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REGIONAL CHARGING INFRASTRUCTURE REQUIREMENTS IN GERMANY THROUGH 2030

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EXECUTIVE SUMMARY

Germany has outlined ambitious plans to increase the sale of electric vehicles and expand its charging infrastructure network to 1 million publicly accessible charge points by 2030. The government intends to invest more than €3 billion in the charging infrastructure for cars and trucks by 2023. As part of the stimulus package in response to the COVID-19 pandemic, the government announced plans to invest an additional €500 million in the expansion of private charging facilities.

This report investigates how the electric passenger vehicle segment may be distributed throughout Germany over this time frame and what infrastructure may be needed to support them. The scenarios detail new passenger electric vehicle registrations of 35% and 50% by 2030 in each of the 69 German metropolitan areas and 13 nonmetropolitan areas in German states and estimate the charging infrastructure needed for each area to sustain this vehicle growth. These charging infrastructure estimates are compared to what currently is installed to determine a charging gap. This detailed look allows for regional variation in housing type, charging access, and vehicle ownership rates. How to evaluate coverage and identify charging needs is a key question for future infrastructure buildout decisions, and the evidence presented in this paper can help planners determine how subsidies for charging infrastructure can be allocated across Germany.

Figure ES-1 summarizes the charging gap by area for the 50% uptake scenario showing the percentage of workplace and public charging installed by the end of 2018 as a percentage of that needed by 2025. Nonmetropolitan areas are denoted with a hatched pattern. Blue colors indicate a smaller charging gap whereas red colors indicate a larger charging gap. Most areas have less than 20% of the charging capacity they will need by 2025. By 2030, the needs grow such that the charging capacity currently installed is only 5% to 10% of what will be needed.

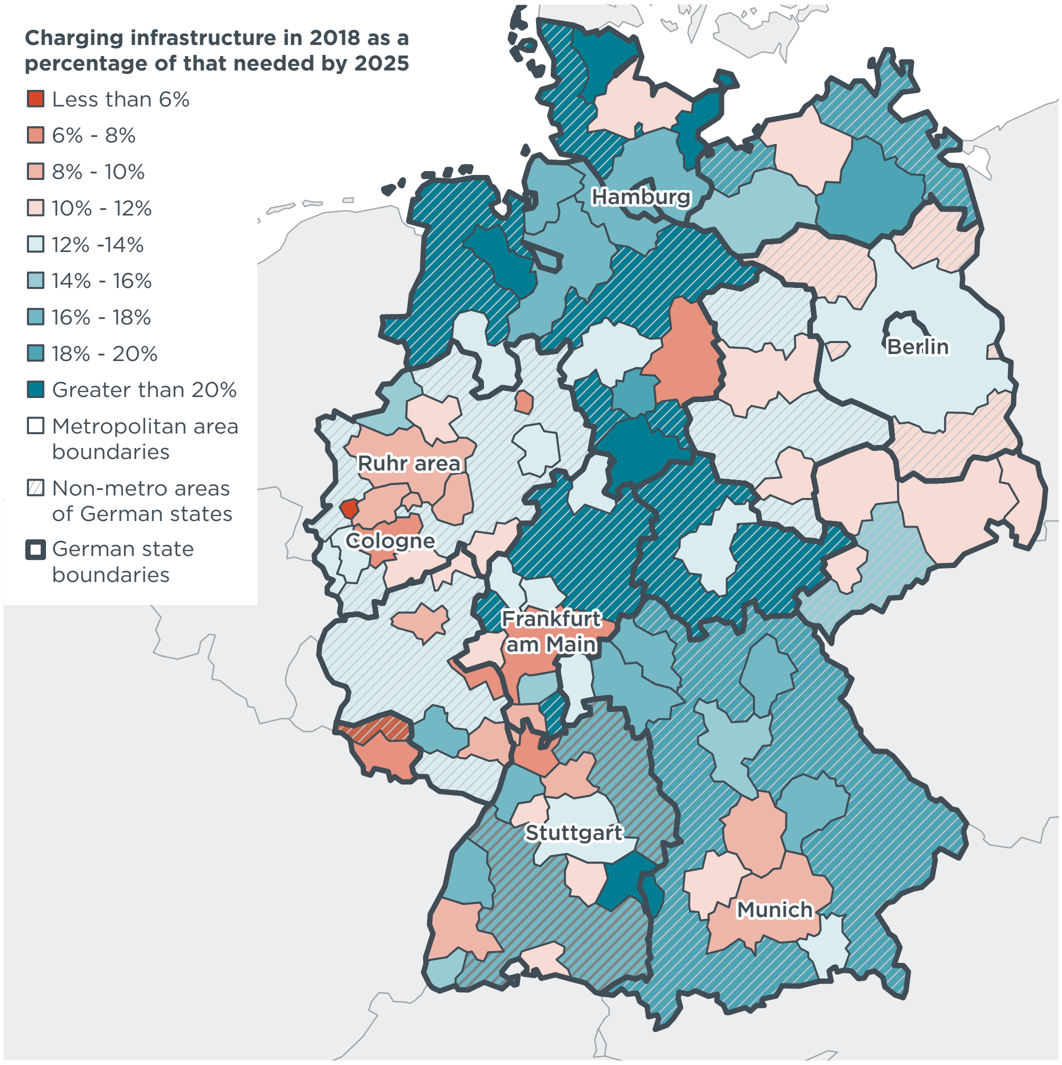

Figure ES-1. Public and workplace charging infrastructure in place in 2018 as a percentage of that needed by 2025 by metropolitan area.

The map illustrates that the largest charging gap exists in metropolitan areas where electric vehicle sales are higher, home charging is less likely to be available, or both. Among nonmetropolitan areas, those in the east and west tend to have the largest charging gap.

The results of the analysis lead to three high-level conclusions:

A large increase in charging infrastructure is needed to support the growing German electric vehicle market. To support approximately 5.7 to 7.4 million electric vehicles in Germany representing a market share of 35% to 50% of passenger vehicle sales, an estimated 180,000 to 200,000 public chargers are needed by 2025, and a total of 448,000 to 565,000 chargers by 2030. Chargers installed through 2018 represented 12% to 13% of 2025 charging needs, and 4% to 5% of 2030 charging needs. Although expanding this charging infrastructure will require greatly increased efforts by governments and private industry, these projected needs are approximately half of Germany's announced goal of 1 million public chargers by 2030. This difference is explained by fewer vehicles and a lower number of chargers per electric vehicle in the scenarios considered in this analysis.

More vehicles can be supported per charger as the market grows. We project the ratio of electric vehicles per normal speed charger will rise from nine in 2018 to 14 in 2030. Battery electric vehicles (BEV) per DC fast charger will increase from 80 BEVs per fast charger to more than 220 vehicles per fast charger. Associated trends over this time include an expected decline in the availability of home charging as more electric vehicles are owned by those without off-street overnight parking, better utilization of public chargers, and an increase in charging speed. As electric vehicles and charging infrastructure evolve, the increasing charger utilization improves the business case for public charging over time.

Affluent areas with higher uptake and metropolitan areas show the largest charging gap. The affluent areas where most electric vehicles are now leased or sold show the greatest increase in need for charging. In less affluent areas, the increased need will mirror affluent areas as electric cars move to the secondary market. Lower home charging availability in metropolitan areas contributes to an increase in need as well. Despite most metropolitan areas tending to have a larger charging gap than nonmetropolitan areas, the need remains great in less affluent rural areas, which will require equal access to electrification.

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INTRODUCTION

A key part of Germany's effort to meet climate targets is to reduce emissions related to transport. As set out in the government's Climate Protection Plan 2050, Germany must reduce carbon dioxide (CO_2) emissions in transport by 40% compared to 1990 levels by 2030 (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit [BMU], 2019). To achieve this goal, the German government is committed to promoting electric vehicles (EVs) and extending the public and private charger networks. By 2030, the government goal is to have 7 to 10 million electric vehicles on the road and a total of 1 million charging points available (Die Bundesregierung [BReg], 2020).

By the end of 2018, the electric passenger vehicle market represented 1.9% of new vehicles in Germany, and a total stock of more than 150,000 electric vehicles on the road (Kraftfahrt-Bundesamt [KBA], 2019a). Electric vehicles include both battery electric vehicles (BEVs) with no combustion engine and plug-in hybrid electric vehicles (PHEVs) which have a backup combustion engine for when battery energy is depleted. This electric vehicle stock is supported by more than 16,100 public charging locations available in Germany at the end of 2018, of which about 12% were fast charging locations (BDEW, 2020). These locations have a total of more than 26,000 chargers.

Since 2009, the German government has supported the deployment of the charging infrastructure network as part of research, demonstration, and funding programs. The government has provided €300 million of funding to support the extension of the public charging infrastructure network in the 2017 to 2020 time frame (Bundesministerium für Verkehr und digitale Infrastruktur [BMVI], 2020a). In 2019, the German government adopted the "Masterplan charging infrastructure," which specifies targets and measures for the deployment of charging infrastructure—public and nonpublic—in Germany by 2030. The aim of the German government is to have 1 million public charging points available by 2030 and to invest more than €3 billion in charging infrastructure for cars and trucks by 2023 and an additional €500 million in the expansion of private charging facilities (BMVI, 2020a; 2020b; 2020c).

The future charging infrastructure in Germany must be able to meet the envisaged demand of a growing number of BEVs and PHEVs with a wide range of body types, styles, ranges, and charging capacities. The availability of home charging is also evolving. Early adopters are more likely to have a charger available to charge at home than those in the broader mainstream market who purchase an electric vehicle through 2030, increasing the need for public charging.

This working paper assesses the electric vehicle charging infrastructure needed in Germany by 2030. The paper first examines the 2018 market for vehicle purchase trends and charging behavior characteristics and models an increasing shift to BEVs along with increased charging speed, and the decrease in home charging availability through 2030. Two scenarios – 35% and 50% of passenger vehicle sales being electric vehicles by 2030 – are explored. Results are presented for metropolitan areas and for the remaining nonmetropolitan areas by German state. Results are discussed for four charging categories: home, workplace, public locations, and at direct current (DC) fast chargers. Based on the analysis, the paper provides conclusions to guide governmental action to support the deployment of charging infrastructure.

MARKET CHARACTERIZATION OF VEHICLES AND CHARGING

The development of the electric passenger vehicle in Germany has been relatively slow in terms of sales in the past but has shown a strong increase in recent years. In parallel with the growing number of electric vehicles, the number of charging points has continuously increased. The following section describes these developments and provides background information on charging infrastructure in Germany in terms of technical specifications as well as housing stock and home charging access.

By the end of 2018, there were approximately 150,000 electric vehicles on German roads (KBA, 2019a). Based on the European Union's Metropolitan Region definition (Eurostat, n.d.), the electric vehicle uptake trends are assessed across metropolitan and the less-urbanized nonmetropolitan areas.

Figure 1 shows electric vehicle uptake across German metropolitan and nonmetropolitan areas in two ways. The maps are based on new registration data from IHS Markit (2019) and KBA (2019a). We consider the new vehicle registration data to be nearly synonymous with new vehicle sales as a measure of electric vehicle uptake. The left map illustrates the share of new passenger vehicle registrations that were electric in 2018 for metropolitan areas (indicated with no stripes) and nonmetropolitan areas (indicated with stripes). The German state boundaries are delineated by thick dark outlines whereas metropolitan area boundaries have a thinner black line. The right map shading shows the cumulative electric vehicle registrations per million inhabitants allowing comparison of cumulative electric vehicle registrations. Charger locations are indicated as red points.

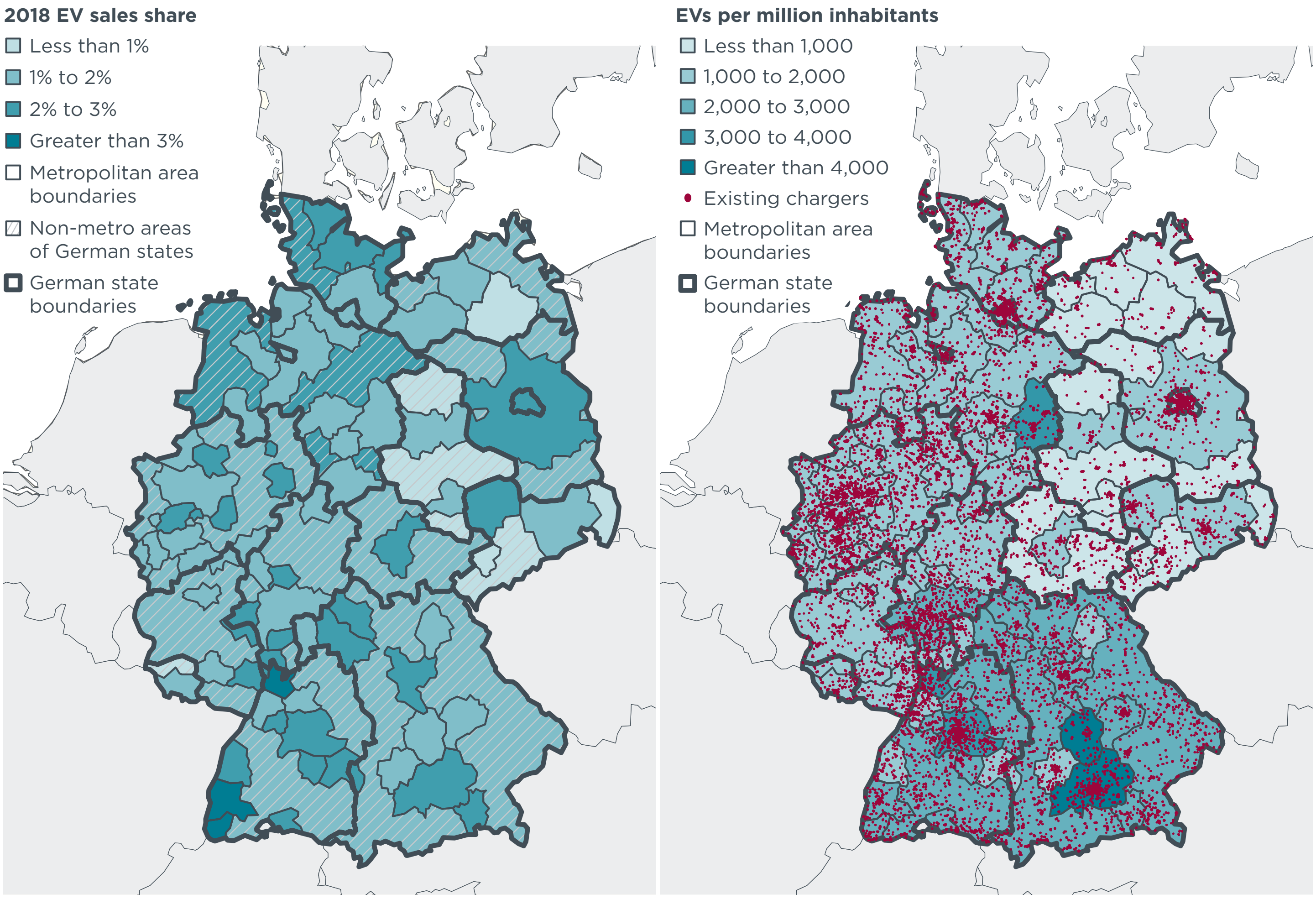

Figure 1. Electric vehicle share of new passenger cars in 2018 and cumulative electric vehicles per million inhabitants overlaid with charging station locations. Metropolitan and nonmetropolitan areas are based on Eurostat (n.d.).

The left map in Figure 1 shows that the highest electric vehicle uptake was in Freiburg im Breisgau (3.5%), Heidelberg (3.3%), and Frankfurt am Main (3.2%), and the lowest in Neubrandenburg (0.8%), Zwickau (0.9%), and Görlitz (1.0%). The areas outside of a designated metropolitan area were organized by German state of which there are 16, but only 13 contain nonmetropolitan areas. The states of Schleswig-Holstein (2.7%) and Lower Saxony (2.2%) recorded the highest electric vehicle shares. In contrast, shares were the lowest in the states of Saarland (0.5%), Saxony (1.0%), and Saxony-Anhalt (1.0%) outside the metropolitan areas. In general, the eastern parts of Germany recorded lower electric shares than the in the north, west, and the south.

The right map in Figure 1 showing the cumulative registrations of electric vehicles per million inhabitants indicates that the eastern part of Germany has been particularly slow to adopt electric vehicles. The greatest concentrations of electric vehicles per million inhabitants, at more than 3,500, are near auto manufacturing headquarters in the metropolitan areas of Braunschweig-Salzgitter-Wolfsburg, Ingolstadt, Stuttgart, and Munich. These areas have high new vehicle registrations generally, so the modest electric vehicle shares still result in high numbers of electric vehicles. The map also shows a relatively even distribution of chargers in the north, west, and south and a sparse public network in the east. In terms of the absolute number of total public charging points, the leading metropolitan areas in 2018 were Hamburg (more than 1,500), Berlin (more than 1,400), Stuttgart (more than 1,100), and Munich (almost 1,100). As for the leading nonmetropolitan areas, Bavaria was far ahead with more than 2,200, almost twice as many as in Baden-Wuerttemberg, North Rhine-Westphalia, and Lower Saxony.

VEHICLE CHARGING INFRASTRUCTURE SCENARIOS

This section describes the modeling approach and data inputs used to identify how many and what types of chargers will be needed in Germany in 2030. This section adapts the relationships for several identified electric vehicle charging behavior trends, including the extent to which workplace and public charging increases for those with no home charging, and accounts for the energy available based on parking times and power available by location.

OVERVIEW OF METHODOLOGY

The charging needs for Germany in 2030 follow an analytical framework similar to that employed in the United States (Nicholas, Hall, & Lutsey, 2019) and the United Kingdom (Nicholas & Lutsey, 2020). For the analysis of Germany, it is necessary to define additional variables and make a number of assumptions regarding vehicle sales, future charging, charging categories, future home charging access in general, and by housing type specifically.

Vehicle sales of all vehicle types are based on past new vehicle registration trends and future projections to match Germany's 2030 electric vehicle goals. Stock is estimated based on sales as applied to a vehicle stock-turnover model and includes Germany-specific data on vehicle retirements. The vehicles are allocated to different housing types where the availability of home charging is assessed. The availability of home charging and user behavior in turn determines the need for public charging.

A key variable for the analysis is the existing charging infrastructure in Germany, which is differentiated by metropolitan and nonmetropolitan area. The data for the analysis are from three sources: Open Charge Map (n.d.), Lemnet (n.d.), and the Bundesnetzagentur (Ladesäulenkarte, n.d.) and reflect 2018 figures. Databases are transferred to a geographic information system for processing, removing overlapping data from multiple datasets to ensure stations are not double counted.

Existing charging in this paper is divided into non-DC fast permanently installed chargers at work and in public, termed *normal chargers*, and DC fast charging. References to DC fast charging use two terms, *DC fast chargers* and *DC fast charge outlets*, which have different meanings. One DC fast charger often has two outlets that meet different standards (for example, CCS and CHAdeMO). Because only one outlet can be used at a time, this has implications for power delivery. Household type Schuko outlets are not designed for vehicle charging and their future relevance for public charging is unknown. Therefore, we exclude them from current charger counts.

Analysis of DC fast charge data from the above-mentioned sources shows that an estimated 78% of charger outlets are on dual-outlet chargers. As a consequence, for a given 100 outlets reported in a database, 78 outlets would be on dual-outlet chargers, so only 39 of those outlets could be in use at the same time. Even by adding the remaining 22 single-outlet chargers to those 39 outlets, only 61 out of 100 outlets could be used simultaneously. This results in an outlet-to-charger ratio of 1.64:1 for DC fast chargers. For modeling the future charging infrastructure, numbers are reported as the number of fast chargers; however, the continued prevalence of dual-outlet chargers and power-sharing chargers is uncertain. Consequently, existing charging numbers in databases that report outlets are multiplied by 61% to obtain the number of chargers for use in the modeling.

All results in this paper are presented by charging categories of home, work, public, and DC fast charging. The home category refers to private chargers in a home or apartment complex. Work, public, and DC fast charging can collectively be referred to as nonhome charging. Work and public charging are often interchangeable in reality, but for modeling purposes, work chargers are defined as those chargers that are used while working regardless of their location. For example, a workplace charger could therefore be in a public parking lot. Finally, all DC fast charging is its own category regardless of location.

Based on the definitions and assumptions outlined above, Figure 2 illustrates the modeling approach and model steps. The blue rectangles represent the model steps and begin at the top left. The yellow trapezoids indicate the data inputs and assumptions between the model steps and the grey ovals explain what occurs at each step in a more readable form. The top left rectangle shows that the model starts with a projection of vehicles and the succeeding steps apportion the electricity demand by location and translate that demand into number of chargers with utilization ratios.

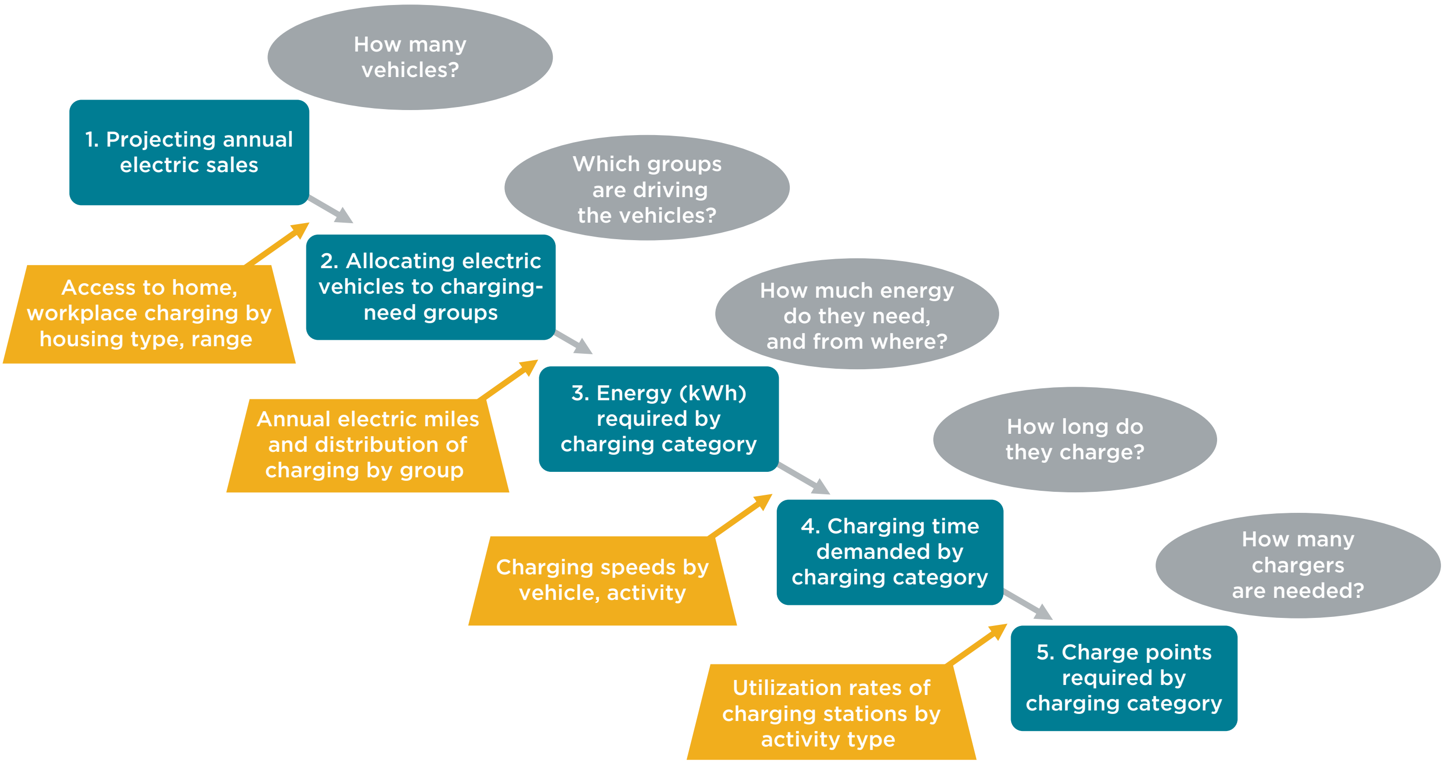

Figure 2. Model to allocate chargers to electric vehicles.

The yellow trapezoids represent data inputs, which are drawn from many sources and other analytical research. The sources for these data areas, and the variables that depend on the data, are shown in Table 1.

Table 1. Data sources for key variables.

Data area	Variables	Source
Population	Population by NUTS 3 statistical area and future projections	Eurostat (2019a), Eurostat (2019b)
Housing	Number of dwellings in houses and apartments	Eurostat (2011)
Metropolitan area definitions	Definition of metropolitan areas in Germany	Eurostat (n.d.)
Passenger vehicle stock	Passenger vehicle stock by NUTS 2	Eurostat (2018)
Electric vehicle registrations by NUTS 3 area	Registrations of new electric vehicles, including battery electric vehicle (BEVs) and plug-in hybrid electric vehicles (PHEVs)	IHS Markit (2019) Kraftfahrt-Bundesamt (2019a)
Existing charging infrastructure	Counts of charging outlets in Germany	Open Charge Map (n.d.) Bundesnetzagentur (n.d.) Lemnet (n.d.)
Charging infrastructure to electric vehicle relationships	Ratios of electric vehicles to charge point, based on market size and/or electric share	Nicholas, Hall, & Lutsey (2019) Nicholas & Hall (2018) Hall & Lutsey (2017)
Charging behavior	Observed charging rates of charging for residential, workplace, public, and DC fast chargers	Schaufenster Elektromobilität (2017) Tal, Lee, & Nicholas (2018)
Travel behavior	Annual mileage, commute distance, vehicle information	Kraftfahrt-Bundesamt (2019c)

Note: NUTS 3 = Nomenclature of territorial units for statistics

GERMAN ELECTRIC VEHICLE MARKET SCENARIOS

Projecting annual electric vehicle sales, as shown in Figure 2, is the first step in determining how much charging infrastructure is needed in Germany. Existing passenger electric vehicle stock by metropolitan area (KBA, 2019a) is used to establish the current electric vehicle market. Electric vehicle sales in future years are estimated as a percentage of passenger vehicle registrations in Germany (IHS Markit, 2019) that increases over time, reaching 35% and 50% by 2030 depending on the scenario.

There are two market scenarios for the percentage of electric passenger car registrations in 2030. Scenario 1 assumes an electric car share of 35%, in line with the target for zero- and low-emission vehicles (ZLEVs) as defined in the EU passenger car CO_2 regulation (Mock, 2019). Scenario 2 assumes an electric car share of 50%, following the announcements of vehicle manufacturers such as BMW, Volkswagen and Daimler (Wappelhorst, 2020). We regard these two scenarios as conservative and indicative of the minimum number of charging points that will be required by 2030. Electric car registrations in absolute numbers rise from 66,000 per year in 2018 to approximately 1.2 million in scenario 1 and 1.7 million in scenario 2 by 2030. The split between BEVs and PHEVs is assumed to shift from about 50:50 in 2018 to 75:25 by 2030.

The number of new car registrations per year is assumed to be constant in the period between 2018 and 2030 due to negligible population growth (Eurostat, 2019a) and a general desire to encourage alternative transportation modes. To reflect the redistribution of vehicles after the conclusion of a lease and to account for used vehicle sales, conventional and electric passenger vehicle registrations per capita were compared to passenger vehicle stock per capita (Eurostat, 2018) and redistributed proportionally after a period of three years. Areas that had more registrations than their vehicle stock suggested had their vehicles redistributed to areas that had lower sales compared to their stock.

Overall electric vehicle stock operating on the road is calculated based on cumulative vehicle sales minus vehicle retirement. Vehicle retirement was calculated based on historical German passenger vehicle retirement (KBA, 2019b) and modeled future retirement (Miller & Jin, 2018). Cumulative electric vehicles on the road in 2030 accounting for this retirement are 5.7 million in the scenario 1 and 7.4 million in scenario 2. Figure 3 (left) shows the year by year passenger electric vehicle stock estimates for scenario 1 representing a 35% electric vehicle sales share in 2030. Figure 3 (right) shows the stock estimates for scenario 2 with a 50% electric vehicle sales share in 2030. The official government target of seven to 10 million electric vehicles, which includes both passenger and light commercial vehicles, is shown in each figure for reference.

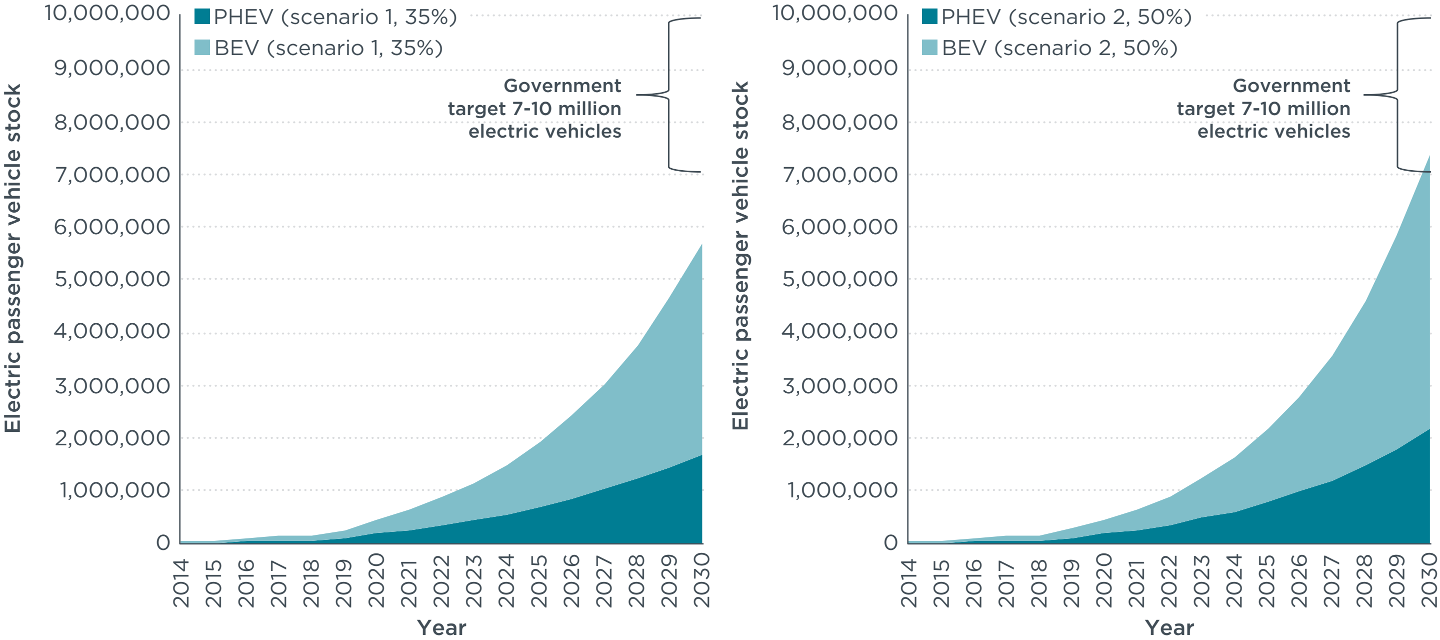

Figure 3. Passenger electric vehicle stock in Germany up to 2030 for scenario 1 (35% of sales are EVs in 2030) and scenario 2 (50% of sales are EVs in 2030).

The sales share in which electric vehicles reach 35% or 50% of the passenger vehicle market by 2030 is insufficient to reach the maximum target of 10 million vehicles. Cumulative sales in the model, not accounting for retirement, reach eight million by 2030 if the sales share is 50%. To reach a stock of 10 million vehicles, the sales share must either rise more quickly than we project or the sales share in 2030 must be approximately 75%.

ALLOCATION OF ELECTRIC VEHICLES TO CHARGING NEED GROUPS

Step two in the model outlined in Figure 2 is to partition the electric vehicle market into charging need groups that show distinct charging behavior. There are three factors considered in determining charging need groups: vehicle type (PHEV or BEV), commuting status, and home charging access. These are the minimum number of factors to enumerate the four charging categories of home, work, public, and fast charging. This results in eight charging need groups as shown in Table 2.

Table 2. Charging need groups modeled.

Vehicle type	Commuting status	Home charging
BEV	Commuter	Home
BEV	Commuter	No home
BEV	Noncommuter	Home
BEV	Noncommuter	No home
PHEV	Commuter	Home
PHEV	Commuter	No home
PHEV	Noncommuter	Home
PHEV	Noncommuter	No home

The vehicle types described above transition from new registrations of approximately 50% BEVs in 2018 to 75% BEVs in 2030. Commuting status also determines charging needs. The early market is likely to have a higher prevalence of commuters than the later market. In 2019, the percentage of electric vehicles purchased for commuting is modeled at 60% but that share is reduced to 40% by 2025. This reduces the relative need for workplace charging.

The type of housing is used to determine if home charging is likely to be available. To estimate home charging access, we first estimate housing type where vehicles are located and infer the likelihood that a charger can be installed at that housing type. Early adopters are more likely to live in single-dwelling buildings, where home charging is more typically available (DLR, 2015). As the market for electric vehicles develops, as analyzed further below, a growing mainstream market will reflect these population groups in proportion to the housing type that Germans now live in.

Table 3 shows the relevant metrics, which help determine where electric vehicles will be by housing type in 2018 and 2030. The first row shows the percentage of dwellings by structure type for the most recent housing census available at a fine enough resolution for metropolitan area analyses (Eurostat, 2011). The second row is an estimate of conventional passenger vehicle stock and incorporates dwelling ownership rates (Ahlfeldt & Maennig, 2013) and average vehicle ownership rates by housing ownership status (BMVI, 2017). The third row shows the estimates for electric vehicles by structure type in 2018. There is no available estimate for the housing type for 2018 of electric vehicle owners. Consequently, these values are imputed to be consistent with survey data (Schaufenster Elektromobilität, 2017). The forth row shows the percentage of total electric vehicle owners in each housing type in 2030. Electric passenger vehicle stock for 2030 in row four is modeled to approach the 2018 conventional vehicle percentages in row two reflecting a broadening market.

Table 3. Housing for the general population in Germany.

	Single-dwelling buildings	Two-dwelling buildings	Three or more dwelling buildings
Percentage of dwellings	30%	16%	55%
Conventional passenger vehicle stock by dwelling type in 2018	35%	19%	46%
Electric passenger vehicle stock by dwelling type in 2018	60%	16%	24%
Electric passenger vehicle stock by dwelling type in 2030	41%	18%	41%

Although future home charging availability is unknown, we use housing type as a proxy for the likelihood that home charging will be available to those who purchase an electric vehicle. Likelihood of installation is different than general availability. For example, general availability of charging in German apartments is approximately 2%–4% (Paulsen, 2019). U.S. examples show apartment charging availability among buyers as high as 48% accounting for self-selection (Tal et al., 2018). This availability among electric vehicle buyers in the self-selected sample is used for all housing types and is called the “home charging availability multiplier” in the first row in Table 4. The second and third rows are the estimates of electric vehicle stock with home charging created by multiplying electric vehicle stock in Table 3 times the home charging availability multiplier.

Table 4. Scenarios for electric vehicle owner housing type and access to home charging.

	EVs in single-dwelling buildings	EVs in two-dwelling buildings	EVs in three or more dwelling buildings	Total
Home charging availability multiplier	92%	83%	48%	—
Percentage of total German electric vehicle stock with home charging available in 2018	55%	13%	12%	80%
Percentage of total German electric vehicle stock with home charging available in 2030	37%	15%	20%	72%

The home charging availability for all electric vehicle sales in 2018 is estimated to be 80% but reduces to 72% of sales by 2030 due to more customers living in apartments. This results in an increased need for workplace, public, and DC fast charging.

ENERGY REQUIRED BY CHARGING CATEGORY

The third step in the model is determining the total energy that each driver-need group will use and at which locations it will be dispensed among home, work, public and DC fast charging. Energy needs for each charging-need group primarily rely on the 2017 German survey of EV drivers (Schaufenster Elektromobilität, 2017) summarized in Table 5, and supported by data from U.S. sources to disaggregate the results (Tal et al., 2018). Typical user groups identified are streetlamp parkers (those without designated parking), car commuters, home chargers, and long-distance drivers. Table 5 summarizes these user groups, differentiated primarily by their place of charging—home, workplace, public, semi-public, or manufacturer. The percentages represent frequency of charge sessions, not energy transferred by location (derived in Table 6) nor number of chargers. Owners of a Tesla who have charging provided by the manufacturer make up a large part of the sample (22%), accounting for much of the charging from some groups, particularly streetlamp parkers and long-distance drivers. Overall, 48% of charging events occurred at home, 20% at work, and 32% at public, semi-public, or manufacturer-provided charging stations.

Table 5. Survey of German charging behavior in 2017.

	Total charging infrastructure	Streetlamp parkers	Car commuters	Home chargers	Long-distance drivers
Home	48%	2%	36%	59%	34%
Workplace	20%	35%	45%	28%	16%
Public	16%	34%	9%	2%	14%
Semi-public	10%	14%	5%	6%	10%
Manufacturer	6%	15%	5%	7%	26%

Table 6 shows how the above survey evidence is applied to charging need groups. There are three factors listed in the first three columns: vehicle type, commuting status, and home charging. After BEV or PHEV vehicle types, commuting status denotes whether the vehicle is used for commuting purposes and the home charging status denotes whether the consumer has access to reliable charging at or near home. The fourth through the seventh columns describe the percentage of energy, in kilowatt hours (kWh), by charging location consisting of home, work, public normal charging, and DC fast charging.

Table 6. Energy breakdown by charging need group.

Vehicle type	Commuting status	Home charging	Home energy	Work energy	Public energy	DCFC energy	Vehicle kilometers traveled per year	Percent vehicle kilometers traveled that are electric	Vehicle kilometers traveled per year that are electric	Percent of vehicle stock in 2030
BEV	Commuter	Home	70%	20%	5%	5%	15,100	100%	15,100	23%
BEV	Commuter	None	0%	55%	20%	25%	15,100	100%	15,100	9%
BEV	Noncommuter	Home	80%	0%	10%	10%	12,354	100%	12,354	28%
BEV	Noncommuter	None	0%	0%	40%	60%	12,354	100%	12,354	11%
PHEV	Commuter	Home	60%	30%	10%	0%	15,100	70%	10,570	10%
PHEV	Commuter	None	0%	65%	35%	0%	15,100	40%	6,040	4%
PHEV	Noncommuter	Home	90%	0%	10%	0%	12,354	50%	6,177	12%
PHEV	Noncommuter	None	0%	0%	100%	0%	12,354	10%	1,235	4%

BEV = Battery electric vehicle; PHEV = plug-in hybrid electric vehicle; DCFC = direct current fast charger

The average annual vehicle kilometers traveled (VKT) in Germany by passenger cars was 13,727 in 2018 (KBA, 2019c). As shown in column eight in Table 6, commuters are assumed to travel 10% more kilometers than this average at 15,100 km and noncommuters are assumed to travel 10% fewer kilometers at 12,354 km. In column nine, the kilometers are converted into energy needed based on assumed efficiency of an average BEV or PHEV of 0.182 and 0.194 kilowatt-hours per kilometer, respectively. New electric vehicle efficiency is assumed to be constant on average as technical efficiency improvements (e.g., motor and vehicle road load) will be consistent but approximately negated by electric vehicle migration to larger vehicle classes.

It is important to note that the eight groups above are meant to represent averages and each group is heterogeneous, with greatly varying individual-level vehicle specifications, driving patterns, and charging behavior. For example, not every commuter has access to workplace charging, and not every driver with home charging plugs in at home. Further, some PHEV drivers have access to charging at home or work, but never plug in. Nevertheless, the average charging behaviors of these groups are distinct and are sufficient for analysis and scenario purposes.

CHARGER POWER AND POWER ACCEPTANCE RATE

The fourth step in the model is to convert the energy needs in step 3 to hours of charging required. This in turn depends on the energy required for vehicles, available power of chargers, and how fast vehicles can accept power.

The rate of power draw varies depending on the capacity of the charger and the ability of a vehicle to accept power. For BEVs, the average rate of power draw for normal chargers is estimated at 8 kilowatts and for PHEVs the average is 3.4 kilowatts. The average rate of power draw is determined both by the acceptance rate of the vehicle over the entire charge cycle and the power limitations of the charger. For DC fast charging, the average rate per charger is expected to increase each year, starting at 35 kilowatts in 2019 and reaching 80 kilowatts in 2030.

CHARGER UTILIZATION AND NUMBER OF CHARGERS

The fifth and final step in the model shown in Figure 2 is to determine the utilization of chargers in hours of use per day, which when combined with average power determines yearly energy capacity in kWh per charger. The kWh determined above for the entire electric vehicle market was divided by the annual energy estimated per charger type in each metropolitan area to get the number of chargers needed. Although this method is simple, determining the kilowatt output and the average hours of usage per day requires some estimation because both metrics can vary over time as technology improves and utilization of chargers varies with market penetration.

Charger utilization was investigated as a function of market development measured in electric vehicles per million population. Figure 4 shows the ratio of electric vehicles per public and workplace charger on the vertical axis as a function of electric vehicles per million population on the horizontal axis. DC fast chargers are excluded from this figure. The assumption is that kWh per vehicle per day remains constant. With an increase in electric cars per charger, this implies increasing utilization of each charger. Utilization in hours per day for each charger is assumed to increase in proportion to this trend similar to benchmarked trends in other studies (Nicholas et al., 2019). Each point represents the vehicle-to-charger ratio in one of 69 metropolitan areas (shown in blue) and the nonmetropolitan areas in 13 German states (shown in brown). Although there are 16 German states, three are city-states with no associated nonmetropolitan areas.

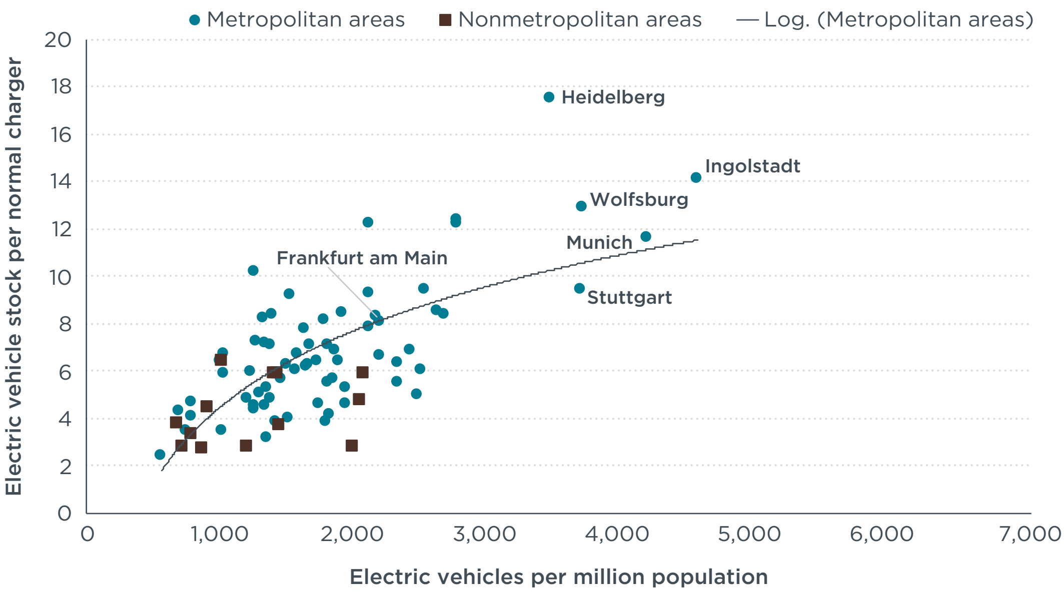

Figure 4. German public and workplace chargers per passenger car electric vehicle stock as a function of market development in terms of electric vehicles per million population in 2018.

The graph reveals relationships that occur as a function of market penetration and hence the sufficient coverage needed at a certain level of development. The relationships are modeled with natural logarithmic functions that approach vehicle-to-charger ratios of approximately 15 across the various metropolitan areas. Less developed markets need more coverage independent of usage. However, if coverage is already established, capacity can be added and more efficient usage can occur. Going forward to 2030, cities will need fewer chargers per vehicle than in 2018. Countering this trend somewhat is reduced availability of home charging and an accompanying increase in demand for public charging.

By using benchmarked studies elsewhere (Nicholas et al., 2019) and adapting to the German context, an estimate of average charger usage in hours per day of chargers in that region can be made, which in turn can be used to determine the number of chargers needed. This increasing usage of normal charging as a function of electric vehicles per million population can be represented by the following equation:

$$\text{Average daily hours of usage} = 0.800 \times \text{LN (EV per million population)} - 4.6148$$

Using a natural log (LN) function prevents the number of hours from rising past a practical threshold at high market penetrations, but also allows for a rapid increase in utilization in the nascent stages of an electric vehicle market. For example, the average hours of use of a public charger at 6,000 electric vehicles per million population is 2.3 hours, but at 100,000 electric vehicles per million population, the average utilization only rises to 4.6 hours. This results in a doubling of charger utilization whereas the market increased over 16 times. It is important to note that every charger will not match the average and certain days of the week will have greater utilization than others. But on average, utilization of chargers will increase as the vehicle market grows.

Workplace charging utilization is dealt with differently in the model and is set at 5 hours per day of usage regardless of market penetration. However, because many workplace chargers are not used on weekends, the average use per day falls to 3.57 hours. The rationale for a relatively high constant 5 hours of use is that the parking time is longer and that capacity adapts to the number of workers in a much more controlled manner than for publicly available chargers at retail establishments, parking garages, curbsides, etc.

DC fast charging is assumed to follow a trend similar to normal charging such that average use in hours climbs with market development. The equation used to define this relationship is:

$$\text{Average daily hours of usage} = 0.5627 \times \text{LN (BEV per million population)} - 2.7327$$

At a level of 10,000 BEV per million population, the average estimated duration of power draw would be 2.4 hours per day. At 100,000 BEV per million, the daily power draw duration would be 3.7 hours. Again, these are averages across the entire year and across a metropolitan region.

Home chargers and highway fast chargers used by drivers from multiple regions are calculated in another manner. Home charger counts are approximately the home availability of charging defined in the housing section above. The estimation of the number of highway fast chargers depends on outside analyses, which estimate that one highway fast charger is needed for every 1,500 vehicles (Jochem et al., 2019). These chargers are assumed to serve infrequent intercity trips and have an average power output of 150 kW, so fewer are needed to serve demand.

SUMMARY OF DATA INPUTS

The inputs for the future scenarios described above that affect the number of chargers are summarized in Table 7. As indicated, values are shown for 2018 to 2030.

Table 7. Summary of data inputs and assumptions for the charging infrastructure model.

	2018	2030
Electric vehicle stock	187,000	5,701,052 – scenario 1 7,391,293 – scenario 2
Market share of electric new car registrations	1.7%	35% - scenario 1 50% - scenario 2
Ratio of BEV/PHEV new car registrations	46% - 54%	75% - 25%
Dwelling type of electric car owners	1 dwelling = 60% 2 dwelling =16% apartment = 24%	1 dwelling = 30% 2 dwelling =16% apartment = 54%
Home charging availability by dwelling type	1 dwelling = 92% availability 2 dwelling = 83% availability apartment = 48% availability	
Commuter share of electric new car registrations	60%	40%
BEV average charging acceptance rate for normal chargers	8 kW	
PHEV average charging acceptance rate	3.4 kW	
Workplace charging daily utilization in hours	5	
Public charging daily utilization in hours	Average daily hours of use = 0.800 * LN (EV per million population) - 4.6148 Increasing utilization of charger increases electric vehicles per charger	
DC fast charging daily utilization in hours	Average daily hours of use = 0.5627 * LN (BEV per million population) - 2.7327 Increasing utilization of fast charging increases battery electric vehicles per charger	
DC fast charging outlet to charger ratio	1.64:1	
DC fast charging kW acceptance per charger	35 kW	80 kW
BEVs per high power highway DC fast charger	1,500	1,500
Electric vehicle efficiency	BEVs: 0.182 kWh/km, PHEVs: 0.194 kWh/km	
Vehicle kilometers per year	Commuter: 15,100 km, Noncommuter: 12,354 km	

Note: BEV = Battery electric vehicle; PHEV = plug-in hybrid electric vehicle; DC = direct current; LN = natural log

EVOLUTION OF CHARGING OVER TIME

As the data inputs vary over time, the number of chargers needed per vehicle changes as well. The effects can be summarized as follows. Increasing electric vehicle stock increases the need for charging. Due to increasing charger utilization, the infrastructure need rises more slowly than the corresponding increase in vehicles. Also, the increase in the share of BEVs in the market increases the need for chargers due to increased electricity demand, but also decreases it as BEVs charge faster than PHEVs. Further, the shift in the type of dwelling from single dwelling buildings to more apartments decreases the availability of home charging and increases the need for public charging. As commuters become a smaller portion of the market by 2030, the relative need for workplace charging decreases and the relative need for publicly available charging increases. The increase in hours of charger use per day decreases the relative need for public and DC fast chargers per vehicle. And finally, the increase in speed of DC fast charging decreases the relative number of chargers needed. The variables shown and the effects described vary by area and have complex interactions whose influence is nonlinear. The effect on the number of chargers per vehicle is summarized in Table 8.

Table 8. Market changes between 2018 and 2030 and their effect on the number of nonhome chargers per vehicle.

	Increasing charger utilization	Increasing BEV share	Decrease in home charging access	Increase in charging speed
Effect on number of chargers needed per vehicle	−	+	+	−

The effects of a changing market using the data described above can be seen graphically in Figure 5. As the German electric vehicle market grows, fewer electric vehicle buyers will have home charging, so the demands on the public charging system will grow. However, the charging infrastructure need not grow at the same rate as the market because the number of chargers needed per vehicle owner system-wide decreases due to increased utilization of chargers that comes with a larger market. The two lines in Figure 5 show the estimated growth in DC fast chargers (purple line) and work and public chargers (red line) as the market grows over a 10 year period.

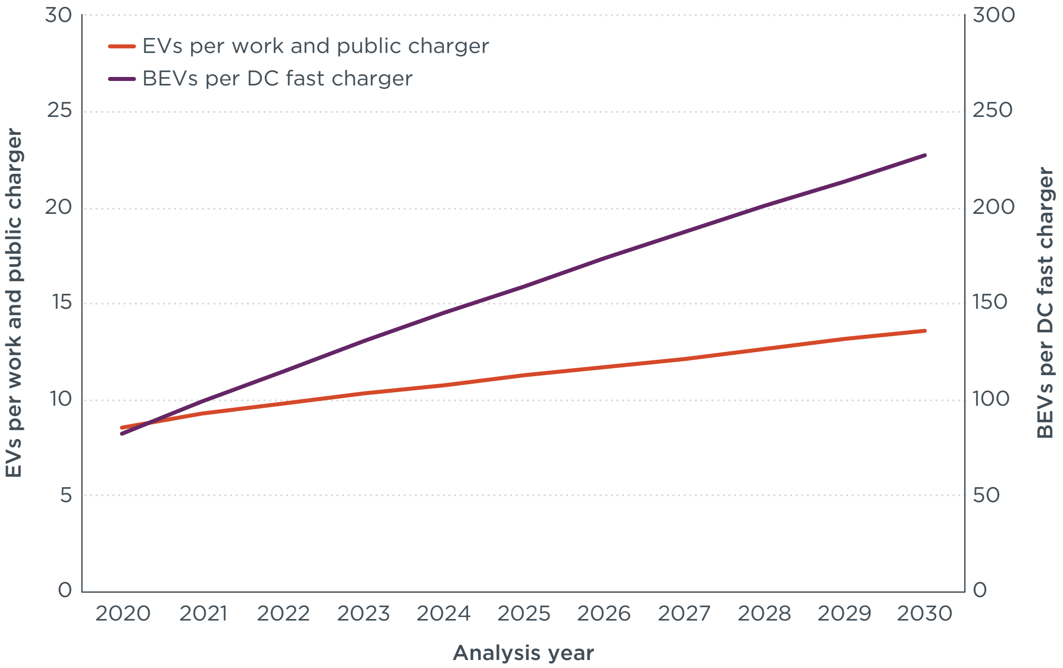

Figure 5. Electric vehicles per work and public charger and battery electric vehicles supported per DC fast charger.

The number of electric vehicles per normal work and public charger increases due to increased utilization in hours of charging per day per charger, and an increasing proportion of BEVs, which accept a higher rate of charge and finish charging faster than PHEVs, freeing up capacity for more vehicles. For normal speed charging at work and public locations, the number of electric vehicles per charger increases from nine in 2020 to 14 in 2030. For DC fast charging, the number of BEVs per charger increases from 84 in 2020 to more than 220 in 2030. This increase is due to the same two factors listed above: increased utilization that occurs in larger markets, and faster charging on average increasing throughput of chargers. These ratios vary on a metropolitan area basis. In Berlin in 2020, the number of electric vehicles per normal charger is 7.5 with 66 BEVs per DC fast charger. These lower ratios are due to the increased need for public charging. Finally, the business case also improves for both normal and fast charging as utilization in hours of use per day increases from 2020 to 2030.

The ratio above represents the BEVs per DC fast charger, not per outlet. As previously noted, on many dual outlet stations only one outlet can be in use at a time. The ratio in Figure 5 decreases if the number of outlets instead of chargers is used as a basis of comparison. The current DC fast charging outlet-to-charger ratio is estimated at 1.64:1 with the future ratios unknown.

The location where energy is dispensed also changes over time. Based on the model, in 2020, 79% of charging energy is dispensed either at home or at work. By 2030, home and work only provide 72% of energy. A relative reduction in commuters buying electric vehicles by 2030 compared to noncommuters causes a corresponding shift away from workplace charging. Similarly, access to home charging declines by 2030 causing an increase in nonhome charging. Finally, a relative increase in BEVs increases the share of fast charging.

RESULTS

For the entire electric vehicle market, by the end of 2018, Germany had installed 6% of the charging it needs in 2030 in scenario 1 and 4% of what it needs in scenario 2. This section describes and discusses this situation in more detail. Differences between metropolitan areas and nonmetropolitan areas are described broadly and comparisons are made between metropolitan areas. The results inform the charging needs for Germany for each metropolitan area to aid in planning infrastructure buildout and allocating funding. Because potential investment in charging infrastructure can be influenced by a region's economic situation, the results are compared with the gross domestic product (GDP).

CHARGING GAP COMPARISONS AMONG METROPOLITAN AND NONMETROPOLITAN AREAS

Electric vehicle charging infrastructure needs for 2025 and 2030 are shown in several different ways. The overall Germany countrywide charger results are reported in comparison with 2018 counts to determine how much more charging infrastructure is needed by 2025 and 2030. Selected results are shown for the highest-population metropolitan and nonmetropolitan areas to provide more detailed comparisons or the relative charging gap across the country. Several of the figures in this section focus on scenario 2, which is to say 50% electric sales in Germany by 2030. Detailed breakdowns of home, work, public, and DC fast charging needed in 2025 and 2030 by metropolitan and nonmetropolitan area are shown in the appendix.

Table 9 summarizes the overall charging infrastructure needs in Germany for 2025 and 2030, including overall results for the metropolitan and nonmetropolitan areas and comparisons versus chargers installed through 2018. This analysis indicates that the total number of public, workplace, and DC fast chargers across Germany will need to increase from 26,000 in 2018 to 180,000 in scenario 1 and 200,000 in scenario 2 by 2025. To meet the electric vehicle goals through 2030, approximately 448,000 to 565,000 chargers will be needed. This infrastructure amounts to about 7 to 8 times more chargers in 2025—and about 17 to 22 times more chargers in 2030—as compared to 2018. About 13% to 15% of the charging needed for 2025 and 5% to 6% of charging needed for 2030 was in place by 2018. To put this in perspective, these results suggest that 32% to 34% annual growth in the number of chargers is needed from 2018 to 2025, and 27% to 29% per year from 2018 to 2030, to meet the electric vehicle growth targets. Further region-specific details are described below.

Table 9. Summary of Germany charging infrastructure needs for two scenarios.

		Scenario 1			Scenario 2		
	Year	Metropolitan areas	Non-metropolitan areas	Country-wide	Metropolitan areas	Non-metropolitan areas	Country-wide
Total chargers (public, workplace, DCFC)	2018	16,987	9,227	26,214	16,987	9,227	26,214
	2025	131,502	48,299	179,801	146,547	53,370	199,916
	2030	328,213	119,802	448,015	415,425	149,895	565,319
Electric vehicle stock	2025	1,382,818	519,976	1,902,793	1,565,153	583,584	2,148,738
	2030	4,134,078	1,566,974	5,701,052	5,375,883	2,015,410	7,391,293
Projected mulitple of future charging needs compared to 2018	2025	7.7	5.2	6.9	8.6	5.8	7.6
	2030	19.3	13.0	17.1	24.5	16.2	21.6
2018 as a percentage of future chargers needed	2025	13%	19%	15%	12%	17%	13%
	2030	5%	8%	6%	4%	6%	5%
Annual increase in chargers from 2018 to meet 2025 and 2030 needs	2025	34%	27%	32%	36%	28%	34%
	2030	28%	24%	27%	31%	26%	29%

Figure 6 and Figure 7 depict the needed electric vehicle charger counts for scenarios 1 and 2, respectively, for 2025 and 2030, as compared to total 2018 charger counts for selected regions. Each figure shows charging needs by state for the seven metropolitan areas and three nonmetropolitan areas with the highest populations. The number of chargers is shown on the vertical axis. There are four categories of chargers shown. Existing charging in 2018 is shown as green bars at the base of each charger estimate. Percentages shown next to the bars represent how much this existing charging contributes to 2025 or 2030 needs. For 2025 and 2030, workplace, public, and DC fast charger needs are disaggregated.

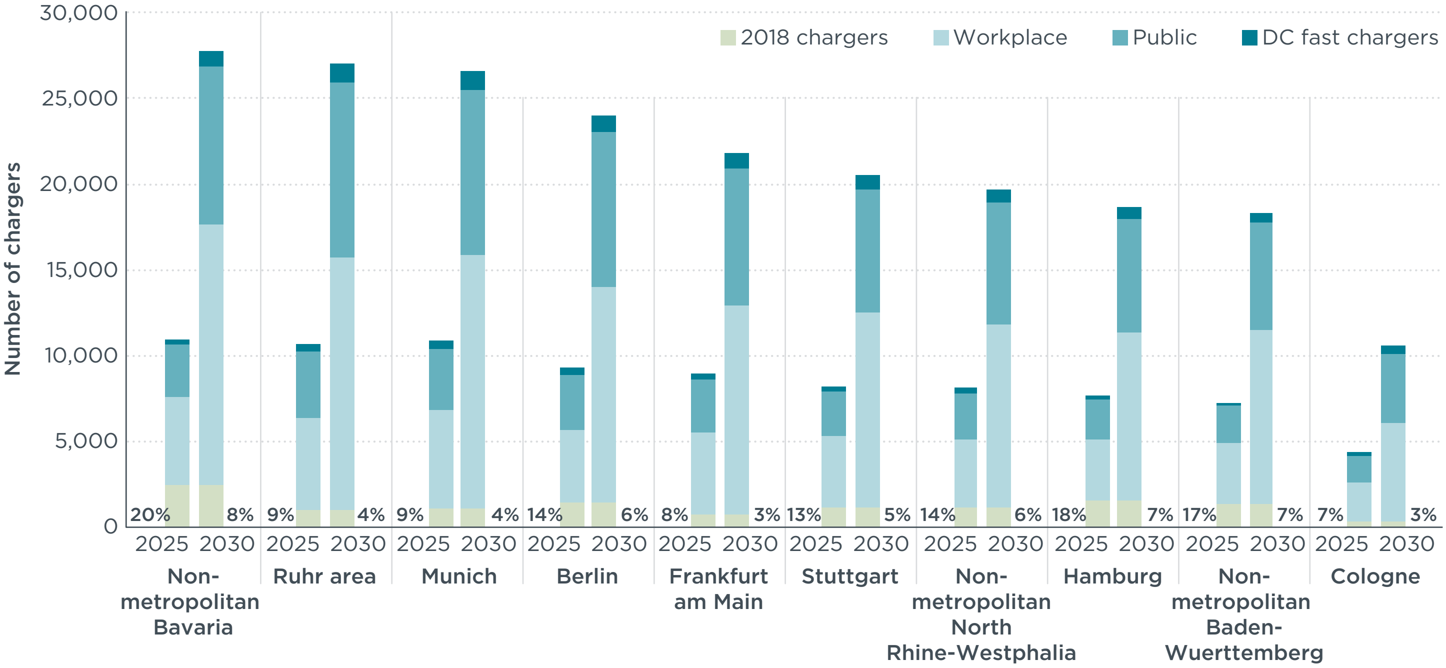

Figure 6. Chargers existing in 2018 versus chargers needed by 2025 and 2030 for scenario 1 of 35% electric car sales by 2030 for selected metropolitan and nonmetropolitan areas.

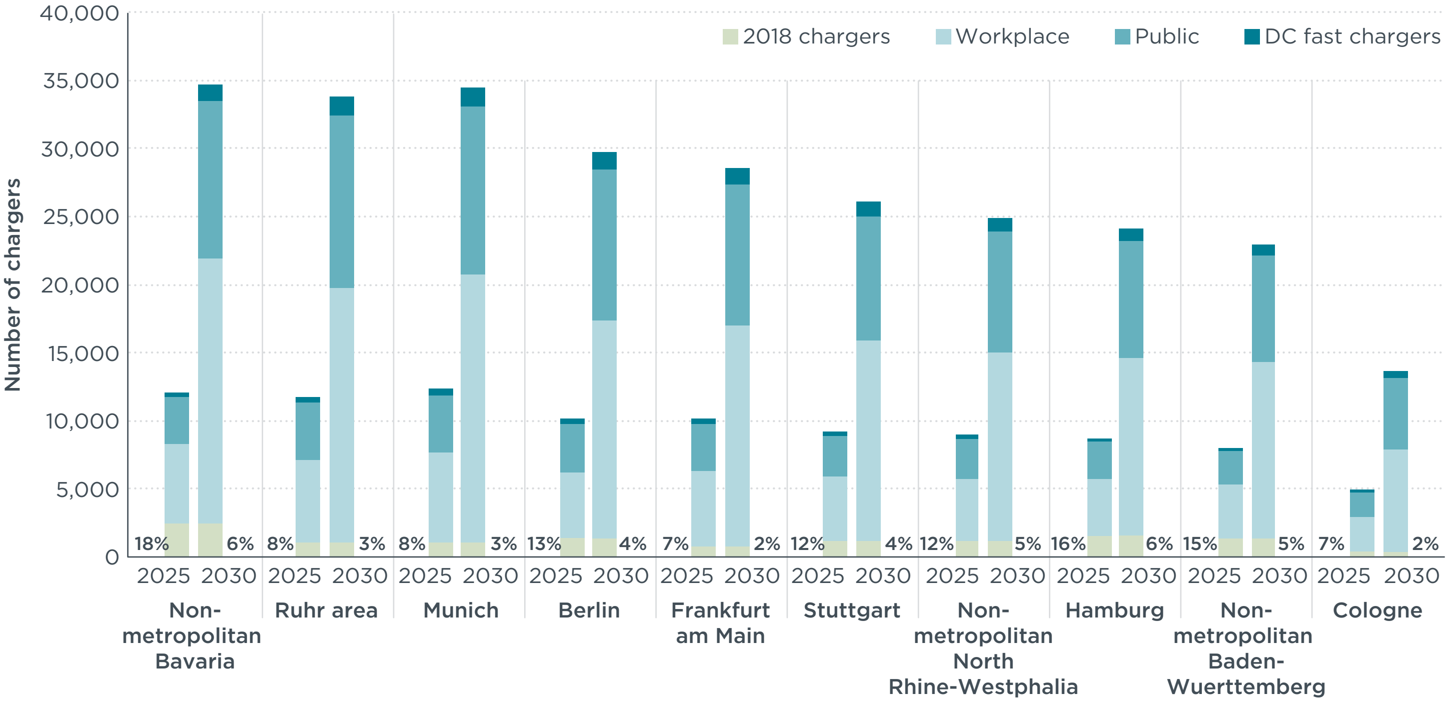

Figure 7. Chargers existing in 2018 versus chargers needed by 2025 and 2030 for scenario 2 of 50% electric car sales by 2030 for selected metropolitan and nonmetropolitan areas.

As shown, Berlin in 2018 had between 13% and 14% of the public and workplace charging it needs by 2025, and 4% to 6% of what it needs by 2030. Nonmetropolitan Bavaria in 2018 had about 18% to 20% of its 2025 charging needs and 6% to 8% of its 2030 charging needs. Cologne on the other hand had only 7% of the charging it will need in 2025 and 2% to 3% of its 2030 needs. Nonmetropolitan North Rhine-Westphalia had 12% to 14% of its 2025 needs, and 5% to 6% of its 2030 needs. In general, nonmetropolitan areas will need fewer chargers per vehicle. This is primarily due the increased availability of home charging in these areas. Berlin is expected to have the lowest home charging availability in 2030, at 63%, of electric vehicle owners, while nonmetropolitan Bavaria is highest with 78%. Although Berlin has the largest population, lower per capita vehicle ownership results in its needing fewer chargers than other areas with smaller populations. Munich surpasses the Ruhr area in charging needs in scenario 2 because its higher presumed leasing rate makes up a large portion of the vehicle stock. The number of workplace chargers exceeds the number of public chargers because of the expected increase in demand for charging at work.

Figure 8 shows the charging infrastructure in place in 2018 as a percentage of the chargers needed by 2025 under scenario 2. The national average charging in place in 2018 is 12% of what is needed by 2025, and 4% of what is needed by 2030. As shown in the figure, some areas in 2018 had less than 6% of the needed charging in 2025, while others had more than 20%. Nonmetropolitan areas by German state are shaded with stripes. The colors indicate the charging gap as a percentage of charging installed as of the end of 2018 that will be needed by 2030. For example, if there are 100 chargers installed in 2018 but 1,000 are needed by 2030, then this would be at a 10% level. Red colors indicate a larger charging gap than blue colors. The seven metropolitan areas in Figure 7 with the greatest population are labeled for context.

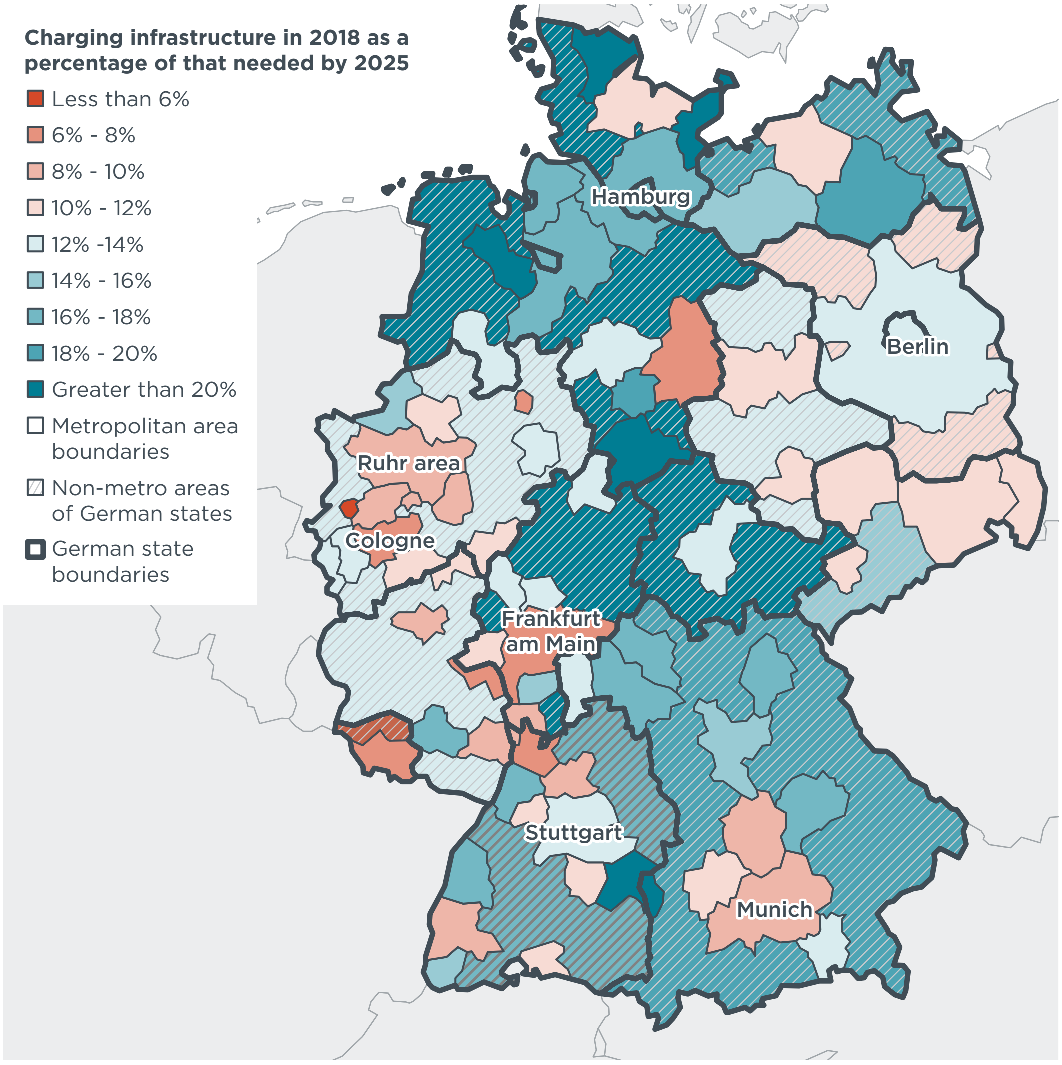

Figure 8. Percentage of charging infrastructure installed as of 2018 compared to 2025 needs for scenario 2.

Figure 8 suggests several aspects about charging. Foremost, it is evident that all areas of Germany have a charging gap, with most areas having less than 20% of the charging they need by 2025. Although not shown, most areas have less than 10% of the charging needed by 2030. The east and the west show the largest charging gap in nonmetropolitan areas, whereas the north, south, and center of Germany show a relatively smaller charging gap. Metropolitan areas, with some exceptions, tend to have a larger gap than nonmetropolitan areas due to two main factors. First, some areas have installed more chargers per vehicle up to 2018 relative to other areas. The second concerns the availability of home charging. Early adopters, which comprise much of the market in 2018, are more likely to have single-family homes with garages. As the market broadens, the number of EV drivers without reliable home charging access, such as those living in apartments, will increase. These new consumers will be concentrated in metropolitan areas, creating a relatively greater need for public and workplace charging than those in nonmetropolitan areas who more likely will have access to home charging.

CHARGING GAP COMPARISON BASED ON ECONOMIC SITUATION

The results of the analysis depict regional differences in future charging infrastructure needs. These variations reflect a variety of other aspects such as income and wealth of a region. The wealth of a region itself can give an indication about the potential investment or financial support necessary to fill the identified future charging infrastructure gap. To gain a better understanding of regional disparities, we compare the GDP per capita and the regional charging needs. Data are based on the German state and federal statistics, aggregating 2017 NUTS 3 data to the metropolitan and nonmetropolitan areas (Statistische Ämter des Bundes und der Länder, 2020).

Figure 9 shows GDP per capita on the horizontal axis, differentiated by affluent areas (i.e., GDP per capita above the German average of €39,650) and less affluent areas (i.e., GDP per capita below the German average). The vertical axis illustrates the percentage of charging infrastructure installed in 2018 as a portion of the charging infrastructure that will be required by 2025 for scenario 2 (50% electric car market share by 2030). Areas above the German average of 12% reflect areas with a smaller charging infrastructure gap. Below this threshold we depict areas with greater charging infrastructure requirements needed in 2025 compared to the 2018 base.

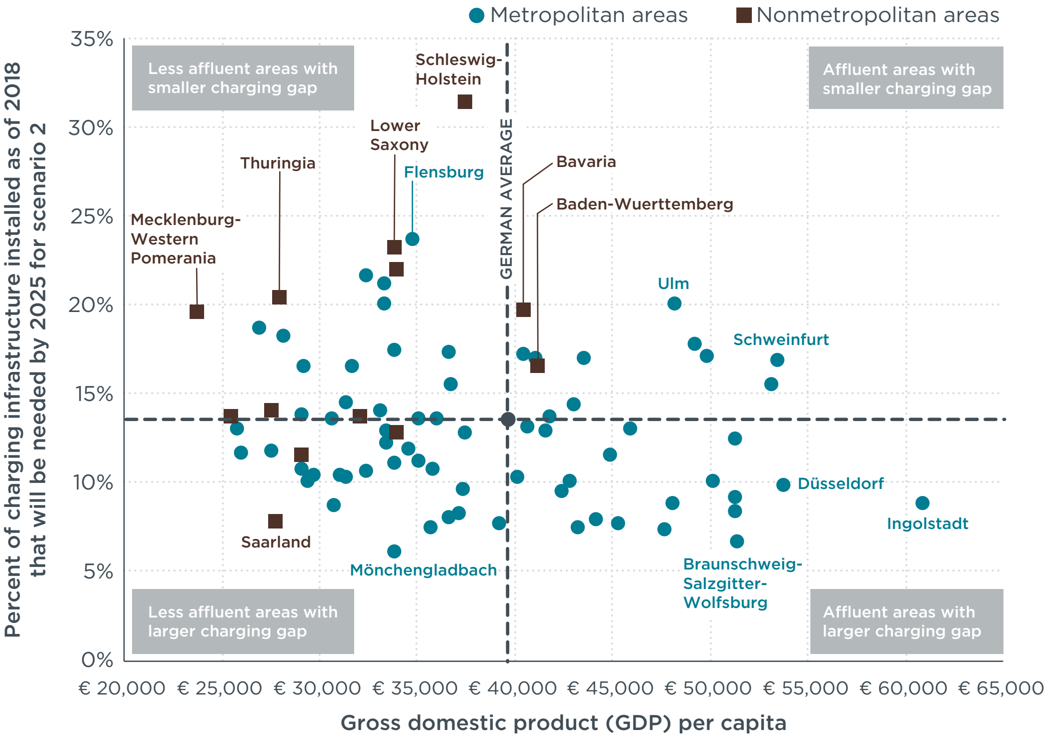

Figure 9. Charging infrastructure needs based on GDP per capita.

Based on the analysis, four different clusters can be identified out of the 69 metropolitan and 13 nonmetropolitan areas. The largest cluster (26) covers less affluent areas with a larger charging infrastructure gap, including 23 metropolitan and three nonmetropolitan areas (e.g., the metropolitan area of Mönchengladbach and nonmetropolitan area of Saarland). Almost the same number of areas (25) belong to the cluster comprising less affluent regions with a smaller charging gap (e.g., the metropolitan area of Flensburg and nonmetropolitan areas of Mecklenburg-Western Pomerania, Thuringia, Lower Saxony, Schleswig-Holstein). This cluster includes 17 metropolitan and eight nonmetropolitan areas. The cluster that reflects affluent regions with greater charging infrastructure needs includes 19 metropolitan areas (e.g., the metropolitan areas of Braunschweig-Salzgitter-Wolfsburg, Düsseldorf, and Ingolstadt). Lastly, there is the cluster of affluent regions with a relatively smaller charging gap. This cluster covers only 12 almost exclusively metropolitan areas (e.g., Ulm, Schweinfurt) with the exceptions of Baden-Wuerttemberg and Bavaria, representing the only two nonmetropolitan areas.

Of the metropolitan and nonmetropolitan areas, 62% are less affluent regions. Of those, the charging infrastructure in place in 2018 compared to what will be needed in 2025 ranges between 6% in the metropolitan area of Mönchengladbach and 31% in the nonmetropolitan area of Schleswig-Holstein. For the affluent regions, the range is from 7% for the metropolitan area of Braunschweig-Salzgitter-Wolfsburg to 20% for the metropolitan area of Ulm. The charging infrastructure needs increase respectively when the data are compared to 2030 needs.

Some further observations can be made based on the analysis. In less affluent nonmetropolitan areas, such as Mecklenburg-Western Pomerania or Thuringia, the future charging infrastructure needs are significantly lower than in more affluent metropolitan areas such as Düsseldorf and Ingolstadt. In fact, in the majority of the nonmetropolitan areas, which at the same time are almost exclusively less affluent based on the GDP per capita, the percentage of charging infrastructure installed as of 2018 compared to what will be needed by 2025 for scenario 2 is below or well below the German average. More specifically, in these regions the charging needs are much smaller than what is needed in most other areas. For example, the nonmetropolitan area of Mecklenburg-Western Pomerania has the lowest GDP per capita, yet in 2018 the charging infrastructure already installed in the region was 20% of the charging infrastructure that will be needed by 2025. On the contrary, in the metropolitan area of Ingolstadt, with the highest GDP per capita, the charging infrastructure covered only 9% of what will be needed in 2025. The gap can vary based on several factors including lower vehicle ownership and greater potential for the installation of home charging.

Assessing the prosperity of a region can help identify potential investment gaps for future charging infrastructure needs at the local levels and thereby optimize the deployment of additional charging infrastructure. However, it is important to not leave less affluent regions behind. Even though less affluent nonmetropolitan areas were found to currently have a lower charging infrastructure gap than other regions across Germany, the additional infrastructure required to be deployed between now and 2025 or 2030 is still substantial and will need further support.

Public funding remains crucial to expanding a nationwide charging infrastructure network. In addition to national and local governments, energy suppliers or municipal utilities as well as automakers could contribute more actively to building up the future charging infrastructure network, such as by providing incentives or investments, as also suggested in the national governments' Masterplan Charging Infrastructure (BReg, 2019). An example for nationwide public and private investment is the United Kingdom (UK). Some of the UK charging infrastructure network is built up with governmental funding, to be matched with private investment as part of the Charging Infrastructure Investment Fund (HM Treasury & Infrastructure and Projects Authority, 2019).

COMPARISON OF RESULTS

Overall, the analysis indicates that throughout Germany, about 180,000 to 200,000 new public charging points are needed by 2025, and a total of 448,000 to 565,000 charging points are needed by 2030. These numbers could support approximately 6 to 7 million electric vehicles in Germany in 2030, representing a market share of 35% to 50% of passenger vehicle sales. To classify the findings of this study, we highlight a selection of publications that have also made estimations about future charging infrastructure needs for Germany. The results are also discussed based on the government's aim to install 1 million charging points by 2030. The publications and estimations are shown in Table 10, listed in the order of the publication date.

Table 10. Comparison of results with selected studies and plans.

Source	Scenario	Estimated public charging points	Estimated electric vehicles	Charger to electric vehicle ratio	Estimated public charging points	Estimated electric vehicles	Charger to electric vehicle ratio
		2025			2030		
Nationale Plattform Elektromobilität (2018)	Intermediate scenario	143,000	1.7 million	1:12	-	-	-
	Optimistic scenario	209,000	3.1 million	1:15	-	-	-
Bundesregierung (BReg, 2019)	-	-	-	-	1,000,000	7-10 million	1:7-1:10
Transport & Environment (2020)	CurrentPolicies scenario	288,000	2,9 million	1:10	534,000	7,5 million	1:14
	Road2Zero scenario	318,000	3,2 million	1:10	719,000	10 million	1:14
Nationale Plattform Zukunft der Mobilität (2020)	Scenario 1	300,000	2.8 million	1:9	950,000	10.5 million	1:11
	Scenario 2	110,000		1:25	360,000		1:29
	Scenario 3	160,000		1:18	470,000		1:22
	Scenario 4	55,000		1:51	180,000		1:58
ICCT model scenarios	Scenario 1	180,000	1.9 million	1:11	448,000	5.7 million	1:13
	Scenario 2	200,000	2.1 million	1:11	565,000	7.4 million	1:13

The German National Platform for Electric Mobility, a former advisory body to the German government, projected in 2018 that 143,000 to 209,000 public charging points will be required by 2025 (Nationale Plattform Elektromobilität, 2018). At the end of 2019, the German government published its Masterplan Charging Infrastructure, which includes measures for the nationwide buildup of charging infrastructure. According to the plan, the government aims at 1 million public charging points without specifying the underlying assumptions (BReg, 2019). A recent study by Transport & Environment suggests almost 290,000 to 320,000 public charging points will be needed in Germany by 2025, and more than 530,000 to almost 720,000 by 2030 (Transport & Environment, 2020). The German National Platform Future of Mobility, continuing the work of the form National Platform for Electric Mobility, assesses in its recent report the future public charging infrastructure needs, ranging between 55,000 to 300,000 in 2025 and 180,000 to 950,000 by 2030 (Nationale Plattform Zukunft der Mobilität, 2020).

In general, the results of this study are comparable to the findings of selected recent studies, which estimate the public charging infrastructure needs for Germany in the 2025 to 2030 time frame. The results suggest charger to electric vehicle ratios of 1:9 (Nationale Plattform Zukunft der Mobilität, scenario 1) and of 1:10 in 2025 (Transport & Environment) similar to the 1:11 ratios in this study. Variations are much larger for 2030 estimates, depending on various factors such as assumed total BEVs and PHEVs, share of public charging, and the proportion of normal and fast charging.

Comparing the findings of the study with the government's target to install 1 million charging points by 2030, our charging needs estimations are significantly lower, almost by half (448,000 to 565,000). Yet, electric vehicle stock estimations differ, ranging between 5.7 and 7.4 million assumed for this study compared to the 7 to 10 million envisaged by the German government. If comparing the charger to electric vehicle ratio, the ratio would be 1:7 to 1:10 based on the government's targets, while this study suggests 1:11 in the near-term to 1:13 by 2030 due to increasing utilization of chargers. The government's targets do not specify a scenario of vehicles, customer types, charging speed, or utilization so it is difficult to assess the government estimates.

CONCLUSIONS

This analysis and future projections show that there is a large charging gap in Germany to be overcome in satisfying the requirements of a growing electric vehicle market up to 2030 and provide access to charging for all. However, various activities are being undertaken by the German government to guide the market in the right direction. These include the funding guideline "Charging infrastructure for electric vehicles in Germany," which provides €300 million of funding between 2017 and 2020 for the extension of the public charging infrastructure network (BMVI, 2020a). In November 2019, the German Cabinet also adopted the "Masterplan for charging infrastructure," calling for 1 million charging points by 2030 and announcing further investments in charging infrastructure of more than €3 billion (BReg, 2019; BMVI, 2020b). As part of the stimulus package in response to the COVID-19 pandemic, the government intends to provide funding of €500 million in the expansion of private charging facilities (BMVI, 2020c).

In addition, since 2019 the government has provided an online tool (StandortTool) that helps investors and municipalities find suitable locations for public charging infrastructure. It also helped in setting up a new "National Control Center for Charging Infrastructure" in late 2019, aiming at a coordinated ramp-up of the public charging infrastructure network (BMVI, 2020a; NOW GmbH, 2019).

This analysis quantifies, from a detailed bottom-up evaluation, the charging infrastructure needed to support Germany's electric vehicle goals through 2030. In contrast to other studies, this analysis enumerates the need for more than 80 areas in Germany allowing more targeted policies to ensure public charging needs are met. Based on the analysis of two scenarios, achieving 35% to 50% electric vehicle sales share of new passenger vehicles by 2030—regarded as conservative and indicative of the minimum number of charging points that will be required—we draw the following conclusions.

A large increase in charging is needed to support the growing German electric vehicle market. To support approximately 5.7 to 7.4 million electric vehicles in Germany, representing a market share of 35% to 50% of passenger vehicle sales, an estimated 180,000 to 200,000 public chargers are needed by 2025, and a total of 448,000 to 565,000 chargers are needed by 2030. Chargers installed through 2018 represented 12% to 13% of 2025 charging needs, and 4% to 5% of 2030 charging needs. Although expanding this infrastructure will require greatly increased efforts by governments and private industry, these projected needs are approximately half of Germany's announced goal of 1 million public chargers by 2030. This difference is explained by fewer vehicles and a lower number of chargers per electric vehicle in the scenarios considered in this analysis.

More vehicles can be supported per charger as the market grows. We project the ratio of electric vehicles per normal speed charger will rise from nine in 2018 to 14 in 2030. Battery electric vehicles per DC fast charger will increase from 80 BEVs per fast charger to more than 220 vehicles per fast charger. Associated trends over this time include an expected decline in the availability of home charging as more electric vehicles are owned by those without off-street overnight parking, better utilization of public chargers, and an increase in charging speed. As the electric vehicles and charging infrastructure evolve, the increasing charger utilization improves the business case for public charging over time.

Affluent areas with higher uptake and metropolitan areas show the largest charging gap. The affluent areas where most electric vehicles are now leased or sold show the greatest increase in need for charging. In less affluent areas, the increased need will mirror affluent areas as electric cars move to the secondary market. Lower home charging availability in metropolitan areas contributes to an increase in need as well. Despite most metropolitan areas tending to have a larger charging gap, compared to nonmetropolitan areas, the need remains great in less affluent rural areas, which will require equal access to electrification.

The scenarios presented here represent two possible paths for the electric vehicle market and charging in Germany leading up to 2030. The scenarios, however, are dependent on supporting policies to ensure that chargers are installed at home and in public. The scenarios are sensitive to policies that encourage one type of charging or another, and an increase in one type of charging will result in a decrease in the need for another. Of particular uncertainty is overnight charging access in apartments, and this remains a key barrier to electric vehicle uptake in Germany. An estimated 46% of German passenger vehicle stock is owned by apartment dwellers. However, only 2% to 4% of apartment dwellers have access to any type of charging. Strong policies in all charging types are needed to support electric vehicle targets.

Further work is needed to determine locations for chargers within a metropolitan area and to determine the associated costs for grid connections, hardware, and installation. Regional and municipal authorities could improve the accuracy of modeling by continual monitoring of charging supply, price, power availability, and utilization as well as by conducting surveys to understand who is using charging. The integration of renewable energy is also not specifically addressed in this paper and can affect deployment strategies and increase the number of chargers needed. Also, overall charger numbers can be reduced if strategies to increase hours of use on a charger, such as coordination of charging times or pricing, to shift usage times are employed.

REFERENCES

Ahlfeldt, G., & Maennig, W. (2013). Homevoters vs. leasevoters: A spatial analysis of airport effects, CESifo Working Paper, No. 4301, Tab A1. Center for Economic Studies and Ifo Institute (CESifo), Munich. Retrieved from https://ssrn.com/abstract=2290926

BDEW. (2020). Ladesäulen: Energiewirtschaft baut Ladeinfrastruktur auf [Charging stations: The energy industry builds charging infrastructure]. Retrieved from https://www.bdew.de/energie/elektromobilitaet-dossier/energiewirtschaft-baut-ladeinfrastruktur-auf/

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (2016). Klimaschutzplan 2050 [Climate Protection Plan 2050]. Retrieved from https://www.fe.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzplan_2050_bf.pdf

Bundesministerium für Verkehr und digitale Infrastruktur. (2017). Mobilität in Deutschland [Mobility in Germany]. Retrieved from http://www.mobilitaet-in-deutschland.de/MiT2017.html

Bundesministerium für Verkehr und digitale Infrastruktur. (2020a). Förderrichtlinie Ladeinfrastruktur für Elektrofahrzeuge [Funding guideline for charging infrastructure for electric vehicles]. Retrieved from https://www.bmvi.de/SharedDocs/DE/Artikel/G/foerderrichtlinie-ladeinfrastruktur-elektrofahrzeuge.html

Bundesministerium für Verkehr und digitale Infrastruktur. (2020b). Bald laden wir allerorts und jederzeit - Masterplan Ladeinfrastruktur [Soon we will charge anywhere and anytime – Master plan charging infrastructure]. Retrieved from https://www.bmvi.de/SharedDocs/DE/Artikel/G/masterplan-ladeinfrastruktur.html

Bundesministerium für Verkehr und digitale Infrastruktur. (2020c). 500 Millionen Euro zusätzlich für Ladeinfrastruktur - 6. Förderaufruf abgeschlossen [500 million euros in addition for charging infrastructure - 6th funding call completed]. Retrieved from https://www.bmvi.de/SharedDocs/DSLAME/Artikel/G/infopapier-sechster-foerderaufruf-ladeinfrastruktur.html

Bundesnetzagentur (n.d.). Ladesäulenkarte, accessed January 2019. https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/HandelundVertrieb/Ladesaeulenkarte/Ladesaeulenkarte_node.html

Die Bundesregierung. (2019). Masterplan Ladeinfrastruktur der Bundesregierung [Master plan charging infrastructure of the German government. Retrieved from https://www.bmvi.de/SharedDocs/DE/Anlage/G/masterplan-ladeinfrastruktur.pdf?__blob=publicationFile

Die Bundesregierung. (2020). Verkehr [Transport]. Retrieved from https://www.bundesregierung.de/breg-de/themen/klimaschutz/verkehr-1672896

DLR. (2015). Erstnutzer von Elektrofahrzeugen in Deutschland [First time users of electric vehicles in Germany]. Retrieved from https://elib.dlr.de/96491/1/Ergebnisbericht_E-Nutzer_2015.pdf

Eurostat. (n.d.). Metropolitan Regions. Retrieved from https://ec.europa.eu/eurostat/web/metropolitan-regions/background

Eurostat. (2011). Conventional dwellings by occupancy status, type of building and NUTS 3 region. Retrieved from https://ec.europa.eu/eurostat/web/products-datasets/-/cens_11dwob_r3

Eurostat. (2018). Stock of vehicles by category and NUTS 2 regions. Retrieved from http://ec.europa.eu/eurostat/product?code=tran_r_vehst&language=en&mode=view

Eurostat. (2019a). Population on 1 January by broad age group, sex and NUTS 3 region. Retrieved from https://ec.europa.eu/eurostat/web/products-datasets/-/demo_r_pjanaggr3

Eurostat. (2019b). Population on 1st January by age, sex and type of projection. Retrieved from https://data.europa.eu/euodp/en/data/dataset/g33Nsv6Vud3AmmX9EJeOw

Hall, D. & Lutsey, N. (2017). *Emerging best practices for electric vehicle charging infrastructure.* Retrieved from The International Council on Clean Transportation, http://theicct.org/emerging-electric-charging-practices

HM Treasury & Infrastructure and Projects Authority. (2019). *Charging infrastructure investment fund* [Policy paper]. Retrieved from https://www.gov.uk/government/publications/charging-infrastructure-investment-fund

IHS Markit. (2019). Purchased dataset on vehicle registrations by European NUTS 3 statistical areas. Data through December 31, 2018.

Jochem, P., Szimbac, E., & Reuter-Oppermann, M. (2019). How many fast-charging stations do we need along European highways? *Transportation Research Part D.* 120-129. Retrieved from https://www.sciencedirect.com/science/article/pii/S1361920919300215?via%3Dihub

Kraftfahrt-Bundesamt. (2019a). Bestand an Personenkraftwagen am 1. Januar 2019 nach Bundesländern und ausgewählten Kraftstoffarten absolut [Number of cars from 2010 to 2019 by selected fuel types]. Retrieved from https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Umwelt/fz_b_umwelt_archiv/2019/2019_b_umwelt_dusl.html?nn=2598042

Kraftfahrt-Bundesamt. (2019b). Kraftfahrzeuge und Kraftfahrzeuganhänger nach Fahrzeugalter 1. Januar 2019 [Inventory on January 1, 2019 by vehicle age]. Retrieved from https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Fahrzeugalter/fahrzeugalter_node.html

Kraftfahrt-Bundesamt. (2019c). Verkehr in Kilometern - Inländerfahrleistung [Traffic in kilometers – national mileage]. Retrieved from https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/verkehr_in_kilometern_node.html

Lemnet. (n.d.). Directory of charging stations for electric vehicles. Accessed January 2019. https://www.lemnet.org/en/home

Miller, J., & Jin, L. (2018). *Global progress toward soot-free diesel vehicles in 2018*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/global-progress-toward-soot-free-diesel-vehicles-2018

Mock, P. (2019). *CO2 emission standards for passenger cars and light-commercial vehicles in the European Union*. Retrieved from the International Council on Clean Transportation, https://www.theicct.org/publications/ldv-co2-stds-eu-2030-update-jan2019

Nationale Plattform Elektromobilität. (2018). Progress report 2018 – Market ramp-up phase. Retrieved from http://nationale-plattform-elektromobilitaet.de/fileadmin/user_upload/Redaktion/Publikationen/NPE_Progress_Report_2018.pdf

Nationale Plattform Zukunft der Mobilität. (2020). Bedarfsgerechte und wirtschaftliche öffentliche Ladeinfrastruktur – Plädoyer für ein dynamisches NPM-Modell [Demand-oriented and economical public charging infrastructure – A plea for a dynamic NPM model]. Retrieved from https://www.plattform-zukunft-mobilitaet.de/2download/bedarfsgerechte-und-wirtschaftliche-oeffentliche-ladeinfrastruktur-plaedoyer-fuer-ein-dynamisches-npm-modell/

Nicholas, M., & Hall, D. (2018). *Lessons learned on early electric vehicle fast-charging deployments* [White paper]. Retrieved from the International Council on Clean Transportation, https://www.theicct.org/publications/fast-charging-lessons-learned

Nicholas, M., Hall, D., & Lutsey, N. (2019). *Quantifying the electric vehicle charging infrastructure gap across U.S. markets*. Retrieved from The International Council on Clean Transportation, https://www.theicct.org/publications/charging-gap-US

Nicholas, M. & Lutsey, N. (2020). *Quantifying the electric vehicle charging infrastructure gap in the United Kingdom*. Retrieved from The International Council on Clean Transportation website: https://theicct.org/publications/charging-gap-UK-2020

NOW GmbH. (2019). Wir werden Nationale Leitstelle Ladeinfrastruktur! [We will become the national control center for charging infrastructure]. Retrieved from https://www.now-gmbh.de/de/aktuelles/presse/nationale-leitstelle-ladeinfrastruktur-bei-now-gmbh

Open Charge Map. (n.d.). The Open Charge Map API. Accessed January 2019. http://openchargemap.org/site/develop/api.

Paulsen, T. (2019, March 26). Elektroauto in der Tiefgarage laden: So kommt der Strom zum Wagen [Charging an electric car in the underground car park: this is how electricity comes to the car]. ADAC. Retrieved from https://www.adac.de/rund-ums-fahrzeug/elektromobilitaet/laden/laden-garage-e-auto/

Transport & Environment. (2020). *Recharge EU: how many charge points will Europe and its Member States need in the 2020s*. Retrieved from https://www.transportenvironment.org/sites/te/files/publications/01%202020%20Draft%20TE%20Infrastructure%20Report%20Final.pdf

Schaufenster Elektromobilität. (2017). Bedarfsorientierte Ladeinfrastruktur aus Kundensicht [Demand-oriented charging infrastructure from the customer perspective]. March. Retrieved from https://www.researchgate.net/publication/318236359_Bedarfsorientierte_Ladeinfrastruktur_aus_Kundensicht

Statistische Ämter des Bundes und der Länder (2020). Regionaldatenbank Deutschland. Retrieved from: https://www.regionalstatistik.de/genesis/online/data;sid=41AC3D5A76BCEF2CE08FF6B710A6C413.reg3?operation=abruftabelleBearbeiten&levelindex=1&levelid=1587995243771&auswahloperation=abruftabelleAuspraegungAuswaehlen&auswahlverzeichnis=ordnungsstruktur&auswahlziel=werteabruf&selectionname=82111-01-05-4-B&auswahltext=&auspraegungen%24%24%247=Zeit+ausw%C3%A4hlen&nummer=8&variable=8&name=KREISE

Tal, G., Lee, J., & and Nicholas, M. (2018). *Observed charging rates in California*. (Working paper ITS-WP-18-02). Retrieved from https://escholarship.org/uc/item/2038613r

Wappelhorst, S. (2020). *The end of the road? An overview of combustion engine car phase-out announcements across Europe*. Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/Combustion-engine-phase-out-briefing-may11.2020.pdf

APPENDIX

This appendix provides results for individual metropolitan areas and nonmetropolitan areas for scenarios 1 and 2.

Table A1. Scenario 1: 35% electric car sales by 2030

Metropolitan area name	2018 normal chargers	2018 DC fast chargers	2025 EVs	2025 normal chargers	2025 DC fast chargers	2030 EVs	2030 normal chargers	2030 DC fast chargers
Berlin	1,341	86	87,106	8,920	448	269,106	23,030	1,049
Ruhrgebiet (Ruhr area)	949	89	105,107	10,227	498	318,491	25,920	1,163
Hamburg	1,392	150	83,602	7,478	355	240,207	17,985	816
München (Munich)	1,031	63	117,463	10,417	499	340,421	25,486	1,163
Stuttgart	1,076	78	89,013	7,931	365	262,783	19,711	853
Frankfurt am Main	698	57	97,645	8,601	391	286,214	20,929	937
Köln (Cologne)	328	43	44,957	4,201	207	130,261	10,149	474
Düsseldorf	420	28	41,128	3,912	183	126,419	10,090	441
Dresden	232	34	21,582	2,127	107	64,442	5,283	244
Nürnberg (Nuremberg)	439	32	30,352	2,827	129	92,262	7,208	307
Hannover	338	43	25,632	2,412	113	77,980	6,141	266
Bremen	373	31	23,668	2,113	90	72,777	5,374	216
Mannheim	266	24	29,035	2,652	117	89,300	6,830	282
Leipzig	213	17	19,035	1,903	93	58,456	4,883	220
Braunschweig-Salzgitter-Wolfsburg	284	46	52,268	4,075	191	147,392	9,667	438
Bonn	193	14	19,632	1,760	78	58,829	4,395	184
Saarbrücken	128	13	17,335	1,613	75	51,984	4,048	176
Karlsruhe	274	16	15,891	1,467	67	47,463	3,656	156
Heidelberg	139	26	20,306	1,837	78	64,366	4,893	194
Augsburg	170	10	15,163	1,370	62	44,527	3,360	145
Freiburg	178	5	17,727	1,682	73	57,417	4,589	182
Kiel	152	8	14,596	1,323	56	45,803	3,475	138
Aachen	146	9	11,229	1,035	49	33,094	2,552	113
Münster	124	1	11,738	1,074	48	36,007	2,755	115
Erfurt	150	17	11,288	1,062	49	35,120	2,766	117
Osnabrück	135	10	10,732	960	41	32,687	2,426	97
Würzburg	184	30	12,389	1,100	46	38,332	2,836	110
Magdeburg	76	24	9,046	865	40	28,139	2,250	96
Ulm	214	27	11,786	1,041	44	36,348	2,664	106
Ingolstadt	157	21	22,124	1,667	74	60,717	3,816	165
Heilbronn	105	36	15,582	1,285	57	43,664	2,990	129
Wiesbaden	142	11	12,361	1,147	53	37,607	2,939	126
Regensburg	231	18	14,002	1,178	53	38,540	2,689	119
Göttingen	170	19	8,356	755	34	24,621	1,854	78
Darmstadt	192	9	12,665	1,125	49	38,667	2,877	117
Kassel	116	14	9,614	871	39	28,712	2,168	92
Offenburg	138	27	9,334	831	36	28,525	2,111	85
Mainz	73	7	9,860	901	41	30,015	2,307	97
Halle an der Saale	70	11	5,841	587	30	17,248	1,437	68
Rostock	81	4	6,340	701	39	19,041	1,735	86
Oldenburg	157	15	8,775	745	31	26,971	1,895	73
Lübeck	175	20	8,724	809	35	27,478	2,133	86
Iserlohn	72	7	8,859	828	37	27,593	2,132	89
Siegen	79	13	8,339	709	30	23,830	1,653	68
Aschaffenburg	109	7	8,909	761	33	25,635	1,802	75
Bocholt	105	-	6,893	592	24	21,213	1,495	56
Wuppertal	77	5	8,757	885	43	27,440	2,328	103
Bielefeld	74	6	9,559	904	42	29,651	2,374	100
Koblenz	54	8	7,211	641	28	21,722	1,609	66
Pforzheim	73	8	7,270	656	29	22,097	1,664	68
Rosenheim	102	17	8,544	756	32	26,430	1,951	78
Zwickau	50	5	4,611	454	23	13,228	1,076	51
Bremerhaven	91	2	5,116	468	20	15,723	1,190	48
Schwerin	66	12	4,212	461	25	12,726	1,150	56
Paderborn	99	4	7,478	666	28	23,622	1,758	68
Flensburg	132	17	6,274	550	23	19,257	1,405	55
Reutlingen	76	1	7,506	657	27	23,088	1,685	65
Konstanz	76	7	6,448	611	27	20,125	1,597	66
Hildesheim	76	14	4,666	431	18	14,333	1,092	44
Kaiserslautern	69	21	5,351	469	20	16,108	1,166	47
Schweinfurt	112	6	7,011	618	25	22,146	1,628	61
Gießen	71	6	6,109	551	23	19,036	1,430	56
Düren	67	2	5,291	457	19	15,753	1,122	45
Mönchengladbach	31	4	5,334	505	24	16,096	1,276	56
Neubrandenburg	60	4	2,936	291	15	8,476	688	32
Görlitz	41	1	3,177	309	15	9,298	743	34
Wetzlar	60	6	5,156	440	18	15,148	1,059	41
Bayreuth	94	9	5,985	518	23	17,391	1,247	52
Basel (German district of Lörrach)	80	5	5,790	535	23	18,478	1,435	56
Nonmetropolitan Baden-Wuerttemberg	1,225	122	81,274	7,093	297	245,412	17,762	703
Nonmetropolitan Bavaria	2,247	180	123,973	10,685	438	376,679	26,893	1,042
Nonmetropolitan Brandenburg	174	16	15,178	1,432	65	46,360	3,642	154
Nonmetropolitan Hesse	548	44	26,812	2,341	96	81,106	5,816	225
Nonmetropolitan Mecklenburg-Western Pomerania	161	13	8,369	764	34	24,666	1,840	77
Nonmetropolitan Lower Saxony	1,113	91	52,688	4,549	177	165,798	11,765	432
Nonmetropolitan North Rhine-Westphalia	1,131	29	89,144	7,805	336	262,634	18,936	773
Nonmetropolitan Rhineland-Palatinate	546	90	46,865	4,035	164	141,769	10,055	387
Nonmetropolitan Saarland	30	-	3,761	321	15	10,118	703	32
Nonmetropolitan Saxony	267	13	17,411	1,694	85	50,355	4,048	190
Nonmetropolitan Saxony-Anhalt	231	25	17,006	1,597	75	49,741	3,838	170
Nonmetropolitan Schleswig-Holstein	361	13	12,266	1,051	41	38,558	2,738	100
Nonmetropolitan Thuringia	512	45	25,229	2,336	109	73,777	5,632	249
All metropolitan areas	15,547	1,440	1,382,818	125,706	5,796	4,134,078	314,584	13,630
All nonmetropolitan areas	8,546	681	519,976	46,309	1,990	1,566,974	115,142	4,660
Germany total	24,093	2,121	1,902,793	172,015	7,786	5,701,052	429,725	18,290

Table A2. Scenario 2: 50% electric car sales by 2030

Metropolitan area name	2018 normal chargers	2018 DC fast chargers	2025 EVs	2025 normal chargers	2025 DC fast chargers	2030 EVs	2030 normal chargers	2030 DC fast chargers
Berlin	1,341	86	97,044	9,785	490	342,408	28,508	1,297
Ruhrgebiet (Ruhr area)	949	89	118,087	11,314	549	409,954	32,466	1,454
Hamburg	1,392	150	95,967	8,450	398	319,160	23,259	1,048
München (Munich)	1,031	63	135,115	11,818	562	453,058	33,106	1,499
Stuttgart	1,076	78	100,840	8,860	406	342,527	25,046	1,080
Frankfurt am Main	698	57	113,147	9,806	444	383,855	27,361	1,217
Köln (Cologne)	328	43	51,615	4,743	232	172,943	13,104	608
Düsseldorf	420	28	46,250	4,333	202	162,710	12,650	553
Dresden	232	34	24,380	2,363	118	83,604	6,657	306
Nürnberg (Nuremberg)	439	32	33,951	3,116	142	118,109	8,985	382
Hannover	338	43	28,735	2,663	124	100,079	7,670	332
Bremen	373	31	26,531	2,332	99	93,312	6,704	269
Mannheim-Ludwigshafen	266	24	32,447	2,921	128	114,077	8,500	351
Leipzig	213	17	21,283	2,095	102	74,731	6,073	273
Braunschweig-Salzgitter-Wolfsburg	284	46	61,445	4,743	218	202,298	13,023	578
Bonn	193	14	22,119	1,953	86	76,056	5,529	231
Saarbrücken	128	13	19,500	1,787	83	67,074	5,083	220
Karlsruhe	274	16	17,856	1,623	74	61,183	4,585	196
Heidelberg	139	26	22,458	2,006	85	81,061	6,016	239
Augsburg	170	10	17,161	1,526	69	57,996	4,256	183
Freiburg im Breisgau	178	5	19,324	1,813	79	71,029	5,550	220
Kiel	152	8	16,164	1,445	61	57,807	4,275	170
Aachen	146	9	12,725	1,155	55	43,158	3,237	143
Münster	124	1	13,142	1,185	53	46,108	3,435	143
Erfurt	150	17	12,604	1,168	53	44,778	3,435	146
Osnabrück	135	10	11,978	1,056	45	41,724	3,014	121
Würzburg	184	30	13,740	1,203	50	48,506	3,498	136
Magdeburg	76	24	10,083	950	44	35,803	2,786	119
Ulm	214	27	13,218	1,150	48	46,619	3,327	133
Ingolstadt	157	21	25,835	1,928	84	82,937	5,111	216
Heilbronn	105	36	17,974	1,462	64	58,550	3,910	167
Wiesbaden	142	11	13,839	1,266	58	48,190	3,670	157
Regensburg	231	18	16,167	1,340	60	51,858	3,525	154
Göttingen	170	19	9,401	836	38	31,822	2,330	98
Darmstadt	192	9	14,178	1,242	54	49,528	3,592	146
Kassel	116	14	10,822	965	44	37,093	2,726	115
Offenburg	138	27	10,426	915	40	36,439	2,626	106
Mainz	73	7	11,018	993	45	38,372	2,873	120
Halle an der Saale	70	11	6,610	653	33	22,450	1,815	85
Rostock	81	4	7,133	775	43	24,570	2,174	107
Oldenburg	157	15	9,832	823	34	34,567	2,366	91
Lübeck	175	20	9,644	882	38	34,597	2,618	106
Iserlohn	72	7	9,940	914	40	35,379	2,660	111
Siegen	79	13	9,516	795	34	31,445	2,120	86
Aschaffenburg	109	7	10,170	855	37	33,822	2,313	96
Bocholt	105	-	7,698	652	26	27,073	1,857	70
Wuppertal	77	5	9,714	968	47	34,701	2,872	127
Bielefeld	74	6	10,573	988	45	37,396	2,922	123
Koblenz	54	8	8,117	711	31	28,041	2,021	83
Pforzheim	73	8	8,114	722	31	28,210	2,068	84
Rosenheim	102	17	9,551	833	35	33,761	2,429	97
Zwickau	50	5	5,254	508	26	17,416	1,373	65
Bremerhaven	91	2	5,707	514	22	20,042	1,476	60
Schwerin	66	12	4,731	509	28	16,380	1,437	70
Paderborn	99	4	8,266	727	30	29,735	2,158	84
Flensburg	132	17	6,990	604	25	24,517	1,742	68
Reutlingen	76	1	8,346	720	30	29,322	2,085	81
Konstanz	76	7	7,131	666	30	25,371	1,963	81
Hildesheim	76	14	5,183	471	20	18,181	1,348	54
Kaiserslautern	69	21	6,021	520	22	20,783	1,463	59
Schweinfurt	112	6	7,692	670	27	27,634	1,983	74
Gießen	71	6	6,773	602	26	24,069	1,762	70
Düren	67	2	5,965	507	21	20,394	1,412	56
Mönchengladbach	31	4	5,998	559	26	20,748	1,600	70
Neubrandenburg	60	4	3,343	325	16	11,145	876	41
Görlitz	41	1	3,601	344	17	12,134	940	43
Wetzlar	60	6	5,819	489	20	19,661	1,336	52
Bayreuth	94	9	6,798	580	25	22,778	1,589	66
Basel (German district of Lörrach)	80	5	6,353	580	25	23,048	1,747	69
Nonmetropolitan Baden-Wuerttemberg	1,225	122	91,042	7,829	328	314,870	22,188	878
Nonmetropolitan Bavaria	2,247	180	138,716	11,783	482	482,386	33,539	1,300
Nonmetropolitan Brandenburg	174	16	16,959	1,575	71	59,241	4,525	192
Nonmetropolitan Hesse	548	44	29,984	2,578	106	103,830	7,242	280
Nonmetropolitan Mecklenburg-Western Pomerania	161	13	9,460	849	38	32,066	2,321	97
Nonmetropolitan Lower Saxony	1,113	91	58,420	4,971	194	209,501	14,482	533
Nonmetropolitan North Rhine-Westphalia	1,131	29	100,767	8,681	372	341,447	23,928	975
Nonmetropolitan Rhineland-Palatinate	546	90	52,471	4,450	180	181,749	12,543	483
Nonmetropolitan Saarland	30	-	4,369	366	17	13,762	930	41
Nonmetropolitan Saxony	267	13	19,858	1,897	95	66,317	5,173	242
Nonmetropolitan Saxony-Anhalt	231	25	19,309	1,780	84	65,066	4,867	215
Nonmetropolitan Schleswig-Holstein	361	13	13,563	1,147	44	48,569	3,363	123
Nonmetropolitan Thuringia	512	45	28,668	2,609	122	96,607	7,158	314
All metropolitan areas	15,547	1,440	1,565,153	140,112	6,434	5,375,883	398,226	17,198
All nonmetropolitan areas	8,546	681	583,584	51,175	2,194	2,015,410	144,064	5,831
Germany total	24,093	2,121	2,148,738	191,288	8,629	7,391,293	542,290	23,029