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Investigation on public eMobility grids - consequences on urban infrastructure

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Summary

On the example of Stuttgart an investigation on the demand of public charging points was conducted based on real mobility patterns of today. With some additional assumptions in example maximum tolerated waiting times, today's and future charging technologies, electric vehicle ranges, etc. a method for the estimation of infrastructure needs is proposed. The method bases on today's Origin Distance (OD)-pairs distinguished between urban and suburban areas. Results are for example hot-spot areas and equipment which needs to be improved in order to get a higher level of acceptance by users of battery electric vehicles.

Keywords: BEV (battery electric vehicle), city traffic, energy consumption, infrastructure

1 Introduction & Fundamentals

Due to a high level of motorized mobility within Germany multiple cities are getting close or even beyond the maximum level of emissions recommended by the World Health Organization. The European Commission gave recommendations on how to treat these so-called local-emission-zones. One of the political supported solution may be the increased use of battery electric vehicles (BEV), but the current selling numbers of those vehicles still shows a lack of customer acceptance. This is outlined by the current sales figures and related growing rates of electric vehicles within Germany, which fall back by far in direct comparison to other industrialized leading countries [1]. In order to amplify the acceptance of customers towards BEV concepts, the positioning and related charging technology especially in a public area needs to be investigated. In the following this will be done on the example of Stuttgart, being beyond the cities with the highest charging point distribution in Germany.

1.1 Analysis of given traffic model data on the example of Stuttgart city area

Already by 2013 a detailed study about current individual travel behavior on the example of the city and region Stuttgart was conducted [2]. The so-called model “mobiTopp” calculated the time based mobility behavior of the urban and rural population by taking into account the individual modal split as well as related destinations. The modal split travel data are calculated, based on all individual trips per day combined with information on OD-pairs, as well as public travel timetable data. Applying these information, the study was able to illustrate the full public and individual transportation situation of Stuttgart.

This paper is focused on charging infrastructure needs as a consequence of individual vehicle transportation with BEVs only, the transportation data were selected from the overall mobility data set. The population residence area of Stuttgart citizens is dominated by the five counties, so it was hypothesized, that main movements from home to another destination will concentrate especially in the area of the inner city of Stuttgart. Hence, the related map model grid was simplified into five counties (Ludwigsburg, Rems-Murr-Kreis, Böblingen, Esslingen and Göppingen) without dissection but the inner city was split into 23 individual districts (see Figure 1).

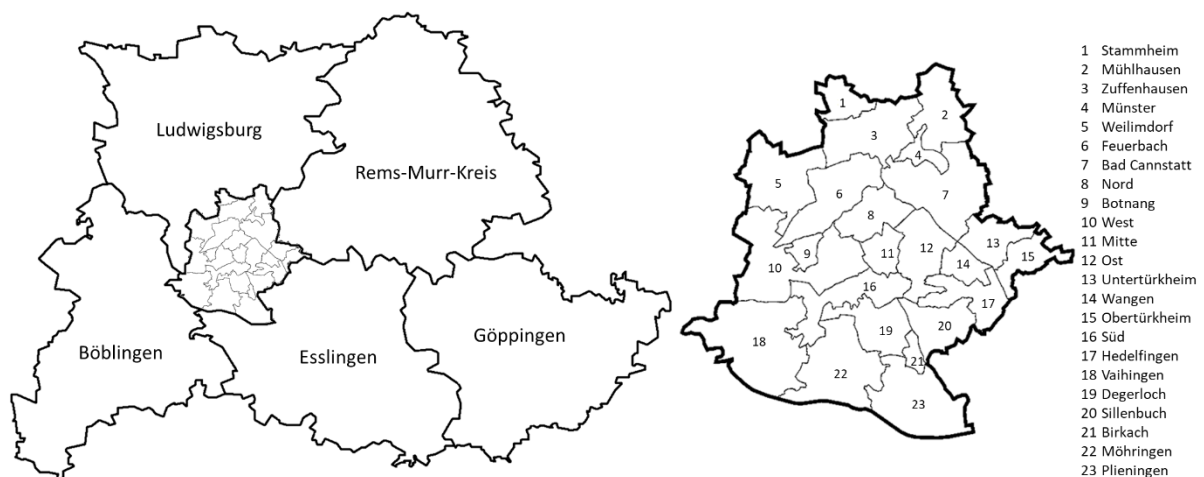


Figure1: simplified map model on the city of Stuttgart and surrounded counties

The “mobiTopp” database included vehicle movements of the selected areas during a full week, which represents more than 21 mio. movements per week in total. These individual trips can additionally be distinguished by the related activity (work, education, shopping, leisure, others or way home), where a combination of these trips is possible. These data can be averaged on a daily base, and differ from real data of each individual day only by a deviation of less than 10%. By investigating the averaged daily based data, the ratio to the total number of trips per day (approx. 3.7 mio. trips per day) gets of interest (see Figure 2).

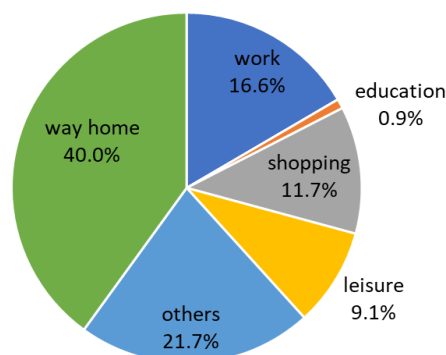


Figure2: ratio of different activities based on individual daily trips (out of 3.7 mio. individual trips) [2]

Here, the individual activities are dominated by the way home (40.0%) and others (21.7%), followed by work (16.6%), shopping (11.7%) and leisure activities (9.1%). From all activities only education can be neglected, due to his low percentage of less than 1% out of all daily trips. This paper is focused on public charging points for electric vehicles, all individual movements to a private home (activity way home and others) using

private charging points are not regarded so only the activities work, shopping and leisure are integrated.

In order to identify the appropriate percentage of movements to each area of Stuttgart, by the arrival of individual vehicle trips, a simplified flow scheme was integrated in these rural and inner city area maps. These flow data are again a result of the “mobiTopp” database, and are calculated on a daily base.

The calculated data shows that only a small proportion of about 12.6% is oriented towards the inner city of Stuttgart, but a greater amount of trips about 62% (incl. the inner city) remains within the outer five counties and is superposed by additional 13.9% of trips in between the five outer counties (see Figure 3). Obviously, mobility demands in the county areas are therefore to be seen as non-neglectable.

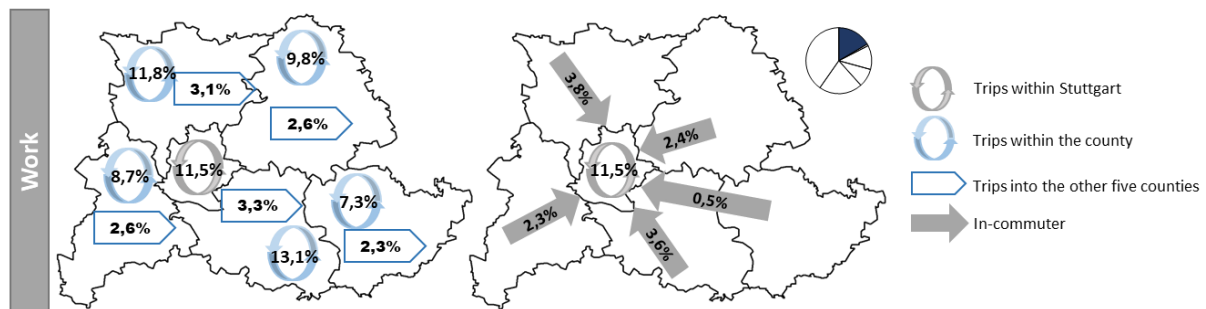


Figure3: trips distribution on the activity work within counties and in-commuter intensity within the city [2]

Looking on the alternative activity shopping, which represents 11.7% out of all trips a day, the amount of trips conducted within a certain area is even more orientated towards trips within the individual counties with an total percentage of 75% (incl. the inner city), which again is superposed by additional 8.1% of trips in between the five outer counties. Here, the decision to travel to the inner city area is a part of all movements with 10.9% of the total number of trips per day linked to the activity shopping (see Figure 4).

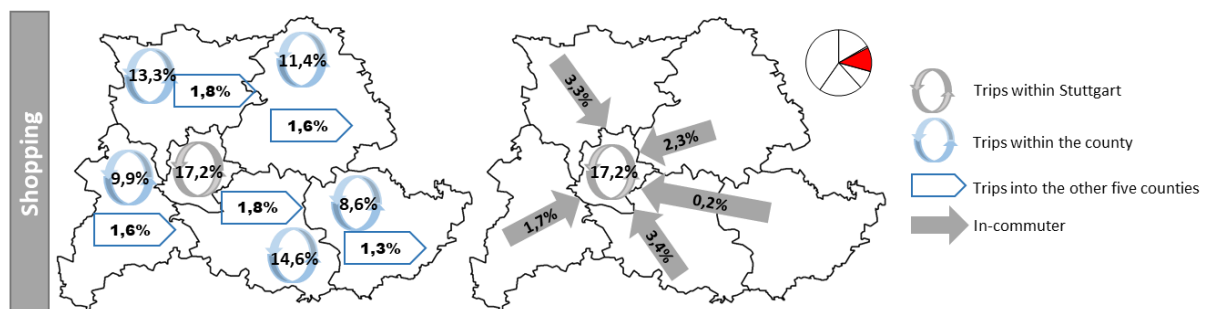


Figure4: trips distribution on the activity shopping within counties and in-commuter within the city [2]

The third and last activity leisure represents a remaining percentage of 9.1% on all daily vehicle based trips. By summarizing the percentage of trips being conducted in the individual counties (incl. inner city of Stuttgart), again 61.1% of all daily trips out of this activity are conducted within this scheme, and additional 17.2% just represents trips conducted from one to another county. So, again the number of trips being orientated towards the inner city is relatively low on a level of 11.8% (see Figure 5).

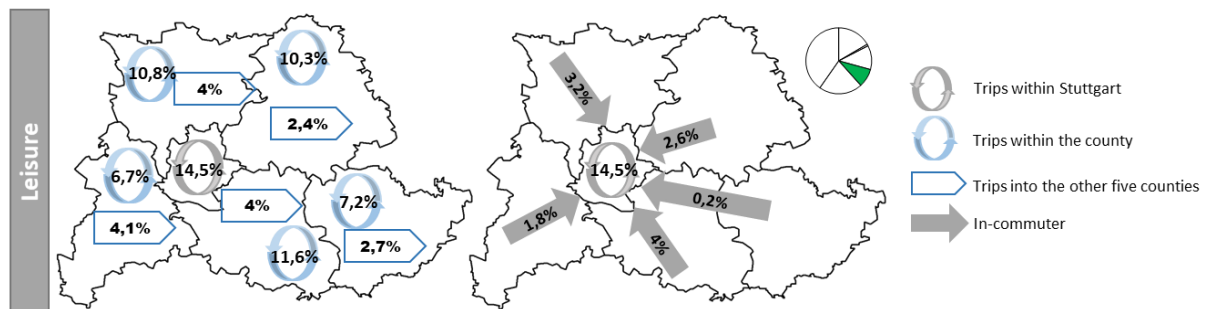


Figure5: trips distribution on the activity leisure within counties and in-commuter intensity within the city [2]

As long as a superposing of the individual vehicle trips results in a considerable movement of the inner city of Stuttgart throughout a day, it needs to be clarified in which of the 23 districts a particularly higher density of vehicle arrivals will occur. Only by identifying these affected districts, an appropriate determination of the right placement of public charging points can be managed. By extracting the OD-pairs of the “mobiTopp” database on the more distincted level of the 23 districts, it gets clear which of the districts are affected. The most affected districts are highlighted by the color red, whereas areas marked by orange or yellow are on a level of less than 50% and areas marked by blue are on a level of less than 10% of the absolute vehicle arrivals in the inner city. Therefore, the central area district seems to be the most affected (see Figure 6). The graphics in Figure6 are not comparable, because of the different maximum level of intensity.

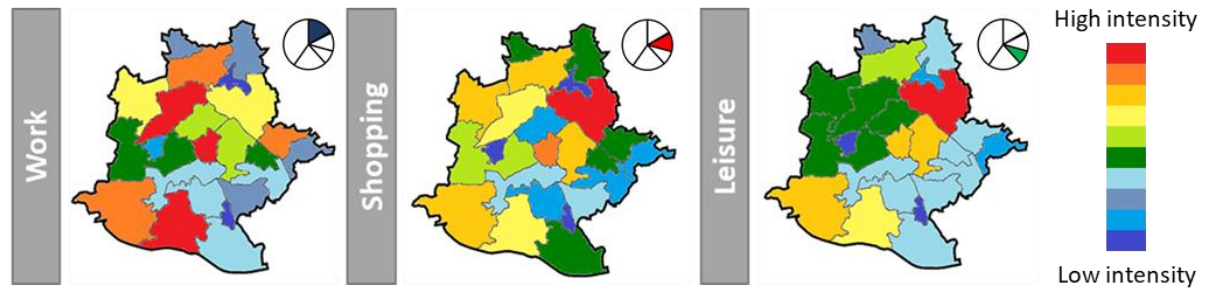


Figure6: in-commuter intensity on all activities within the inner city districts of Stuttgart

Hence, the daily trips destination areas by passing from the outer counties to the inner city can be reduced to four out of the 23 districts in the inner city, which results in an increased density of vehicles arriving in a considerable small area of the inner city. Therefore especially these four inner districts will be affected by a particularly higher need on public infrastructure for electric charging points.

1.2 Segmentation of current BEV types & consequences on infrastructure

Now that the vehicle trips to individual areas has been calculated, it is necessary to investigate on the distribution of different types of BEVs within the market. Therefore it is in a first step necessary to classify those sold vehicles in adequate groups. Of importance for all customers is the maximum achievable travelling distance (derived out of standard driving cycle, being in Europe the NEDC), furthermore the maximum rated driving power which allows the indirect distinction of the implemented technology in terms of temporarily available power.

Based on recently published selling numbers of battery electric vehicles in Germany [3], this classification shows a distribution which may be assorted in at least two different groups. First, vehicles with a maximum travelling distance of approximately 200 km with a driving power of 100 kW (or less) represent the B/C-segment type. Furthermore vehicles with a maximum travelling distance of approximately 500 km with a higher driving power of 200 kW up to 500 kW representing the D/E or luxury segment type (see Figure 7).

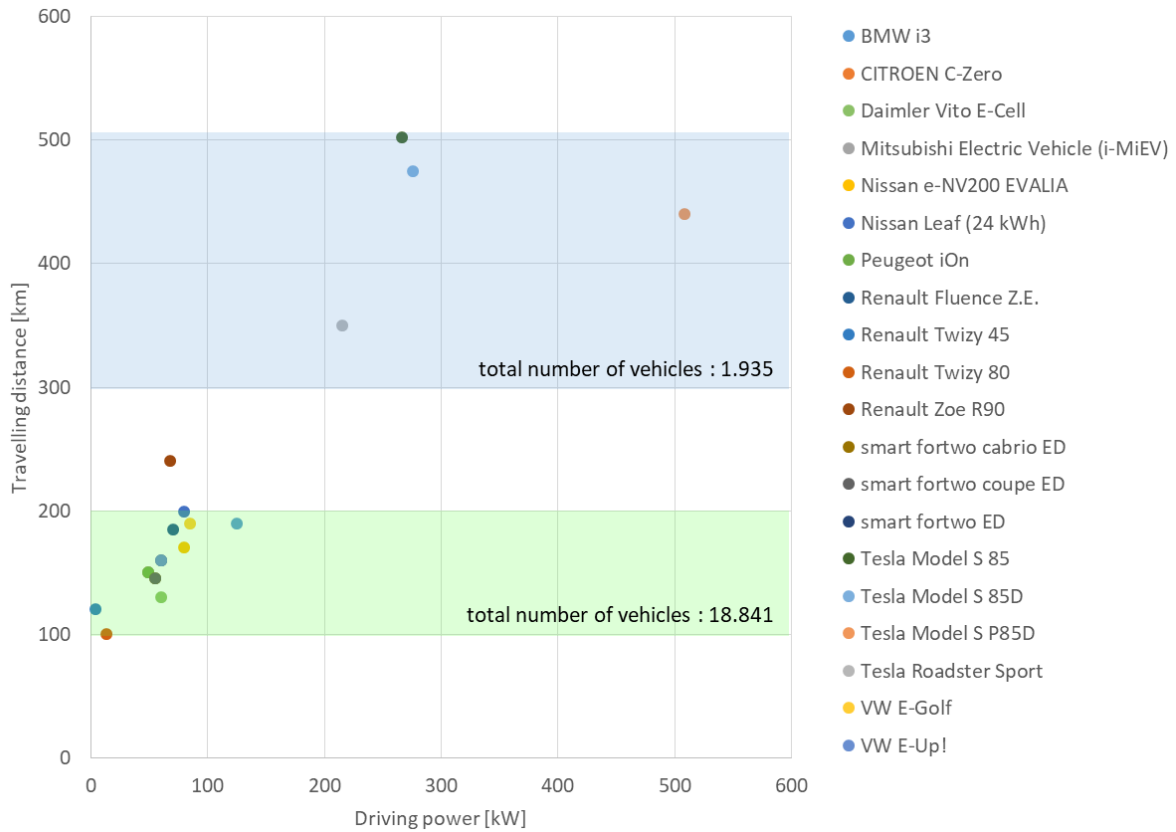


Figure7: segmentation of current BEVs based on selling numbers of BEVs in Germany [3,4]

Now, having classified these currently available BEVs on the market, the relative percentage for each of these vehicle groups can be established. In the case of Germany, the absolute vehicle selling numbers of 2016 lead to a covering percentage of more than 90% for those vehicles which were previously linked to the B-/C-segment, but only 10% belonging to the D/E or luxury segment were chosen by all other customers (see Table 1).

Table1: BEVs dispersion in Germany (selling numbers from 2016) [3]

	selling number (out of 2016)	relative percentage
B-/C-segment	18,841	90.7%
D-/E-segment	1,935	9.3%
total number	20,776	100%

The classification of the available battery electric vehicles in two different categories allows an appropriate assignment of averaged energy consumption for each type of these BEVs. Based on the official certification data provided by the OEM's of these BEVs, the assumed average energy consumption for B-/C-segment vehicles is within a range of 17–20 kWh/100km, whereas for D-/E-segment vehicles the energy consumption may be assumed in the range of 25–28 kWh/100km.

In order to derive the appropriate level of energy consumption it is then necessary to determine the average distance for each of the relevant destinations. Therefore, a statistical distribution on the full spread of different distances needs to be extracted out of the previously mentioned “mobiTopp” database, where the relevant activities (work, shopping and leisure) need to be analyzed individually. The Figure 8 summarizes the individual trip distance distribution depending on the activity.

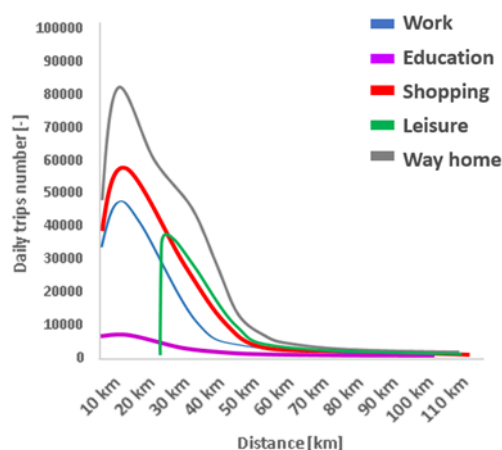


Figure8: distribution of different trip distances distinguished between individual activities [2]

By applying a calculation of the related mean value for each of these activities, it comes out that the mean individual distance for the activity work in the range of 13.6 km. Furthermore in case of the activity education it is in the range of 9.6 km, then for the activity shopping it is in the range of 5.4 km and in case of the activity leisure it can be assumed in the range of 5.1 km. The way home mean distance in that case is in the range of 11.5 km.

Then, the appropriate percentage of battery electric vehicle in the field needs to be determined for the above mentioned representative vehicle types. In this paper it is assumed, that the customers market will gather exactly that level of BEVs, which is needed as selling number to achieve future CO₂-fuel consumption regulations. The baseline for these estimations is the anticipated selling volume on new vehicles by 2020, which may be assumed by approx. 3.4 mio. vehicles, and a related total market volume of vehicles in the range of 46 mio. vehicles in Germany [3]. Furthermore the related fleet fuel consumption was assumed to be kept also constant for conventional powertrain systems, related data were extracted from the ACEA data base [5]. Based on this, the BEV ratio can be determined with a relative level of BEVs of 2.3% by 2020 and 8.3% by 2025 compared to the overall market volume (see Table 2).

Table2: scenario of BEV future magnitude for Germany [6]

Calculated selling numbers based on full compliance of OEMs to CO ₂ fuel target consumption	BEVs magnitude	BEVs percentage (estimated)	BEV ratio (suggested scenario)
selling number by 2020	392,591	11.7 %	-
absolute market volume by 2020	1,069,956	2.3 %	2.5%
selling number by 2025	564,532	16.8 %	-
absolute market volume by 2025	3,815,579	8.3 %	10%

But to define customer's expectations in terms of the vehicle related tolerated charging time it is then important to understand their regular daily mobility demands, characterized by the activities linked to each of the destinations chosen by the customer. The INFAS and DLR institute together conducted a study in 2010, where customer's destination based activities were divided into five groups: business, education, shopping, leisure and other private destinations. The customers spending time for each of these activities can be assumed in the area of approx. 30 min to 60 min for shopping and leisure activities, whereas for business and educational activities the spending time may be oriented in the area of 180 min to 240 min. [7]

Based on this information it is possible to determine the charging technology demands for each of the above mentioned use-cases, since the charging period is just a result of the needed electrical stored energy in relation to the available charging power. In Europe, available charging systems are defined on 230 V-/400 V-technology (either AC or DC) and can be furthermore distinguished by the applied electrical power.

AC-charging points based on the so-called Type 2 connection allow in principle a power supply of less than 11 kW (one-phase AC voltage), but may be able to support even 43 kW (three-phase AC voltage). In case of DC-voltage supply, based on the CCS-connection a higher power level of more than 150 kW can be achieved. More sophisticated super-charger concepts, which may be available won't need to be taken into account for these urban applications, since already the CCS-charging systems provide a sufficient power to satisfy even extreme needs marked by the shopping destination with a charging time duration of less than 30 min in order to fully recharge even D-/E-segment vehicles described earlier in this chapter.

As result, the appropriate power grid connection in dependency of the available charging time and activity of the customer (see table 3) can now be assigned:

Table3: calculation premises on charge point determination

[B-/C-Segment] versus [D-/E-Segment]	Trip specification		Specified charging connector	
	Mean distance for individual trip	Maximum tolerated charging period	Type 2 based charging point	CCS based charging point
Business activity	13.6 km	180 min	x / x	[x] / [x]
Shopping activity	5.4 km	30 min	[x] / [x]	x / x
Leisure activity	5.1 km	60 min	x / [x]	[x] / x

Reasons to use a CCS charging point only may be the given hardware interface (connector and charger concept of vehicle) or a higher demand on charging power due to the battery state-of-charge level. By applying the two options B-/C-segment or D-/E-segment classified vehicle, the right charging technology to be applied for each of these vehicle segments can now be determined.

2 Scenarios on public charging points for BEVs

In the first chapter OD-pairs of Stuttgart were extracted out of the more complex and precise multi agent travel demand model “mobiTopp”, as well as a detailed definition of BEV and charging concepts including their ratio in relation to today’s conventional vehicle system intersection was established.

In this chapter these boundary conditions will be compared to today’s electric charging infrastructure, as well as an extrapolation to further needs will be described base on different future ratios of BEVs. In a first step the today’s situation of given electric charging points in Stuttgart including the five outer counties was investigated. Data which were selected and integrated out of existing internet sources [8], prove the high density of already installed electric charging points in the inner districts of Stuttgart with an absolute number of more than 400 charging points, whereas the number of charging points installed in the five counties is by far lower on a magnitude of less than 100 for each of the counties (see figure 9).

Furthermore the disposal of a maximum charging power level of 22 kW for more than 95% of all available charging points clearly indicates a limitation in respect of customer’s demands on sufficiently fast charging points especially in the case of short activities like shopping.

The intersection of electric vehicles throughout Germany is currently still on a very low share of less than 0.1%. One may doubt therefore whether this charging capacity might fit also to the future demands and necessities of a city which will clearly step ahead towards eMobility due to given constraints by particulate emissions of current traffic in Stuttgart.

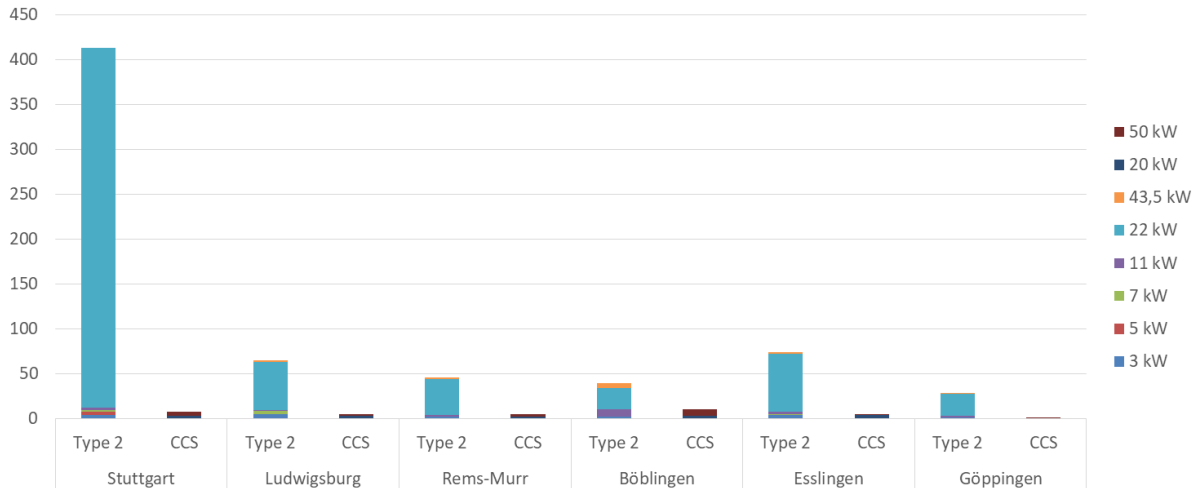


Figure9: current distribution of charging points for Stuttgart and outer counties [8]

Therefore, an extrapolation on the future needs was conducted, where in comparison to today's situation the assumption on a BEV intersection of 5% and 10% was calculated. Vehicle concepts were split into two groups with a 90% ratio in the case of B-/C-segment vehicles and only 10% ratio in the case of D-/E-segment vehicles. What still needs to be specified, is the energy demand of customers once they choose a public charging point to recharge their vehicle battery. Here, two scenarios were chosen: first the (i) best-case scenario describes a situation, where customers are able to recharge after any individual trip (so that the power demand may keep on a low level), and secondly a (ii) worst-case scenario, where customers will only choose to recharge the battery, once the lowest possible state-of-charge level is reached (here the demands for charging power will surely be higher in order to maintain the maximum tolerated charging time). These scenarios will especially allow to define the future demand for high power charging concepts and robustness of today's public charging point power supply technology.

In order to calculate the number of related charging points, it is then necessary to define the appropriate number of vehicles, which may occupy the public charging points at a certain moment. To do so, again the database of the "mobiTopp" OD-data was chosen, in order to understand the time based distributed need for charging points. Figure 10 shows in the case of Stuttgart the distribution of individual departure times where different activities of all vehicle trips were distinguished.

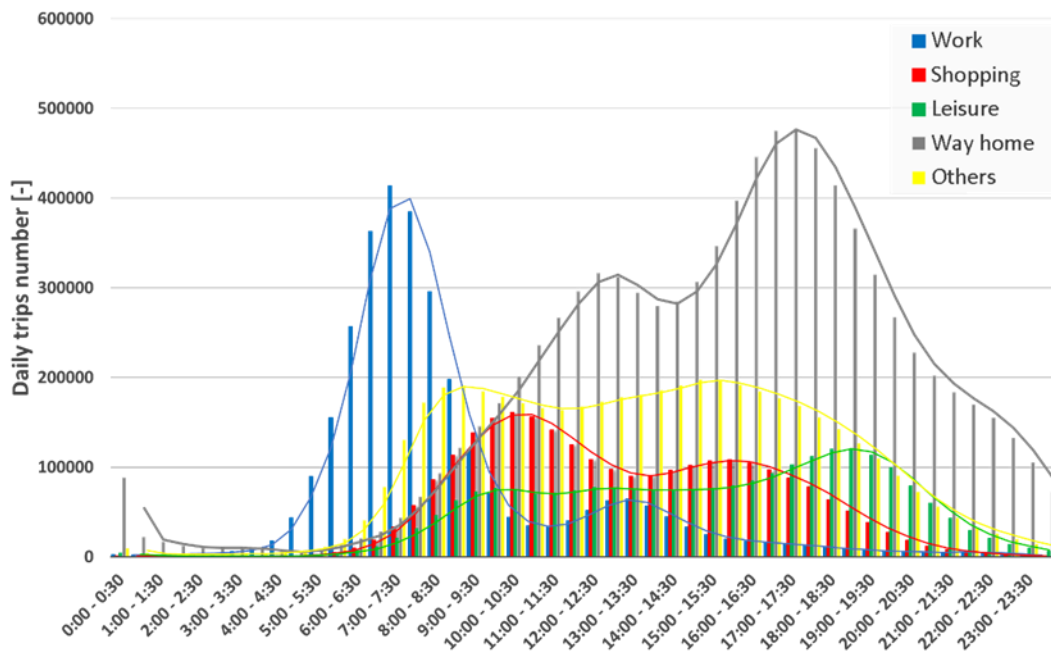


Figure10: distribution of departure times for vehicle trips on the example of Stuttgart [2]

Since it was pointed out already in the chapter one, that the maximum trip distance of vehicle trips remain lower than 14 km (business trip), it can be assumed that the arrival time distribution for each of the activities will not differ dramatically from the given departure time. Looking more closely to the time delay especially in between of the most interesting activities work, shopping and leisure, it comes out that these three destinations will surely not occupy the same area, so it can be assumed to summarize these individual needs to one total number of necessary individual charging points.

Taking into account these boundary conditions, a first investigation was made on the future needs on charging points for the inner 23 districts of Stuttgart. Figure 11 shows the results of this calculation, where three activities work, shopping and leisure were combined.

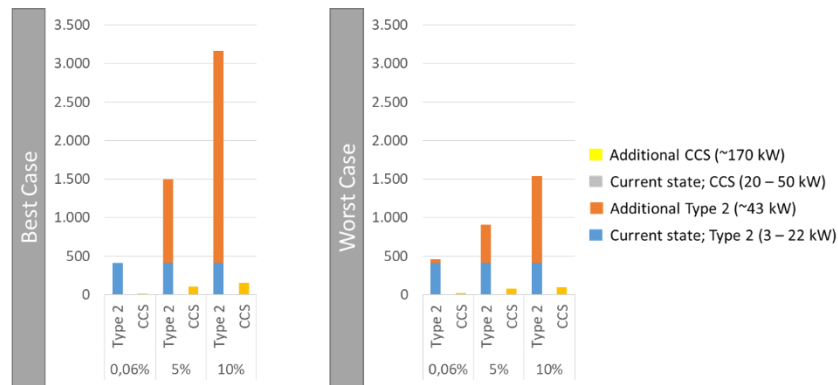


Figure11: calculated number of future charging points in relation to current state for the city of Stuttgart

Regarding these results any increased ratio of BEVs will lead to a demand especially of high power charging points, since the step towards a ratio of 5% BEVs is dominated by Type 2-charging points. The worst-case scenario amplifies this need, but after doubling the BEVs intersection rate to 10% both scenarios lead to a still increased demand of additional charging points with changed technical demands on a mid-power supply level of at least 43 kW as well as high power charging supply points.

In order to locate these demands more precisely within the established grid of the 23 districts of Stuttgart, a second calculation with local parameters were conducted. Figure 12 shows on the example of the activity work the related results for the best-case-scenario. Red plotted areas are highly affected by further needs of charging points, whereas yellow areas have an increased need for CCS-based charging points, only green marked areas don't have a further need on additional electric charging points. Already by a step of BEV ratio at a level of 5%, only the districts Mühlhausen, Münster, Botnang, Stuttgart-West, Stuttgart-Süd, Sillenbuch and Birkach are not highly affected by further need of charging points. An even higher BEV ratio of 10% then excludes just Birkach and Botnang. In the case of the activity shopping the demand of additional charging points is even higher due to the shorter charging period.

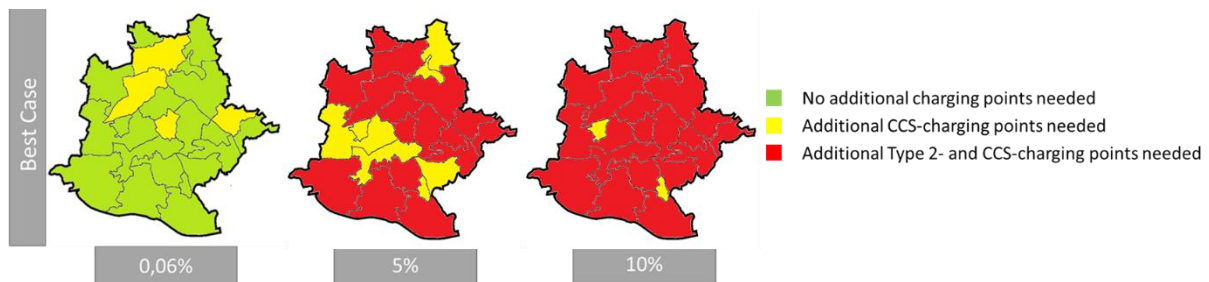


Figure12: Necessary charging infrastructure (activity work) for the districts of Stuttgart (best-case)

In chapter one it was shown, that the percentage of daily trips in the counties of Stuttgart is higher compared to the daily trips leading to the inner city. It is also important to know that the number of available charging points is by a factor four lower (see Figure 9). Therefore a further calculation was conducted, taking into account both scenarios best-case and worst-case (see Figure 13 and Figure 14).

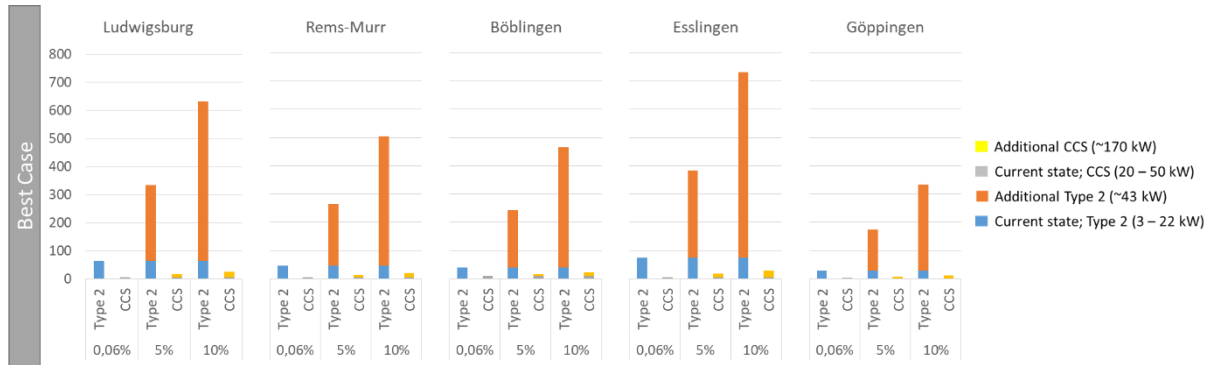


Figure13: number of future charging points in relation to current state for the counties (work, best-case)

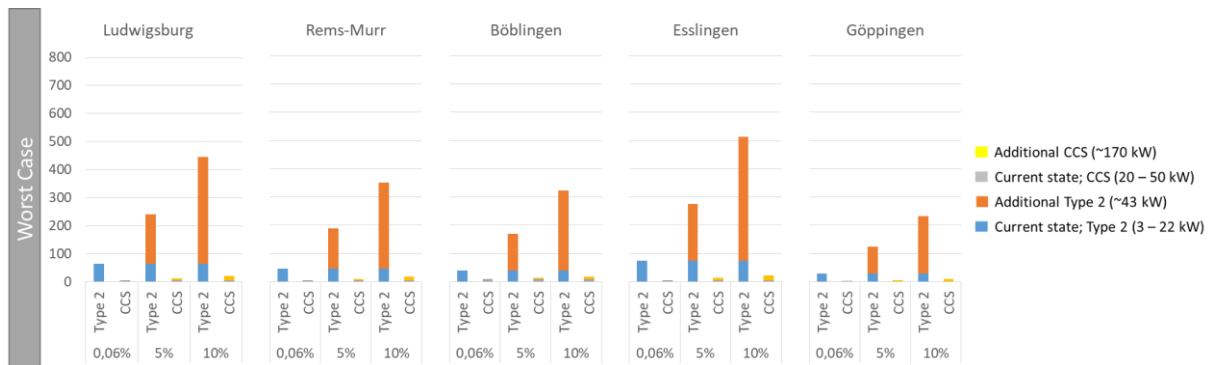


Figure14: number of future charging points in relation to current state for the counties (work, worst-case)

Already the best-case-scenario reveals the direct need of a high number on additional charging points if the ratio of BEVs increases to 5% or beyond – the number of installation may increase to a factor ten, compared to today. In comparison to the calculated needs of the inner city of Stuttgart these demands are also clearly higher. Again, the demand of charging power level exceeds the concepts of current installations.

3 Conclusions

The current study derives needs on further improvements for public charging points in the case of Stuttgart. These investigations were conducted based on simplified OD-pairs of the more sophisticated model called “mobiTopp”. The intersection of BEVs was derived from current market data, and related extrapolations correlating to future CO₂-penalties.

The investigation indicates a clear need for further installations of charging points. The majority of installations can be found in the inner city of Stuttgart, but there is now a higher need to cover also the counties of Stuttgart with additional charging points. Furthermore the number of charging points with chosen charging technology (mainly based on 22 kW power capacity) needs to be increased, since the customer acceptance is linked to a relatively low charging period, which should not exceed the given time constraints of related activities. Finally, regarding these results, also more high power DC charging stations (> 38 kW) need to be included in future installations.

Regarding the positioning of the additional charging points it may be acceptable to locate those in hot-spot areas, if the remaining distance can be reached by feet. The acceptable distance should be assumed to be lower or equal to 500 m, which will be the case already by the investigated scenario of 5% BEV ratio.

Therefore, the recommended increase of charging points correlates not only with the demands due to a higher ratio of BEVs, but amplifies also the acceptance of the customers due to a reduced remaining distance to the next available charging point.

Acknowledgments

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Prof. Dr. Ralf Wörner became chair professor on the field of vehicle technology in the automotive industry at the Esslingen University of Applied Sciences by the end of 2016. In between of 1997 till 2016 he worked as leading Engineer at Daimler Company, whereof he was in charge for the development activities of powertrain systems applied in international cooperation programs from 2011 to 2016 and of different types of automatic transmissions at Daimler Company from 2007 to 2011. Before that he led the development activities of high performance powertrains at Mercedes-AMG from 2000 to 2007. His professional activities were started in the research & development department of combustion engines at Daimler Company between 1997 and 2000.



Dr. Harald Braun is Strategic Project Leader for the topics Charging and Electric Vehicle Services at Mercedes-Benz Cars. From 2013 to 2016 he was in charge for working out the Mercedes-Benz Cars eMobility Strategy, which is the basis for all vehicle related eMobility activities today. Between 2010 and 2013 he played a major role to harmonize charging plugs and connectors between the European vehicle manufactures at ACEA. During this time he also defines the innovation roadmaps for conventional and alternative powertrains for Daimler Company. He coordinates different cooperation projects for Daimler Company between 2007 and 2010. From 2003 to 2007 he was Project Leader for the S400 Hybrid Powertrain. He started his industrial career at Daimler Company in the exchange program for powertrain research & development in 1997.



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Ms. Daniela Schneider has been going to the Esslingen University of Applied Sciences from September 2013 till August 2017. She studies “Industrial Management/Automobile Industry”. She wrote her graduation work for the Daimler Company. The topic was “charging infrastructure for users of battery electric vehicles in areas with primary public park space”. She will work until August 2017 as a student research assistant at the Esslingen University of Applied Sciences.