluded as they form a major part of the traffic volume but utilization of carsharing is not likely in large scales due to planning security and financial issues. For the following analysis the remaining carsharing potential consists mainly of irregular accruing journeys e.g. for purposes of private transaction, shopping or leisure in a limited range within the city. From this carsharing potential source-target relationships matrices based on 195 statistical districts are generated for the source-target groups defined by purposes and location types. As expected, the resulting aggregated matrix clearly differs from the overall traffic matrix in the city. These empirical findings were used to a fine dispersion using a Berlin traffic model.

(a) (b)

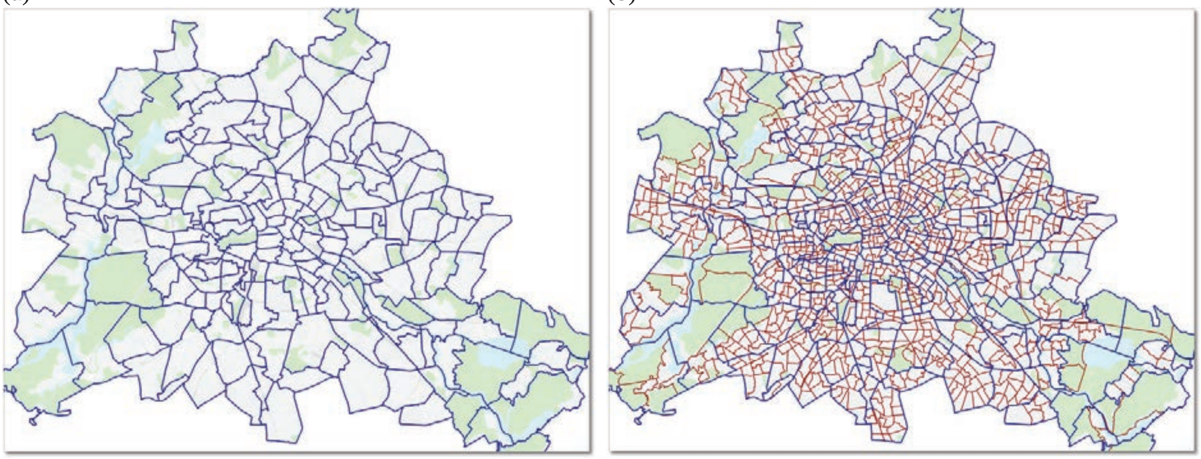

Fig. 1 (a) Berlin area classified in Statistical Districts (blue lines); (b) Berlin area classified in Traffic Cells (red lines).

The regional division of the Berlin traffic demand within the above-mentioned traffic survey system SrV takes place in so called statistical districts. In this regional clustering, the city of Berlin with its extent of 890 km² is separated into 195 distinct cells with an average size of 1.8 km² in the inner city area to 5.5 km² in the outer city areas (see Fig. 1 (a)). Using this granularity for dispersing charging stations would result in too broad clustering since, within those statistical districts, partly high differences in demand can occur due to heterogeneous spatial structure and different land use. For dispersing the demand of charging infrastructure within the city an existing and more finely granulated knowledge about the traffic within the city of Berlin was used - a VISUM traffic model containing demand matrices and traffic nets on the regional clustering of 1224 so-called traffic cells. Those traffic cells have an extent of 0.28 km² within the inner city which leads to a large regional refinement, since traffic cells are on average less than 1/6th of the size of the statistical districts (see Fig. 1 (b)). The traffic model depicts the motorized individual traffic for typical working days with five million single trips. Unlike the SrV, the Berlin traffic model does not integrate linkages between individual trips. Therefore, no trip chains (e. g. of single cars, inhabitants, households, companies) can be reproduced directly from the model. The matrix is symmetric; every cell has the same amount of inbound traffic as outbound traffic.

For further dispersion of traffic demand from statistical districts to traffic cells, methods are transferred from the SrV to the VISUM traffic model. The above-mentioned rules of selecting relevant ways from the complete demand matrix are assigned to the traffic model. In particular, the mentioned findings regarding trip lengths, trip purposes and the operating areas of the carsharing providers are applied to the model. As a result of the fine modeling, a submatrix containing potential carsharing journeys of a typical working day for the city of Berlin is gathered. This matrix contains approx. 350,000 trips that are seen as raw potential.

2.3. Simulation

Not every trip with an electric vehicle leads to an immediate charging demand at the end of the trip. In the urban context of the city of Berlin, according to the demand matrix, a typical trip in motorized individual traffic has a length of about 10 km. With a typical range of about 150 km from full charge with one of today's electric vehicles, several trips can be done before a charging requirement arises.

For the location of charging infrastructure with a demand-driven approach, this fact necessitates a change of perspective, away from single trips of separate carsharing customers towards vehicles' trip chains themselves. While information based on empirical surveys on a household or company level is available for privately used cars and for commercially owned cars, such information is not yet accessible for free-floating carsharing. The chosen planning approach is therefore supplemented by a simulation process, to close the gap between single trips and potential trip chains of carsharing vehicles. This process, integrated in a software tool, simulates the routes of a fleet of free-floating carsharing vehicles, given the relevant trips obtained by the previous analysis.

All non-feasible trips from the traffic model are first removed and the resulting trips calibrated with the official traffic model, by using trip-purpose-specific day curves and passengers per vehicles. The single trips per day are then extrapolated to vehicle-trips at each hour of the day.

By connecting the single trips of separate drivers to vehicles' trip chains, the need for energy in the form of charging demand can be located within the city. Therefore technical details of the vehicles, such as energy capacity (range per charge), charging technology (charging speed) as well as fleets' operational characteristics, such as the operators' dealings with the charging process itself, can be varied within the simulation to represent different scenarios. The simulation of a typical working day is performed a variable number of consecutive times to skip the initial phase, and can be performed for variable interval lengths. The algorithm locates charging demand within a traffic cell whenever the charge of a car falls below an individually adjustable minimum level.

The simulation process results in a charging demand per traffic cell which is transferred to a time-based factor with respect to the used charging technology. The resulting charging demand per typical working day is expressed in the unit *charging hours per day*. The transition from charging demand per day to demand of charging stations per traffic cell is performed by using the charging demand within the maximum hour combined with a concurrency factor and a rating threshold.

Seven different scenarios were simulated, varying the expected fleet size of electric free-floating carsharing vehicles between 500 and 1,600, the charging speed between AC and DC charging technology, and the operational handling of the fleet in three scenarios. Of those seven scenarios, one base scenario was selected as the most probable development under current knowledge.

2.4. Results

As a result of the modeling and simulation under the assumptions of the base scenario, a charging demand of 1.621 charging hours per typical working day is predicted. The distribution of the charging demand can be seen in Fig. 2 (a) where the color represents the charging demand expressed in hours per day and warmer colors represent higher demand. While especially in the outer areas of the most regions there is a low demand of below two hours per day, the inner city area contains 70 cells with more than 5 hours per day of demand, of which eight cells have a demand for between 8 and 15 charging hours. The result of the transfer of the time-based charging demand to a demand of charging points (actual charging infrastructure) can be seen in Fig. 2 (b). A demand of 338 charging points is calculated within 308 traffic cells. Of these cells, 280 should be equipped with one charging point, 26 with two points and 2 with three points. Following the results of the initial stocktaking, 279 publicly accessible charging points already existed in Berlin within 124 traffic cells. Considering these as a steady stock, the demand for additional charging points falls to 264 in 242 traffic cells, spread across 222 cells with one charging point, 18 cells with two charging points and 2 cells with three charging points (see Fig. 2 (c)). If the existing charging stations stay in operation and the recommended addition is fully implemented, Berlin would be equipped with 543 publicly accessible charging stations in 366 traffic cells with a distribution as shown in Fig. 2 (d) below.

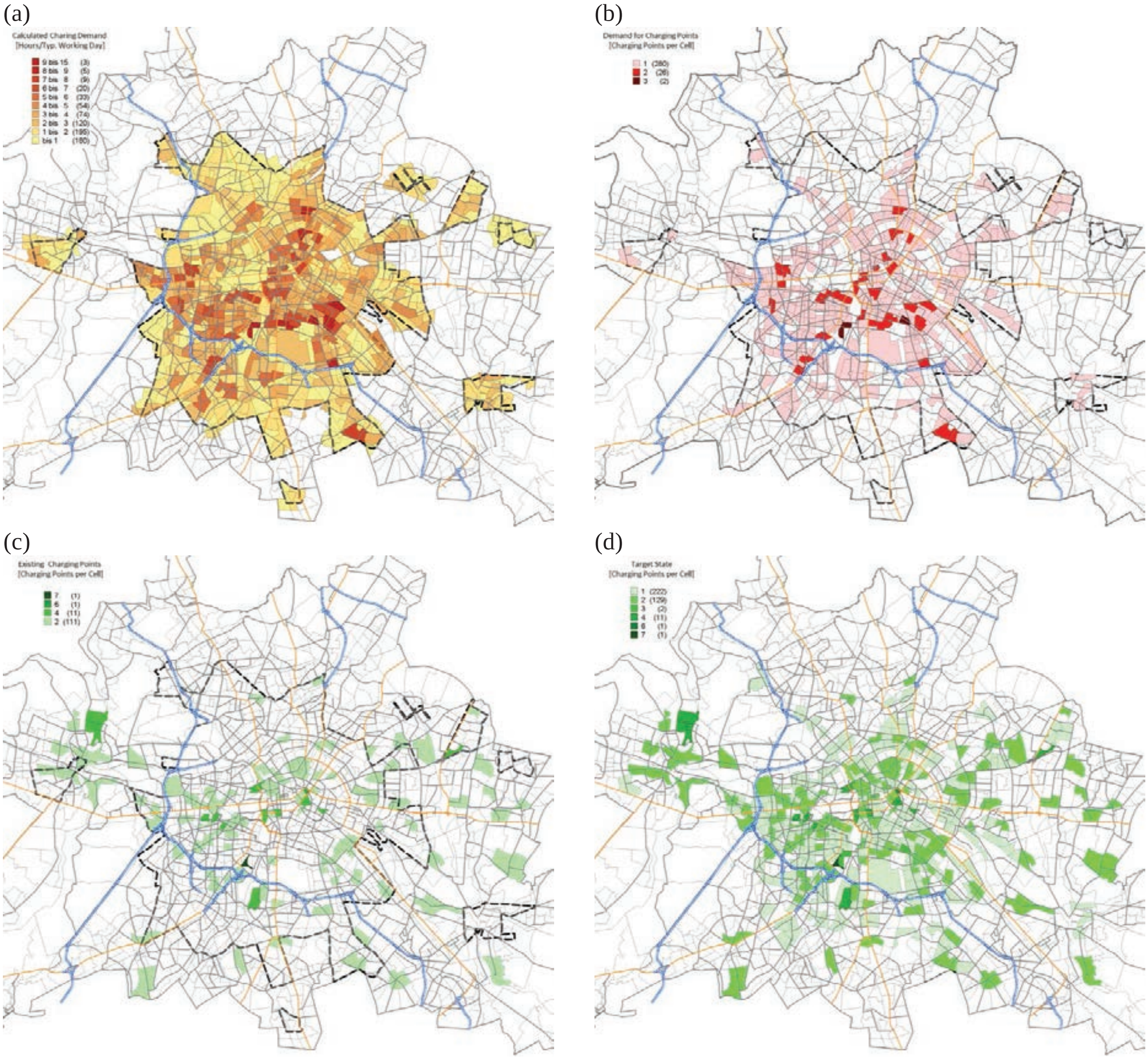

Fig. 2 (a) Distribution of charging demand; (b) Recommended distribution of charging points without consideration of existing charging infrastructure; (c) Existing charging infrastructure; (d) Target state, existing infrastructure plus implementation of recommended addition.

To give planning advice derived from the model results based in traffic cells and to merge low rates of demand in neighboring cells together, the results are transformed into buffered, round so-called searching-zones. Every searching-zone determines the area in which two charging points should be constructed. The final definition of individual micro-locations is done in application procedures between operators, chosen later in the process, and official bodies coordinated by the municipal office. In deciding on micro-locations, considerations such as main-street access, no parking restrictions, easy finding, historic preservation issues or intermodal options are taken into account.

3. Contract awarding procedure

After estimating the demand, the implementation and operation of the charging infrastructure in Berlin was tendered out. An innovative two-stage tendering process was chosen. In this approach, the expressions of interest by several bidders were followed by a competitive dialog to specify the contract details. This costly and time-consuming process was chosen, as no models or experience existed on the topic and there was a lack of technical standards. Therefore, the classic tender process with clearly defined services by the public client and a simple comparing of the bids was inappropriate. Nevertheless the city administration set up a conceptual framework described below:

- Implement a role-based model that distinguishes between two clearly defined and separate roles: the charge point operator (CPO), who runs the infrastructure and the mobility service provider (MSP), who holds the contract with the electric vehicle user as customer. That means the customer is free to choose any MSP and is ensured to receive the service at any charging point.
- Follow a two-phase expansion of the charging infrastructure: In the first supply-oriented phase based on the location concept described above, the installation of 340 charging points within defined searching-zones has to be completed within 21 months from the signature of the contract. This first phase is followed by a demand-oriented second phase for the further extension based on occupancy rate, further research and political concerns.
- Include all conductive charging technologies (AC, DC, different plug types, charging columns and technological approaches that use street lightning masts).
- Demonstrate interoperability of different operators by splitting the overall funding into three batches.
- Ensure interoperability of different infrastructure operators by running an operator-independent authentication platform and providing operator-independent user information.
- Include installations on public ground as well as on private ground that is accessible day and night (“semi-public”).
- Integrate the charging function to the smart card, as an integrated service solution for mobility services that is being introduced in Germany.

The Europe-wide announcement received a positive response with 28 expressions of interest. Out of these bidders, seven participants, companies as well as consortia, were selected to take part in the competitive dialog process between city administration and potential operators with a structured step-by-step approach to develop the complete and detailed contract conditions. The whole process, until it came to the final decision for one consortium, lasted 15 months. The final choice of bidders took place in January 2015.

4. Provider-independent user information

Another important step towards a successful implementation and operation of an efficient charging infrastructure is the challenge of implementing the required operator-independent user information. User information for charging infrastructure includes static information such as location, charging technique (AC, DC), type of plug and name of operator as well as dynamic information about the actual status of the charging infrastructure. The City of Berlin already operates its own Traffic Information Center (here, TIC) that bundles traffic information to be used by the Berlin public free of charge and free of discrimination. Real-time information about where charging stations are and whether they are occupied is therefore integrated into the traffic information platform of the TIC. Operators of charging infrastructure in the Berlin public space are obliged to supply this static and dynamic information to the TIC: Besides showing this information on traffic maps, they are furthermore integrated into intermodal routing services by VMZ Berlin. These services, currently available on www.viz.berlin.de and being tested on apps within research projects, allow users to find routes route from their origin directly to free charging points near their destinations.

5. Authentication platform

Users of public charging stations should not be at the mercy of one monopolist operating those stations. Therefore, an authentication platform has been set up to ensure provider-independent and non-discriminatory access to the publicly funded charging stations. This platform is a precondition to implement the defined role-based model. Every mobility service provider prepares a list of his customer-IDs that are allowed to use the charging infrastructure each day. All personalized customer information remains with the mobility service provider solely, guaranteeing a maximum of data protection and privacy. The authentication platform furthermore collects the IDs of all service providers and puts together an overall white list, containing all users allowed to use charging infrastructure in public space. This white list is updated every day. The technical back offices of all charging point operators pick up the white list daily and send the list to all their charging points. This concept prevents the high costs of roaming platforms and keeps the market open for a maximum of mobility service providers. In particular, existing charging infrastructure can be integrated into this model.

6. Discussion

Using the case of Berlin, a procedure and method was developed to estimate future charging demand and implement the buildup of a public charging infrastructure. Using the expectations of stakeholders as well as empirical mobility data and traffic models, it was possible to estimate future charging demand in a relatively high spatial resolution of 1224 traffic cells. As shown, the distribution of charging demand is unequal. There are obvious peaks and troughs in the city area. Between all calculated scenarios, the amount of charging demand varies; the relative distribution between the cells, however, stays virtually constant. Therefore, based on this approach, the main areas for charging demand within the city of Berlin are seen as relatively fixed. The final amount of charging stations per regional unit, as well as the microscopic location of those charging stations, depends on these assumptions. The peaks in demand seem to occur in quite densely populated, sought-after inner city areas with mixed use including a high amount of leisure opportunities. This clearly relates to both the defined carsharing user group and the selected trip purposes. Nonetheless, more research is needed to confirm correlations between public charging demand and urban structure and, ideally, to formulate schematic rules to simplify the transfer of the findings to other cases. This works is currently being done by the present authors.

As has been shown, due to the early status of market penetration and the relatively new mobility services and business model of “free-floating carsharing”, there were only a few empirical results available in the relevant phase of the planning process. The approach described here handled this by including relevant stakeholders and discussing assumptions. Nevertheless, agreed assumptions and expert assessments on user groups and user behavior should be validated by quantitative findings.

The results of several quantitative studies with corresponding research questions are currently coming up. Regarding the available results of two big data studies using vast recorded vehicle data, the results of this approach match well in terms of demand hotspots in spatial localization (Weigele 2014: 20/ Lehmann et al. 2015).

Also, the comparison to monitored utilization rates delivered by one operator tallies with the reported results (see Fig. 3).

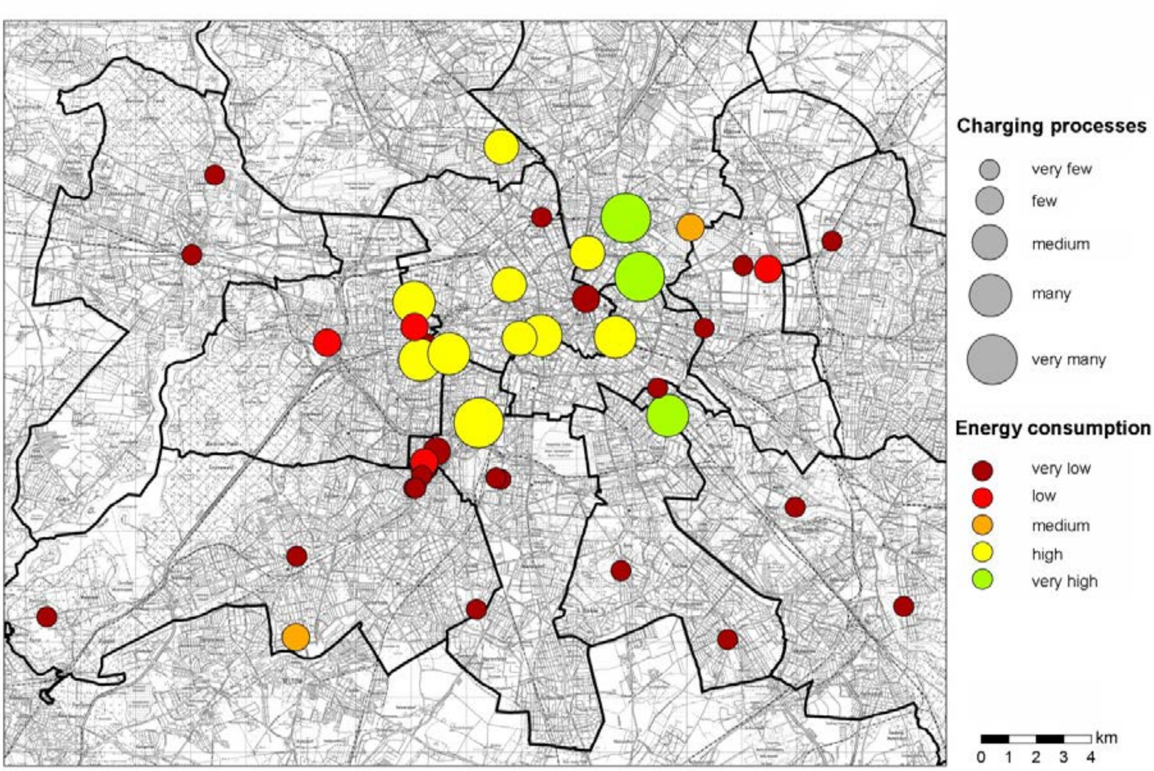

Fig. 3. Charging processes and energy consumption on public charging points by carsharing cars in 2014.

Yet, regarding the positive validations, the method described still shows a model-based approach rests upon assumptions and existing data and can only approximate a future situation by making estimations.

Generally, the pictured approach in the case of Berlin shows the importance of an integrated and structured planning process when implementing the uptake of a new infrastructure. Therefore, a structured methodology using qualitative and quantitative data was introduced. This elaborate approach was able to ascertain enormous differences in the spatial distribution of charging demand within the city. As these differences can now be compared to the results of big-data studies and utilization rates, both the methodology and the results of this study can be seen as being broadly validated. The specific findings referred to in the location concept will be generalized to ensure easy application in other areas in the near future.

The efforts described above regarding the contract awarding procedure defined solutions for many non-standardized questions that can be used by other municipalities to reduce such efforts and cut costs when dealing with the uptake of public infrastructure in the future.

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