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Charging infrastructure in cities: Metrics for evaluating future needs

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Introduction

Local governments are motivated to set long-term charging infrastructure targets to achieve their electric vehicle goals. These targets have traditionally been indexed to the number of vehicles. Research has identified more advanced approaches to setting charging metrics, but these require more data and are more difficult to continuously monitor.

Increasingly, governments around the world are working to address one of the key barriers preventing widespread electric vehicle uptake: charging infrastructure. Governments at the local, regional, and national level have provided financial support to homeowners and companies, instituted supportive building codes, and convened multi-stakeholder initiatives to coordinate investments. As the urgency to shift toward electric vehicles grows, governments are searching for new solutions to ensure that charging infrastructure accelerates, rather than restricts, electric vehicle uptake.

There has been steady global progress in building the necessary charging infrastructure to power electric vehicles. Figure 1 shows the growth in cumulative global electric vehicle sales and public electric vehicle chargers between 2011 and 2019. Light-duty electric vehicle sales grew to over 7 million by the end of 2019.[1] Public charging infrastructure has averaged over 60% growth annually over the same span to reach almost 900,000 chargers at the end of 2019.[2] These trends are inter-related: broader availability of

1 EV-Volumes (EV Data Center, 2020), http://www.ev-volumes.com/datacenter/.

2 Sources include European Alternative Fuels Observatory (EAFO) (Charging infrastructure counts, updated January 2020), https://www.eafo.eu/alternative-fuels/electricity/charging-infra-stats; Alternative Fuels Data Center (AFDC) (Electric Vehicle Charging Station Locations, updated January 2020), https://afdc.energy.gov/fuels/electricity_locations.html#/find/nearest?fuel=ELEC; China Electric Vehicle Charging Infrastructure Promotion Alliance (EVCIPA) (Distribution of public charging piles by province, updated March 2020), http://www.evcipa.org.cn/.

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charging increases electric vehicle drivers' confidence, and more electric drivers encourage governments, industry, and property owners to install charging stations.

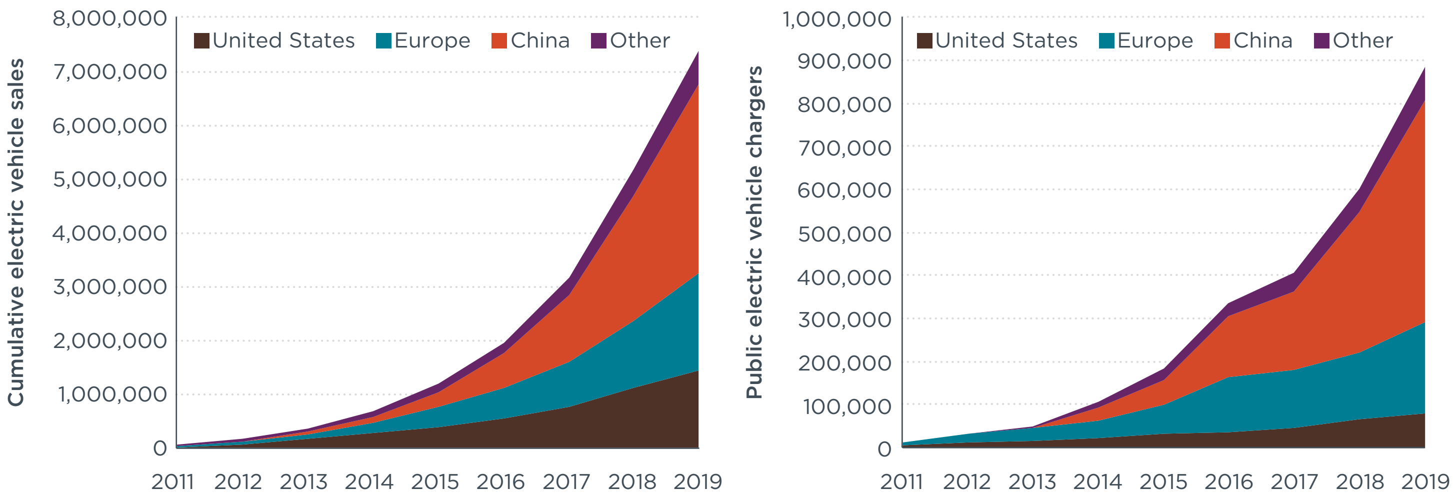

Figure 1. Global electric vehicles and public electric vehicle chargers.

Although it is relatively simple to identify the general global trend, tracking, measuring, and comparing the relative city-by-city progress on electric vehicle infrastructure is more difficult. The 25 largest electric metropolitan area markets, with 43% of the world's electric vehicles, have a diverse range of public charging infrastructure networks in place.[3] Even when adjusting for each city's number of electric vehicles, overall population, and population density, there are no simple one-size-fits-all metrics that define the ideal amount of charging infrastructure. The reasons for this include differing percentages of households with overnight private charging, power grids that vary in their regulatory structures and electrical specifications, different driving patterns, and a diverse mix of battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV) models. Nonetheless, comparisons of charging infrastructure growth rates, ratios, and densities allow for quantitative tracking of progress in the availability and coverage in metropolitan regions.

This working paper identifies metrics that cities can use to track charging infrastructure policies and deployment to support electrification goals in cities. Using the most recent available electric vehicle and charging infrastructure data, this paper analyzes how electric vehicle per charger ratios are evolving, the relationship between public charging and housing type, and considers the contrasting needs for public charging networks in the early versus mature markets. Best practice policies to grow the charging infrastructure network are identified to illustrate how these lessons can be used to estimate future charging needs.

3 Dale Hall, Hongyang Cui, and Nic Lutsey, *Electric vehicle capitals: Showing the path to a mainstream market,* (ICCT: Washington DC, 2019), https://theicct.org/publications/ev-capitals-of-the-world-2019.

Review of charging metrics in policy and literature

Governments and researchers have used several methods to assess the status of charging infrastructure buildout. Table 1 below identifies four of the metrics most frequently used in public charging infrastructure plans.

Table 1. Typical metrics for evaluating public charging infrastructure and policy examples.

Metric	Policy example
Chargers	**Germany:** 1 million public charge points by 2030 [a] **Region of Ile-de-France (France):** 12,000 chargers by 2023 [b]
Chargers per square kilometer	**State of Baden-Württemberg (Germany):** Minimum public charger coverage of one 20 kW charger in every 10x10 km grid and one 55 kW charger in every 20x20 km grid [c]
Chargers per kilometer of road	**United Kingdom:** 95% of motorways and A-roads should be within 20 miles of a charger [d]
Electric vehicles per charger	**France:** One charging station for every 10 electric vehicles [e]

[a] "Masterplan Ladeinfrastruktur der Bundesregierung [Master plan for charging infrastructure for the Federal Republic]," German Federal Ministry of Transport and Digital Infrastructure, https://www.bmvi.de/SharedDocs/DE/Anlage/G/masterplan-ladeinfrastruktur.pdf?__blob=publicationFile.

[b] "En Ile-de-France, le nombre de bornes de recharge va tripler d'ici 2023 [In Ile-de-France, the number of charging stations will triple by 2023]," AVERE France, December 4, 2019, http://www.avere-france.org/Site/Article/?article_id=7752.

[c] "SAFE BW," e-mobil BW, GmbH, Accessed February 28, 2020, https://www.e-mobilbw.de/safe.

[d] "Major charger contract to benefit electric vehicle users ," Highways England, March 7, 2019, https://www.gov.uk/government/news/major-charging-point-contract-to-benefit-electric-vehicle-users.

[e] "Contrat stratégique de la filière Automobile 2018-2022 [Auto sector strategic contract 2018-2022]," Conseil National de l'Industrie, http://www.pfa-auto.fr/wp-content/uploads/2018/06/DP-SCF-Automobile.pdf.

Metrics used to measure progress toward government targets typically focus on normalizing charging infrastructure by population, land, or vehicle stock, making them convenient for tracking and comparing infrastructure developments from year to year. Each of these metrics offers important information for tracking the development of an expanding charging network and identifying infrastructure and policy gaps, and can be calculated using easy-to-access data.

These simple metrics have several limitations. Many metrics do not distinguish between slower AC chargers and DC fast chargers, although one DC fast charger can charge many more vehicles per day than an AC point. In addition, the metrics do not distinguish among different types of electric vehicles. PHEVs typically can only use AC chargers, while BEVs can also use DC fast charging. The makeup of a market's electric vehicle fleet therefore influences the optimal amount of AC versus DC charging. Additionally, such targets do not account for important local factors like differing housing types and car ownership rates, further making it difficult to compare even markets of similar electric vehicle uptake. The metric of chargers per road distance does not account for traffic volumes on those roads, making it more useful for assessing coverage in early stages of the market to provide basic geographic coverage.

More complex metrics for tracking charging infrastructure progress have been used in academic research. As part of an assessment to create European targets for charging infrastructure through 2030, Transport & Environment created a "supply metric," which weights chargers based on their power, ranging from 1 point for AC chargers delivering 3-7 kW to 10 points for a DC fast charger delivering 150 kW or more, as well as their accessibility in terms of hours of public access per day.[4] Based on local travel data, Kontou, Liu, Xie, and Wu developed a "charging opportunity" metric based on local travel data, which expresses the likelihood that drivers will find a charger during typical daily travel.[5] The European Joint Research Centre (JRC) has developed a methodology to assess charging network sufficiency and efficiency based on eight inputs, including utilization, spatial concentration, and energy use.[6] The German Ministry for Transport and Digital Infrastructure developed the "StandortTOOL" to indicate where and how much charging infrastructure may be needed through 2030 according to travel demand and market dynamics.[7] When all necessary data is available, cities may benefit from using advanced metrics such as the StandortTOOL or JRC method; however, the greater data requirements and customization make it more challenging to track development across different jurisdictions or timescales.

Electric vehicle charging deployment in Europe

The Netherlands and Norway lead Europe in public charging deployment, with charger density generally correlated with electric vehicle uptake. Electric vehicle-per-charger ratios vary widely across Europe, ranging from 3 to 30, with denser cities and markets with more BEVs typically having lower ratios.

By the end of 2019, there were approximately 193,000 public chargers in Europe, with about 11% of those being DC fast chargers.[8] However, charging infrastructure deployment is uneven across the region, displaying variation at the national and local level. The Netherlands, with 50,000 public chargers, had the most chargers on an absolute basis, followed by Germany (40,000) and France (29,000). When adjusted for population, the Netherlands also leads at 2,200 public chargers per million population, followed by Norway (2,150), Sweden (690) and Germany (510). The percentage of public chargers that are DC fast ranged from 3% in the Netherlands to 23% in Norway.

While useful for comparing high-level deployment, national-level statistics do little to reveal the relationship between charging infrastructure and electric vehicle uptake, nor are they useful for establishing city-level policy guidance. Electric vehicle charging ecosystems are shaped at a regional level, as most driving takes place within a metropolitan region, and charging needs are shaped by driving and charging behavior, housing stock, and land use. Therefore, this analysis is focused on charging at the local level using Nomenclature of Territorial Units for Statistics third-level (NUTS3) areas and metropolitan regions composed of one or more NUTS3 areas.[9] Charging infrastructure

4 Lucien Mathieu, *Recharge EU: How many charge points will Europe and its Member States need in the 2020s,* (Transport & Environment: Brussels, 2020), https://www.transportenvironment.org/publications/recharge-eu-how-many-charge-points-will-eu-countries-need-2030.

5 Eleftheria Kontou, Changzhen Liu, Fei Xie, & Xing Wu. "Understanding the linkage between electric vehicle charging network coverage and charging opportunity using GPS travel data." Transportation Research Part C 98 (2019): 1-13. https://www.sciencedirect.com/science/article/pii/S0968090X18305539.

6 Alexandre Lucas, Giuseppe Prettico, Marco Giacomo Flammini, Evangelos Kotsakis, Gianluca Fulli, and Marcelo Masera. "Indicator-Based Methodology for Assessing EV Charging Infrastructure Using Exploratory Data Analysis." Energies 11:7 (2018). https://www.mdpi.com/1996-1073/11/7/1869/htm.

7 Bundesministerium für Verkehr und digitale Infrastruktur, "Ausbaupotenzial – StandortTOOL," accessed April 21, 2020, https://www.standorttool.de/strom/ausbaupotenzial/.

8 Europe as defined by the European Union plus the European Free Trade Area as of January 1, 2020. Data from European Alternative Fuels Observatory (EAFO) (Charging infrastructure counts, updated January 2020), https://www.eafo.eu/alternative-fuels/electricity/charging-infra-stats.

9 For more information, see information on Nomenclature of Territorial Units for Statistics (NUTS) classification and Metropolitan regions: "Regions and cities – Overview," Eurostat, accessed February 24, 2020, https://ec.europa.eu/eurostat/web/regions-and-cities/overview.

data at a subnational level were derived from several sources in order to create a comprehensive data set, as described in Table 2.

Table 2. Charging infrastructure data sources by country.

Country	Data sources
Austria	LEMnet[a]
Belgium	Open Charge Map,[b] LEMnet
Denmark	LEMnet
Finland	Nobil,[c] Open Charge Map
Germany	LEMnet, Open Charge Map, Bundesnetzagentur[d]
Ireland	Open Charge Map
Netherlands	RVO[e]
Norway	Nobil
Spain	Electromaps[f]
Sweden	Nobil, Open Charge Map
Switzerland	LEMnet
United Kingdom	Open Charge Map, OLEV[g]

[a] LEMNET e.V. (Directory of charging stations, updated January 2020), https://www.lemnet.org/en.

[b] Open Charge Map (Public registry of electric vehicle charging stations, updated January 2020), https://openchargemap.org/site/develop#api.

[c] Nobil (Charging infrastructure data, updated January 2020), https://info.nobil.no/api.

[d] Bundesnetzagentur (Ladesäulenkarte, updated January 2020), https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/HandelundVertrieb/Ladesaeulenkarte/Ladesaeulenkarte_node.html.

[e] Netherlands Enterprise Agency (Charging points data, updated December 2019), personal correspondence.

[f] Electromaps (Charging stations in Spain, updated March 2020), https://www.electromaps.com/en/charging-stations/espana.

[g] Office for Low Emission Vehicles (OLEV) (National Chargepoint Registry, updated January 2020), https://data.gov.uk/dataset/1ce239a6-d720-4305-ab52-17793fedfac3/national-charge-point-registry.

Figure 2 illustrates public charging infrastructure deployment through 2019, measured in chargers per million population, at the NUTS 3 level in 12 European countries. Darker red illustrates a greater concentration of chargers. Some countries were excluded due to lack of consistent data.

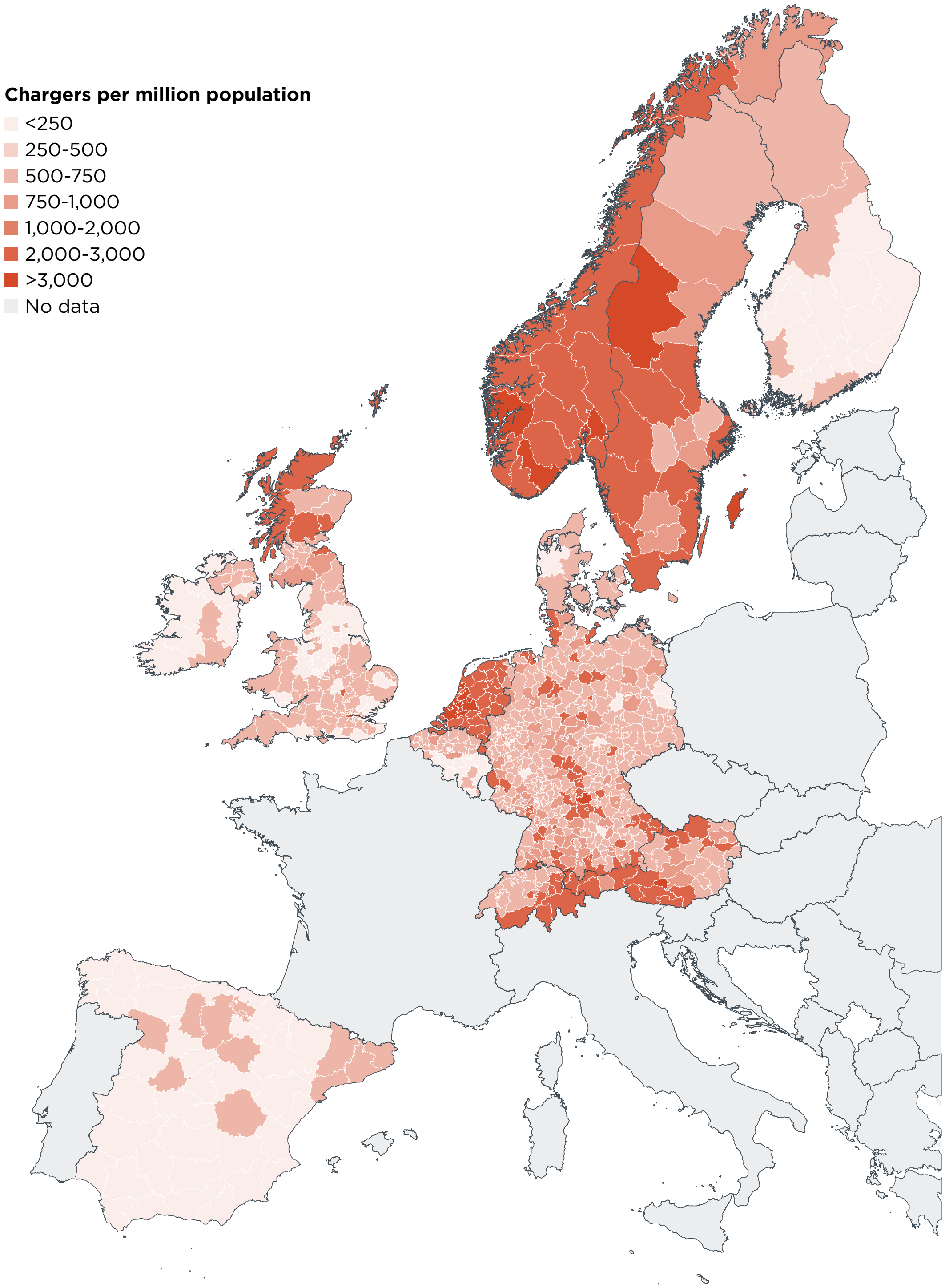

Figure 2. Public chargers per million population in 12 European countries by NUTS3 levels.

This visualization offers several high-level observations. The countries with the most public chargers per population are the Netherlands with 2,940 chargers per million population (pmp), Norway with 2,560 pmp, and Sweden with 1,020 pmp. These three countries also had the highest electric vehicle sales shares among countries in Europe in 2019. The figure also shows several regional distinctions within countries. For example, some regions in Scotland tend to have greater charging availability than in the rest of the United Kingdom, southern and eastern Switzerland have higher availability than other parts of the country, and Catalonia has more chargers than other parts of Spain. Regions in northern and western Europe most commonly have about 250-500 public chargers per million population.

Electric vehicle-per-charger ratios

Normalizing local-level electric vehicle and charger data to population reveals differing charging infrastructure development across markets. Figure 3 compares public chargers per million population (vertical axis) and cumulative electric vehicle registrations per million population (horizontal axis). The sizes of the circles indicate the cumulative electric vehicles registered in each metropolitan region. The relative position of each bubble indicates not only the concentration of chargers and electric vehicles, but also the ratio of electric vehicles per charger: metropolitan regions closer to the upper left have a lower number of vehicles per charger, while those toward the bottom of the chart have a higher ratio. The figure also includes four lines illustrating ratios of 5, 10, 20, and 40 electric vehicles per charger. Electric vehicle registration data comes from Hall, 2020;[10] this data does not account for electric vehicle scrappage or flows of electric vehicles into and out of metropolitan regions.

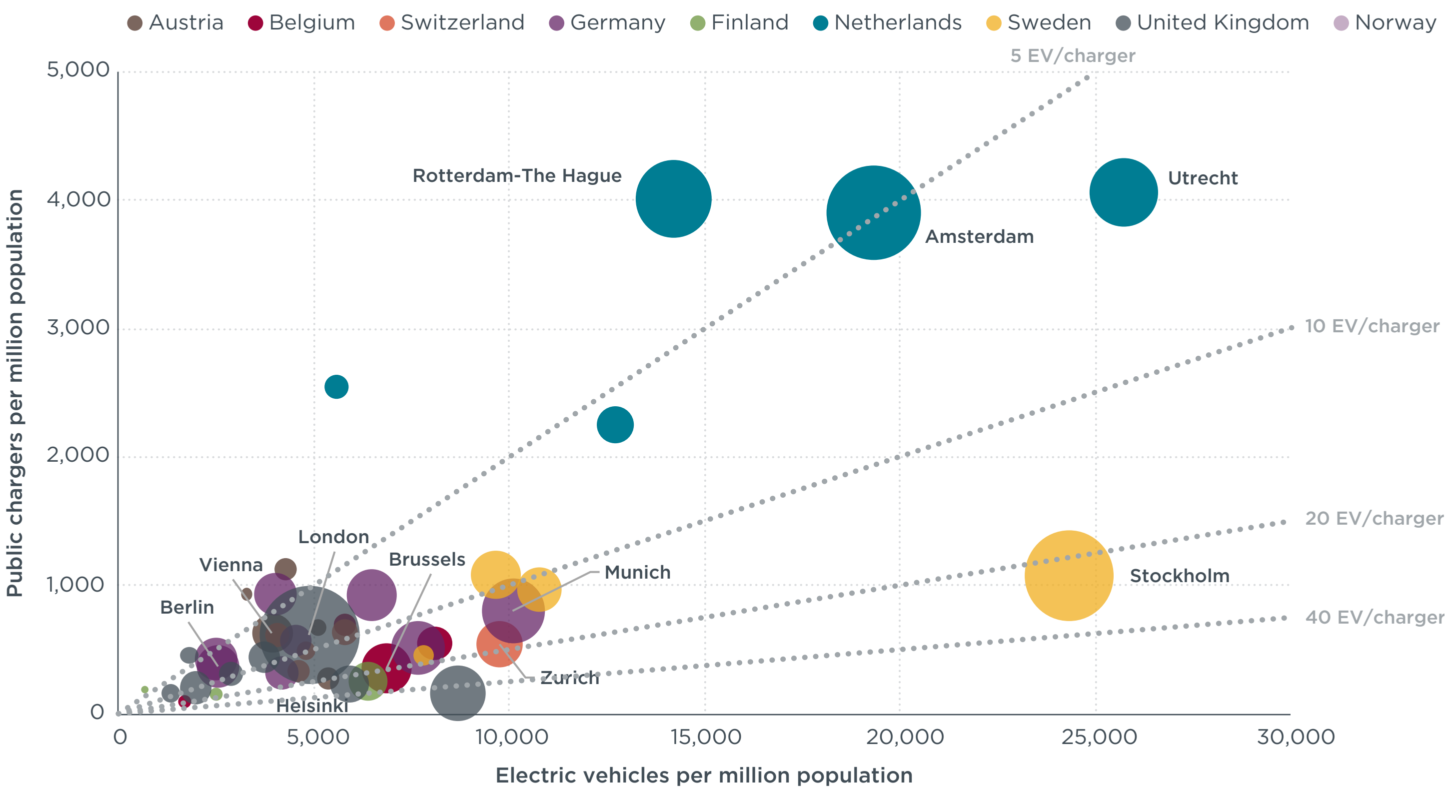

Figure 3. Charging infrastructure and electric vehicles concentration in major metropolitan regions.

The figure illustrates that charging ecosystems are disparate even among Europe's leading electric vehicle markets. Metropolitan regions in the Netherlands tend to have the highest levels of charging availability and the lowest ratios of electric vehicles per public charger, generally between two and seven, although they have a lower share of

10 Dale Hall et al., "European Electric Vehicle Factbook 2019/2020" (ICCT: Washington, D.C., 2020), https://theicct.org/publications/european-electric-vehicle-factbook-20192020.

DC fast charging than the European average. Other metropolitan regions, such as those in Finland and some in the United Kingdom, tend to have much higher electric vehicle/charger ratios, often around 40 electric vehicles per public charger. Oslo and Bergen in Norway, not pictured in this figure, have 60,000 and 100,000 electric vehicles per million population, and 2,500 and 4,000 public chargers per million population, resulting in ratios of 20 and 25 electric vehicles per charger, respectively.

In comparison to a previous analysis of data through 2016, distinctive trends at the national level have become less pronounced.[11] Instead, there is more variation within each market based on city size (larger, denser metropolitan regions tend to have lower ratios) and electric vehicle penetration level (more advanced markets tend to have lower ratios). Across Europe, a large share of metropolitan regions falls in the range of 10-20 electric vehicles per public charger, although metropolitan regions in the Netherlands remain a notable outlier. In comparison, metropolitan areas in the United States tend to have greater electric vehicle per public charger ratios (typically from 20-30 in the leading markets) and also display a clear trend of supporting more electric vehicles per public charger as electric vehicle penetration increases.[12]

Figure 4 provides additional detail on selected metropolitan regions, highlighting the largest cities for which local-level data was available. The bars illustrate the number of chargers adjusted for population. The blue markers, corresponding to the right axis, indicate the ratio of electric vehicles per public charger.

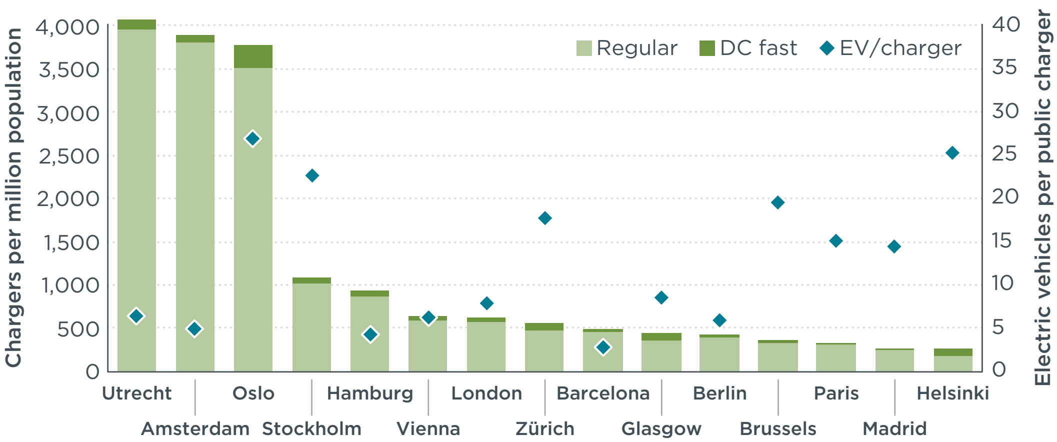

Figure 4. Chargers per million population and electric vehicles per charger in selected major metropolitan regions.

The figure further underscores the gap in charging density between metropolitan regions in the Netherlands and Norway compared to the rest of Europe—the number of chargers per capita in Oslo, Amsterdam, and Utrecht is over three times that of any other metropolitan region. In the case of Oslo, the electric vehicle market is much more developed than in other parts of Europe, with a 64% electric share compared to 5% Europe wide average. In Utrecht and Amsterdam, the electric share is not as high as in Oslo, but the charging needs are greater due to the low availability of home charging,

11 Dale Hall and Nic Lutsey, *Emerging best practices for electric vehicle charging infrastructure,* (ICCT: Washington DC, 2019), https://theicct.org/publications/emerging-best-practices-electric-vehicle-charging-infrastructure.

12 Michael Nicholas, Dale Hall, and Nic Lutsey, "Quantifying the Electric Vehicle Charging Infrastructure Gap across U.S. Markets" (Washington, D.C.: International Council on Clean Transportation, January 23, 2019), https://theicct.org/publications/charging-gap-US.

which is discussed further below. The wide variation in the electric vehicles per charger ratio is also apparent, ranging from 4 to 6 in Barcelona, Amsterdam, Hamburg, Vienna, and Berlin, to between 23 and 26 in Oslo, Stockholm, and Helsinki. Those three Nordic cities each had higher-than-average electric vehicle uptake; Stockholm and Helsinki also have more PHEVs, which are less reliant on public charging.

Finally, Figure 4 also illustrates the wide variation in the percent of chargers that are DC fast among the selected metropolitan regions. In most markets, the DC fast share of public charging was below 10%. However, Helsinki (29%), Glasgow (18%), and Zurich (15%) had higher shares of DC fast charging. This shows that while DC fast charging is a critical component of the charging ecosystem, most regions have focused on regular-speed charging within urban areas. This trend may shift as ultra-fast charging becomes more widespread and high-mileage applications, such as taxis, increase the demand for fast charging in urban cores.

Impact of housing type on charging demand

The share of a city's housing stock that is comprised of apartment buildings serves as a proxy for access to home charging. With other factors equal, denser cities with more apartment-dwellers will have a lower electric vehicle-per-charger ratio.

While this analysis focuses primarily on public charging, private charging at home and at work accounts for the majority of charging energy for electric vehicles, with some variability across markets.[13] Because all types of charging function together in an ecosystem, understanding the relationships between home charging and public charging usage is crucial to projecting future public charging needs at a local level. Access to home charging is driven largely by local housing patterns. Those in single-family homes are much more likely to have convenient access to home charging; those in apartment buildings will need more public charging as an alternative. While differences in data reporting make international comparisons difficult, patterns are observed within markets.

The Netherlands, with high electric vehicle penetration, a similar BEV/PHEV mix nationwide, and national and local programs to promote charging deployment,[14] provides a strong example of the effect of housing patterns on charging needs. Figure 5 compares public charger availability with the share of residents living in multi-unit dwellings in each NUTS3 area in the Netherlands.[15] The bars illustrate chargers per million population (left axis), while the red markers shows the percent of residents in multi-unit dwellings (right axis). For reference, the Netherlands overall has approximately 2,900 chargers per million population, 2% of which are DC fast chargers, and 36% of the country's residents live in multi-dwelling units.

13 Dale Hall and Nic Lutsey, *Electric vehicle charging guide for cities,* (ICCT: Washington DC, 2020), https://theicct.org/publications/city-EV-charging-guide.

14 Ministry of Economic Affairs, "Vision on the Charging Infrastructure for Electric Transport" (The Hague, April 2017), rvo.nl/sites/default/files/2017/05/Vision%20on%20the%20charging%20infrastructure%20for%20electric%20transport.pdf.

15 CBS StatLine (Netherlands housing stock data, updated March 2020), https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82550NED/table.

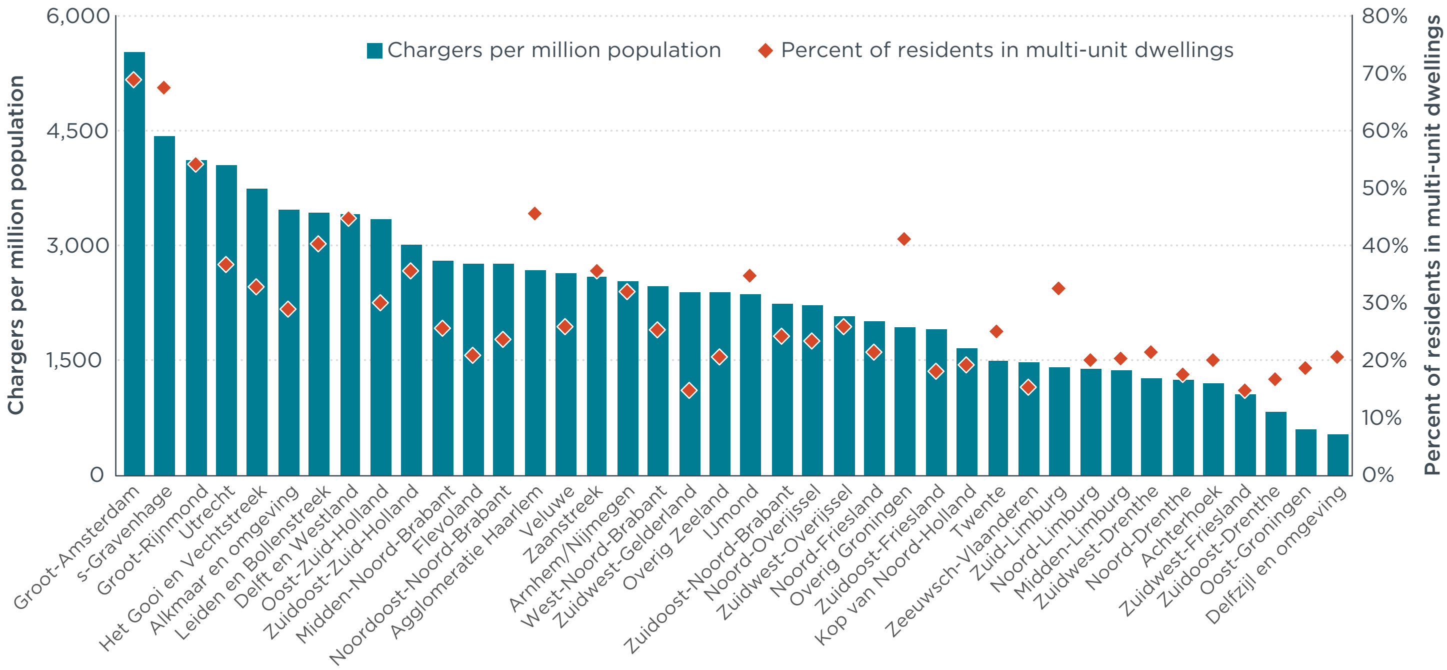

Figure 5. Charging infrastructure per million population and apartment share in NUTS3 regions in the Netherlands.

Despite some exceptions, the figure shows a clear overall trend whereby regions with more apartment dwellers have greater public charging deployments. The three regions with the highest shares of apartment dwellers, Amsterdam (Groot-Amsterdam), the Hague (s-Gravenhage), and Rotterdam (Groot-Rijnmond), are also the three regions with the highest public charging availability. In fact, the impact of housing stock could be understated by this relationship: the regions in the Netherlands with a higher multi-unit dwelling share also have a lower rate of car ownership, which means that the charging infrastructure per vehicle ratio would be disproportionately higher.[16] The higher concentrations of chargers in these major cities could also be a reflection of the sustained local policies to construct charging infrastructure, which could in turn be a demonstration of electric vehicle owners' sustained demand for increased charging infrastructure.

Major Dutch cities have promoted public charging explicitly as a solution for urban drivers without access to private home charging. Amsterdam, in partnership with power company Nuon, has built curbside charging infrastructure primarily designed to be used by local residents, a program which has been replicated and expanded upon by other major cities such as Rotterdam and Utrecht.[17] The power companies and municipalities in the Netherlands have created fewer wide-scale programs for fast charging. As a result, the numbers of fast chargers per capita in the Dutch metropolitan regions are similar to those in other metropolitan regions in the United Kingdom, Germany, or Finland, and DC fast charging accounts for only 1%-3% of public chargers in Dutch metropolitan regions.

In contrast, other dense cities outside the Netherlands, including London and New York City, are focusing on fast charging "hubs" or "plazas" to enable charging for residents

16 Based on Eurostat (Stock of vehicles by category and NUTS 2 regions, updated April 2020), https://ec.europa.eu/eurostat/statistics-explained/index.php/Stock_of_vehicles_at_regional_level.

17 Julie Chenadec, "Amsterdam's demand-driven charging infrastructure," (Interreg Europe), accessed March 5, 2020, https://www.interregeurope.eu/policylearning/good-practices/item/1699/amsterdam-s-demand-driven-charging-infrastructure/.

and fleets such as taxis and delivery vehicles, which requires less land and fewer separate construction projects. Cities with a higher share of DC fast charging will likely have higher electric vehicle per public charger ratios, as one fast charger can serve as many vehicles as several regular chargers. This accentuates the importance of more nuanced market-specific metrics that acknowledge the value of both types of charger deployment.

Planning charging for coverage versus capacity

As electric vehicles become mainstream, each public charger will be able to serve more vehicles than in the early stage of the market due to improved utilization. Consequently, the rate at which new public chargers are needed may decrease.

Charging infrastructure needs and related policy goals vary depending on the stage of market growth. During the early stages of the transition, when there is lower demand to support a private business case, governments often focus on building out basic spatial coverage of charging infrastructure. Many of these stations will likely face low utilization with limited numbers of electric vehicles on the road but are important for encouraging greater range confidence and promoting awareness of electric vehicles. As the market grows, the demand for charging in urban areas and along major travel corridors far outstrips the capabilities of the initial stations. At that point, planning for new public chargers will be based on ensuring sufficient charging capacity at the most popular locations. This typically leads to larger stations with more chargers per location.[18] As charger utilization grows with electric vehicle adoption, so does the number of electric vehicles per charger. The utilization increase encourages more private investment in charging infrastructure.

While many other factors make international comparisons difficult, this trend can be seen when comparing metropolitan regions within countries. The United Kingdom provides an example of how fewer chargers may be needed per electric vehicle at different stages of market development. Figure 6 plots the electric vehicle penetration in cumulative electric vehicle registrations per million people in the 27 largest metropolitan regions in the United Kingdom, with the most populous regions and those with the highest electric vehicle uptake labeled. As shown, markets like Glasgow, Bristol, and Belfast were closer to the UK average in electric vehicle penetration and had 8-20 electric vehicles per public charger. Markets like Leeds and Birmingham have grown to about twice as many electric vehicles per capita as the UK average and have had approximately 25-35 electric vehicles per charger.

18 Mike Nicholas and Dale Hall, *Lessons learned on early electric vehicle fast-charging deployments,* (ICCT: Washington DC, 2018), https://theicct.org/publications/fast-charging-lessons-learned.

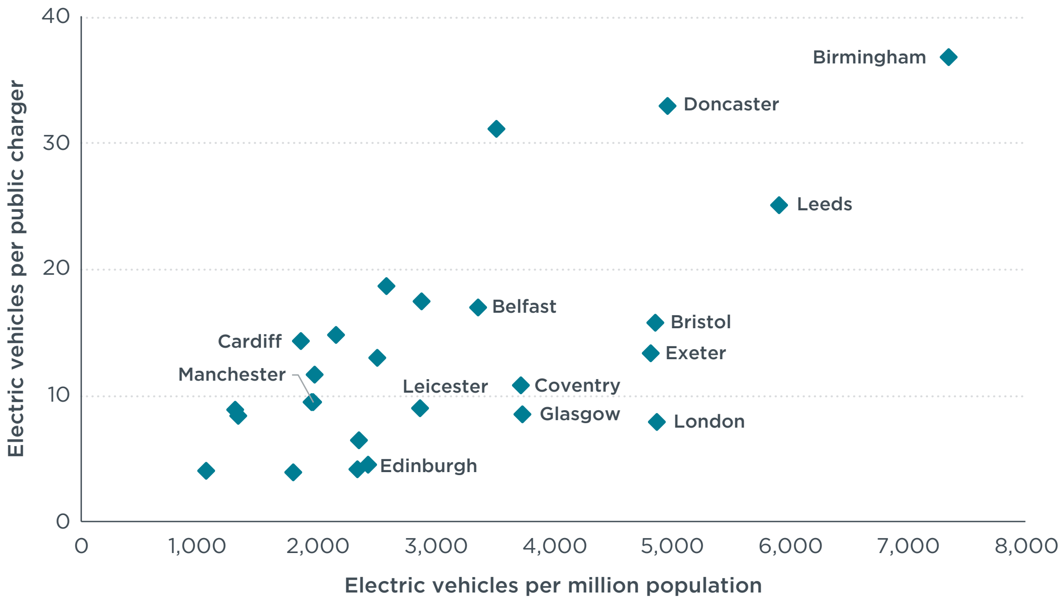

Figure 6. Electric vehicle per charger ratios in the 27 largest UK metropolitan regions

As shown in Figure 6, there is a clear relationship between these two factors for these regions, with more advanced markets in terms of electric vehicles per million population generally having significantly higher charging ratios. A similar relationship has been observed in other markets, such as the United States.[19] Nonetheless, this does not suggest that the ratios can grow indefinitely as the market continues to develop; on the contrary, infrastructure may be lagging in some of the more advanced markets where uptake has grown more quickly. Some research suggests that a charger utilization (related to the electric vehicle per charger ratio) will begin to plateau as uptake increases.[20]

This trend can also be seen when comparing the development of electric vehicle markets over time. Figure 7 shows the growth of electric vehicle stock and public chargers in eight of the largest and fastest-growing metropolitan region electric vehicle markets in the United Kingdom from 2017 to 2019. The vertical axis tracks public chargers, both regular and fast, per million population, while the horizontal axis tracks cumulative battery electric and plug-in hybrid vehicles sales per million population. For each region, the sequence of years (2017, 2018, and 2019) are from left to right. The slopes of the lines indicate that five of the eight selected UK markets had about 10-20 electric vehicles per charger in 2019, while London, Leicester, and Edinburgh had fewer than 10 electric vehicles per charger. The Figure 7 trends indicate that even as growth to a more efficient charger network persists (per Figure 6), regions are likely to have their own unique electric vehicle market and charging patterns.

19 Peter Slowik and Nic Lutsey, *The surge of electric vehicles in United States cities,* (ICCT: Washington DC, 2019), https://theicct.org/publications/surge-EVs-US-cities-2019.

20 Mike Nicholas, Dale Hall, and Nic Lutsey, *Quantifying the electric vehicle charging infrastructure gap across U.S. markets,* (ICCT: Washington DC, 2019), https://theicct.org/publications/charging-gap-US.

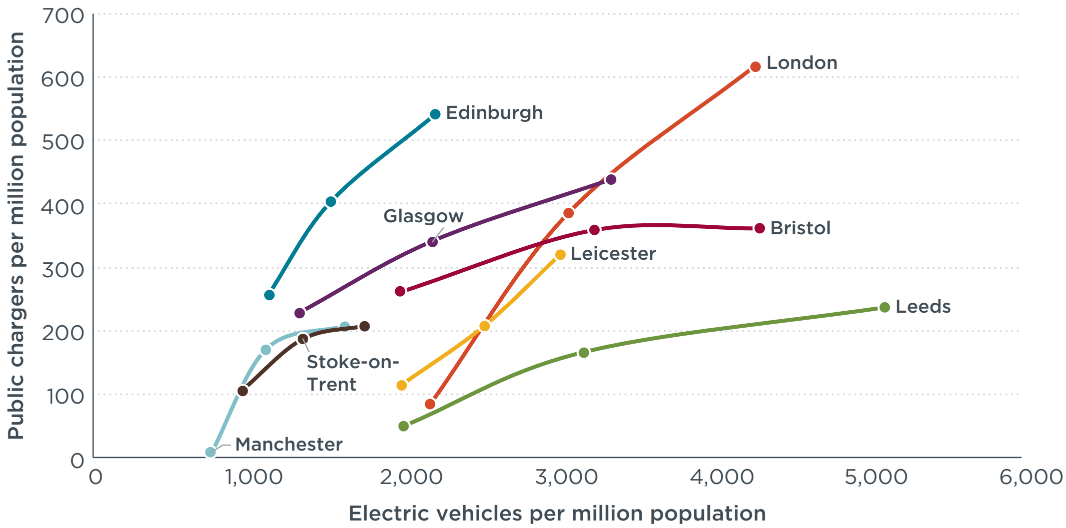

Figure 7. Electric vehicle market growth in selected UK metropolitan regions, 2017-2019.

The figure shows that the electric vehicle markets and public charging networks have grown together over the past three years in the selected regions. For comparison, the UK electric vehicle share of new vehicles during that time more than doubled from 1.4% in 2017 to 3.1% in 2019, and the BEV share more than tripled from 0.5% to 1.6%. However, for 7 of the 8 markets, with the exception of Leicester, the lines curve downward, meaning that the ratio of electric vehicles per public charger increased from 2018 to 2019 as electric vehicle sales grew at a greater rate than chargers. Although there are annual fluctuations in charging deployments, market conditions, and data recording practices, this trend indicates that charging infrastructure networks are becoming more efficient over time. Still, public charging will need to greatly expand to support electric vehicle market growth.

Future charging targets in cities

According to projections for future public charging needs through 2030 in Amsterdam, London, and Berlin, public charger counts will need to grow by 25-35% annually over the 2020-2030 period.

The trends and metrics evaluated above enable not only a comparison of cities' charging networks through 2019, but also provide a way to identify future charging infrastructure targets. In this section, the above dynamics are applied to estimate public charging needs through 2030 in three major European electric vehicle markets: Amsterdam, London, and Berlin. These estimated charging targets are based on local and national electric vehicle goals, observed market dynamics, the mix of charging by type across European markets, and local housing factors in order to create an approximate picture of the charging ecosystem necessary to support a broad transition. Such estimates can continue to be refined as the electric vehicle market grows, more charging data are assessed, and comprehensive charging infrastructure actions are developed.[21]

21 Dale Hall and Nic Lutsey, *Electric vehicle charging guide for cities,* (ICCT: Washington DC, 2020), https://theicct.org/publications/city-EV-charging-guide.

Amsterdam

A perennial global leader in electric vehicles and charging infrastructure, Amsterdam has ambitious goals to further accelerate its shift to electric vehicles. The city has committed to making 100% of the city's traffic zero-emissions by 2030, following targets for zero-emissions transport within specific areas and modes in 2022 and 2025.[22] While Amsterdam already has the highest concentration of charging per capita in Europe, much more will be needed to achieve the city's goal of 100% zero-emission traffic.

Applying lessons from the previously discussed trends in Europe, we can estimate the approximate scale of charging needed to support the electric vehicle growth. In this scenario, we assume that all new passenger vehicle sales in greater Amsterdam will be electric beginning in 2025, with a steep ramp-up before then, leading to approximately 400,000 electric vehicles in the metropolitan region by 2025 and 1 million by 2030. As there were 2.9 million passenger cars in the region in 2017, the uptake could be higher in order to enable access to the city for remaining drivers. We further assume that electric vehicle sales will continue to trend toward BEVs, meaning that by 2030, the electric vehicle fleet will be fully battery electric.

Figure 8 illustrates a scenario for the deployment of public charging in Amsterdam to support this future electric vehicle growth. The brown wedge shows future deployment of public regular AC chargers, while the smaller blue wedge shows DC fast chargers. In total, this scenario amounts to 58,000 public chargers in 2025, with about 3% of those being DC fast, and over 103,000 chargers by 2030, with 4% being DC fast. This compares to 12,700 public chargers installed in the region as of the end of 2019, 2.3% of which are DC fast. The annual growth rate in chargers is highest in the years 2020-2024 at 35%, when the electric vehicle stock is predicted to increase 45% annually over the same period. From 2026 to 2030, the rate of growth slows to a 13% annual increase in public chargers and a 20% annual increase in electric vehicle stock.

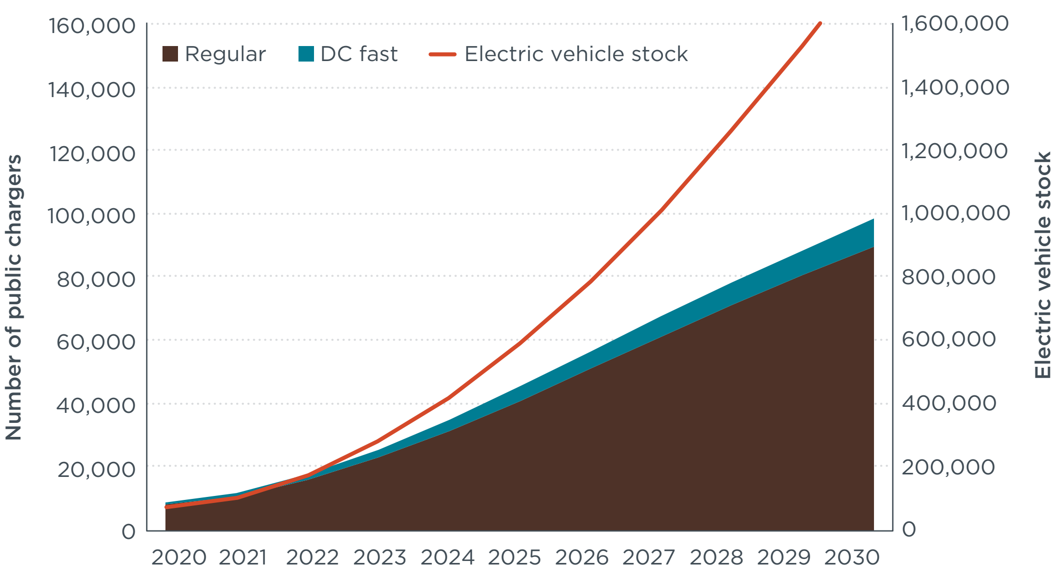

Figure 8. Projected charging infrastructure and electric vehicle growth in the Amsterdam region through 2030.

22 "Clean Air Action Plan," (City of Amsterdam: 2019), https://www.amsterdam.nl/en/policy/sustainability/clean-air/.

We emphasize that this is just one possible scenario for future charger needs, based on trends seen in other leading electric vehicle markets of increasing electric vehicle-to-charger ratios and a shift toward DC fast charging. The scenario implicitly accounts for Amsterdam's lack of private residential parking, which limits the increase in the ratio, and extends the historical emphasis on providing curbside AC charging. If Amsterdam were to continue with its 2019 mix of DC fast and Level 2 charging through 2030, 12,000 more regular charging points would be needed. An increase of DC fast charging of up to 10% in 2030 would instead result in a mix of 82,000 regular chargers and 9,100 DC fast. This does not take into account the option of installing significantly more private home and workplace charging, which would result in less need for public charging of all types.

London

London, the leading electric vehicle market within the United Kingdom in terms of total electric vehicle sales, has strong ambitions to further grow its electric vehicle share to meet air quality and climate targets. This includes creating a central city zero-emission zone by 2025 and transitioning the city's thousands of black cabs to zero-emission capable. Furthermore, the government of the United Kingdom has proposed moving up their target for the end of new combustion vehicle sales, including all hybrids to 2035.[23] The amount of charging infrastructure in the London region will need to significantly increase in order to meet these targets.

The number of public chargers needed to support these accelerating electric vehicle sales through 2030 are estimated for Greater London. This charger growth is shown in Figure 9, with regular AC chargers in brown and DC fast (typically called "rapid" in the UK) in blue. Electric vehicle stock, comprised of both BEVs and PHEVs is shown on the right line, corresponding to the right-hand axis. This scenario supports electric vehicle sales share growth to 55% in 2025 and 100% by 2030, with a gradual shift toward BEVs from 58% of the electric stock in 2019 to 80% in 2030. We also assume that new passenger car sales within Greater London will decline by 7% annually in accordance with the Mayor's Transport Strategy.[24] We assume an increase in DC fast charging from 5% of chargers in 2019 to 8% by 2023, reflecting the increased focus on this technology to supply taxis, private-hire vehicles, and delivery vehicles. In total, this amounts to approximately 60,000 public AC chargers and 4,900 public DC chargers by 2030 across Greater London.

23 Office for Low Emission Vehicles, "Consulting on Ending the Sale of New Petrol, Diesel and Hybrid Cars and Vans," GOV.UK, accessed May 1, 2020, https://www.gov.uk/government/consultations/consulting-on-ending-the-sale-of-new-petrol-diesel-and-hybrid-cars-and-vans.

24 Transport for London, "Mayor's Transport Strategy: Supporting Evidence" (London, July 2017), https://consultations.tfl.gov.uk/policy/9b28c200/user_uploads/mts-outcomes-summary-report---full-report-final.pdf.

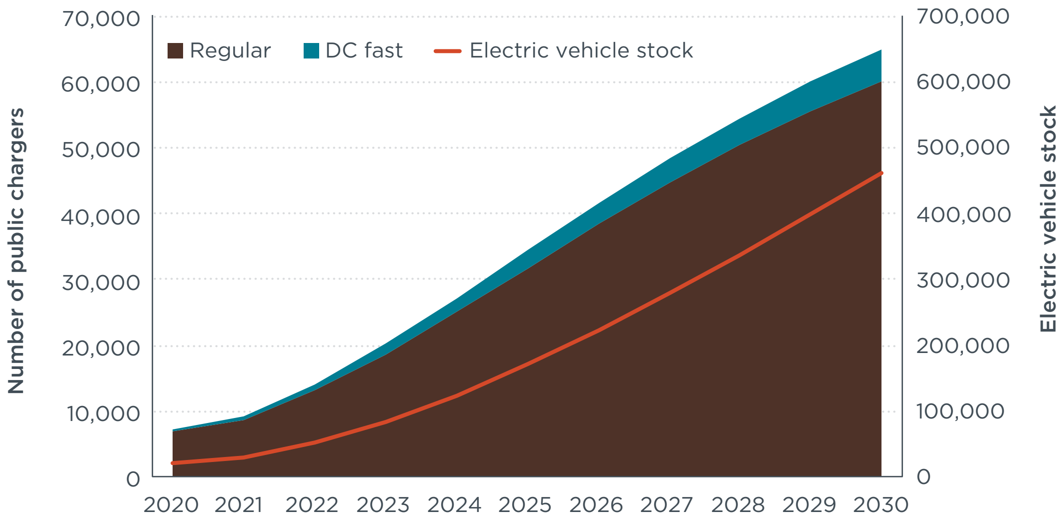

Figure 9. Projected charging infrastructure and electric vehicle growth in Greater London through 2030.

This scenario shows that meeting London's electric vehicle goals will require substantial growth in the number of public chargers, with over a 35% annual increase through 2025, and 10%-20% annual growth afterward. The results of this brief analysis are in line with the "high rapid charging" scenario from the Mayor's Charge Point Delivery Plan, given similar assumptions on electric vehicle uptake.[25] As with other cities, future charging planning will require a regional approach, as the surrounding districts in the London Metropolitan Region have greater vehicle ownership but fewer chargers per capita.

Berlin

Berlin, Germany's capital and largest city, experienced significant growth in its electric vehicle sales in 2019 with a 4.1% sales share. The city has made substantial strides toward the electrification of its transport and has several charging infrastructure policies already in place.[26] The city has also implemented a low-emission-zone which primarily targets older diesel vehicles and has pledged to create a substantial zero-emission area in the city by 2030.[27] Despite having among the largest public charging networks in Germany, Berlin will need to deploy much more public charging infrastructure over the next decade to meet future demand.

Figure 10 shows the projected charging infrastructure need for the Berlin region from 2020 to 2030, along with the anticipated electric vehicle growth over the same period. This scenario estimates the charging infrastructure to enable electric vehicles to grow to 50% share of the light-duty vehicle stock by 2030, or to over 340,000 electric vehicles in the Berlin region. We estimate the electric share of the vehicle stock will gradually shift from 56% in 2020 to 70% in 2030. To meet this challenge, approximately 28,000 regular public chargers and 1,200 fast chargers will be needed and that fast charging accounts for 4% of 2030 chargers. In terms of cars served per public charger, this

25 "London electric vehicle infrastructure delivery plan" (Mayor of London, 2019), http://lruc.content.tfl.gov.uk/london-electric-vehicle-infrastructure-taskforce-delivery-plan.pdf.

26 Sandra Wappelhorst, Dale Hall, Mike Nicholas, and Nic Lutsey, Analyzing policies to grow the electric vehicle market in European cities, (ICCT: Washington DC, 2020), https://theicct.org/publications/electric-vehicle-policies-eu-cities.

27 "Our commitment to green and healthy streets" (C40 Cities, 2019), https://www.c40.org/other/green-and-healthy-streets.

represents an almost 100% increase. Through the end of 2018, the Berlin region had only 6% of the public and workplace charging necessary through 2030, requiring an average annual increase of 25%.

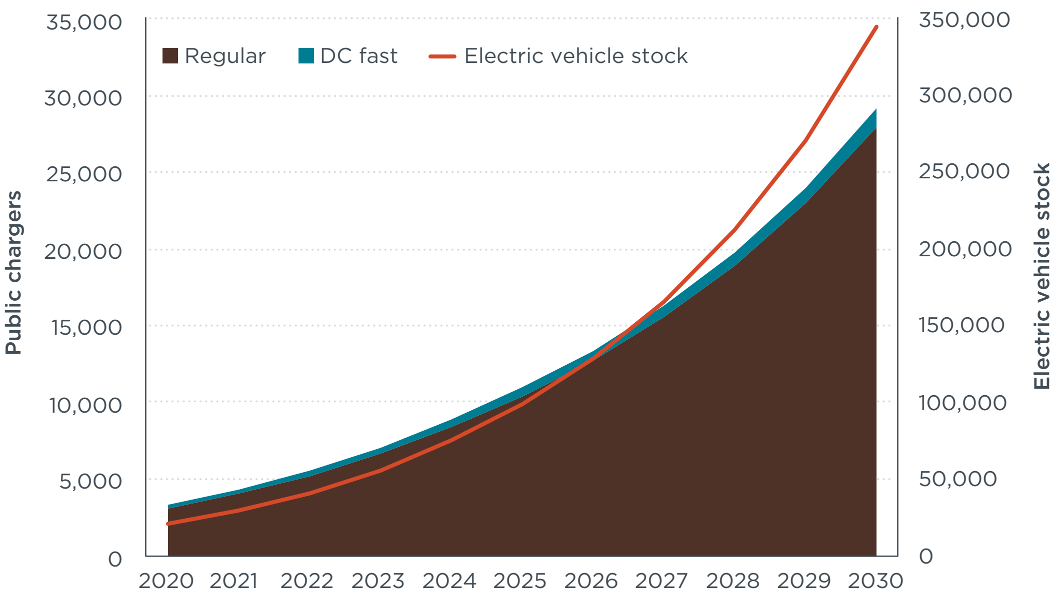

Figure 10. Projected charging infrastructure and electric vehicle growth in the Berlin region through 2030.

The charging infrastructure estimate for Berlin in Figure 10 mirrors several of the trends seen in this broader analysis of Europe. For example, the number of electric vehicles per public charger is expected to increase over the course of the decade. This is particularly true for the ratio of BEVs per fast charger, which is expected to increase from 80 in 2018 to 200 in 2030, reflecting greater utilization. The Berlin region has a greater percent of residents living in multi-unit dwellings than Germany overall; providing home charging for those in multi-unit dwellings and attached homes, as the city plans to do, will be important for achieving electric vehicle targets and reducing outlays on public charging.[28]

Charging infrastructure policy adoption

Cities have implemented diverse policies and programs to assess charging needs, accelerate public charging construction, and support private home and workplace charging. Going forward, cities can improve their readiness by filling in policy gaps and strengthening existing policies with best practices.

Local governments have many policy tools to increase the availability of public and private charging infrastructure. As cities plan their future charging deployments, it is also important to evaluate how well their suite of policies encourages charging investments. This section discusses several categories of policies regarding charging infrastructure

28 Federal Ministry of Transport and Digital Infrastructure, "Masterplan Ladeinfrasruktur der Bundesregierung" (Berlin, 2019), https://www.bmvi.de/SharedDocs/DE/Anlage/G/masterplan-ladeinfrastruktur.pdf?__blob=publicationFile.

and provides examples of their implementation in leading European cities, and quantifies the number of policies in place as of early 2020.[29]

Creating charging infrastructure plans

A critical part of building an efficient, convenient charging ecosystem is creating a comprehensive strategy in line with electric vehicle targets and broader transport policy.[30] These plans ideally involve multiple relevant government agencies, consider the roles of the public and private sectors, and take into account both public and private charging options. Cities are increasingly choosing to also set concrete targets for chargers based on analysis of driver behavior; such analysis requires that an electric vehicle target first be in place. As technology and consumer behavior are quickly changing, such plans may be limited in their time horizon and will need to be updated at regular intervals.

An exemplary case is London's electric vehicle infrastructure delivery plan, written by the Mayor's task force on charging infrastructure.[31] The task force includes government agencies from Greater London, the city's boroughs, and the national government; power sector companies; and trade groups representing other businesses in the city and in the electric vehicle industry. The initiative includes modeling of public charging needs through 2025 in order to ensure that charging would not be a barrier for near-term market growth. The delivery plan identifies several strategies to improve fast charging access for taxis, commercial vehicles, and private drivers and identifies priority locations types.

Public infrastructure deployment

Cities take different roles in facilitating the rollout of public charging, adopting different policies to increase deployment. This can take the form of direct installation of charging, often in partnership with power companies or network operators, providing land for private installations, adjusting codes and zoning, offering subsidies, and streamlining permitting processes. City governments are increasingly leveraging their electrical assets, including lampposts or utility poles, to enable low-cost curbside charging, as in London, Berlin, Los Angeles, and Tokyo.[32] These policies are often tailored to fill in gaps where private sector investment is less likely, such as in disadvantaged communities, or support city goals to electrify dedicated taxi or commercial vehicle charging.

The government of Berlin has supported public charging since 2012 through the be emobil program. Through 2020, the program, co-financed with the national government of Germany, has funded over 800 public chargers, with a mix of AC regular and DC fast points.[33] The city has partnered with Allego to build and operate the stations, and to ensure that the stations are connected to many major charging networks to maximize their use.

29 Sandra Wappelhorst, Dale Hall, Mike Nicholas, and Nic Lutsey, Analyzing policies to grow the electric vehicle market in European cities, (ICCT: Washington DC, 2020), https://theicct.org/publications/electric-vehicle-policies-eu-cities.

30 A template for designing such a policy is described in: Dale Hall and Nic Lutsey, *Electric vehicle charging guide for cities,* (ICCT: Washington DC, 2020), https://theicct.org/publications/city-EV-charging-guide.

31 "London electric vehicle infrastructure delivery plan" (Mayor of London, 2019), http://lruc.content.tfl.gov.uk/london-electric-vehicle-infrastructure-taskforce-delivery-plan.pdf.

32 Suguru Kurimoto, "Tokyo's Utility Poles to Serve as EV Chargers," *Nikkei Asian Review,* June 11, 2019, https://asia.nikkei.com/Business/Companies/Tokyo-s-utility-poles-to-serve-as-EV-chargers.

33 "Über be emobil," (Berlin Senatsverwaltung für Umwelt, Verkehr und Klimaschutz), accessed March 5, 2020, http://www.be-emobil.de/.

Private infrastructure support

While public charging infrastructure is the focus of the quantitative metrics evaluated above, private home and workplace infrastructure can cover much of the charging needs for many electric vehicle drivers and are often the most cost-effective charging solutions. Many cities have adopted policies to encourage lower-cost home charging installation, including subsidies, education campaigns, and electric vehicle-ready building codes which mandate capacity for charging in new construction. These complement national-level policies in many countries to incentivize home charging, such as the £500 electric vehicle home charge grant in the United Kingdom.[34] Although the installation of workplace charging is largely a private company decision, cities can encourage this type of charging deployment by designing rates and pilot programs with local power companies, providing support such as tax incentives for employers, creating favorable building and parking codes, and tracking and publicizing progress on employer-provided charging. These actions may be especially important in areas where public transport is unavailable, and for industries which rely on commercial vehicles. Often, local- and national-level policies will target incentives toward locations where charging installation may be more difficult or expensive, such as apartment buildings, or toward high-usage businesses, such as taxi drivers.

Oslo demonstrates how cities can play an important role in private charging. In its planning to build a complete charging network to support high levels of electric vehicle uptake, the city discovered that, in many cases, it was less costly to provide partial incentives for home charging than to more heavily subsidize additional public charging. The city concentrated its efforts on multi-unit dwellings and housing cooperatives, which can receive a grant from the city covering 20% of total costs.[35] In 2018 alone, the city provided assistance for 16,000 private chargers through this program. Additionally, Oslo is working to strengthen their electric vehicle-ready building codes, which would require that 50%-100% of parking spots in new construction to include wiring for charging.[36]

Comparison of initiatives across cities

To evaluate the robustness of cities' charging initiatives, Table 2 catalogs the actions in place across 16 major European metropolitan regions. The table tracks 12 policies which fit into the three categories described above: infrastructure planning, private infrastructure support, and public infrastructure support.[37] Additionally, we track whether each city has an electric vehicle target, an important first step in planning future infrastructure needs. Except where noted, we consider only programs implemented at the city or local level. A policy was counted if it was in place as of January 1, 2020, based on publicly available resources. Not all actions in a category are equal, and this table does not attempt to identify the most impactful actions across cities.

34 "Customer guidance: Electric Vehicle Homecharge Scheme" (Office for Low Emission Vehicles, 2019), https://www.gov.uk/government/publications/customer-guidance-electric-vehicle-homecharge-scheme.

35 Michael Shank, "Building a ubiquitous electric vehicle charging network," (Carbon Neutral Cities Alliance, 2019), https://carbonneutralcities.org/building-a-ubiquitous-electric-vehicle-charging-infrastucture/.

36 Sture Portvik, personal correspondence via email, April 2019.

37 For a more extensive list of policies in leading cities, see: Sandra Wappelhorst, Dale Hall, Mike Nicholas, and Nic Lutsey, *Analyzing policies to grow the electric vehicle market in European cities,* (ICCT: Washington DC, 2020), https://theicct.org/publications/electric-vehicle-policies-eu-cities and Dale Hall, Hongyang Cui, and Nic Lutsey, *Electric vehicle capitals: Showing the path to a mainstream market,* (ICCT: Washington DC, 2019), https://theicct.org/publications/ev-capitals-of-the-world-2019.

Table 3. Charging infrastructure policies and actions in leading electric vehicle markets in Europe

	Charging infrastructure planning			Public infrastructure deployment					Private infrastructure support			
City	**Electric vehicle target**	**Public charging infrastructure target**	**Charging infrastructure action plan**	**EV charging incentive/benefit**	**Public charger promotion (national)**	**Public charger promotion (local)**	**EV curb side charger and lamp post charging program**	**EV charging interoperability requirements**	**Private and workplace charger promotion (national)**	**Private and workplace charger promotion (local)**	**EV-ready building codes**	**Total actions (out of 12)**
Oslo	X	X	X	X	X	X	X	X		X	X	10
Paris	X	X	X	X	X	X	X		X	X	X	10
London	X	X	X	X	X	X	X		X		X	9
Vienna	X	X	X	X	X	X	X	X	X			9
Amsterdam	X		X	X	X	X	X	X	X			8
Madrid	X		X		X	X	X		X	X	X	8
Rotterdam-The Hague	X		X	X	X	X	X	X	X			8
Stockholm	X		X	X	X	X	X	X	X			8
Berlin	X	X	X		X		X	X				6
Helsinki	X			X	X	X	X		X			6
Bergen	X			X	X			X			X	5
Brussels	X			X		X		X		X		5
Hamburg	X		X		X		X	X				5
Birmingham	X				X		X		X			4
Copenhagen	X						X					2
Zurich					X		X					2
Total regions with action	15	5	10	10	13	10	14	9	9	4	5	

The table indicates that Oslo and Paris have the broadest charging infrastructure policy packages, each with 10 actions. Most cities have between 5 and 8 actions. An electric vehicle target was the most commonly implemented, in place in 15 of the 16 cities. Of the total cities, 14 also had some form of curbside or lamppost charging program in place, although they differ widely in scale and form. On the other hand, only 4 to 5 of these leading cities have adopted quantitative charging infrastructure deployment targets, electric vehicle-ready building codes, or incentive programs for private home or workplace infrastructure.

Learning from best-practice policies

Local governments are increasingly adopting a suite of policies based on the experiences of leading cities. There are also opportunities to further strengthen and adapt each policy to prepare for electric vehicle adoption in the mainstream market. Table 3 identifies components of the strongest policies in each category, based on best practices in the cities of London,[38] Oslo,[39] and Amsterdam.[40] Other cities can use this list of actions and regulations as a scorecard to track their own policy development, accepting that some adjustments may be necessary according to local market conditions and government authorities.

Table 4. Detailed charging infrastructure policy list for cities

Category	Comprehensive policy element	Example
Electric vehicle target	Targets for electric vehicles in 2025, 2030	Amsterdam
	Planned zero-emission area covering city by 2030	Amsterdam
	Strong targets for taxis, private-hire vehicles, and government fleets	London
Electric vehicle charging infrastructure goal	Charging infrastructure demand modeling aligned to electric vehicle target	Amsterdam
	Neighborhood charging gap analysis based on housing and transport needs	Oslo
Electric vehicle charging infrastructure action plan	Coordination among transportation, energy, local districts, and other city departments	London
	Consultation with private stakeholders including utilities, charge point operators, major fleet operators	London
	Identification of priority public charging locations	Oslo
Public charger promotion	Provide public right-of-way for private charging investments	Stockholm
	Data reporting requirements for stations receiving public support	Amsterdam
	Dedicated chargers for taxis and fleet vehicles	Amsterdam
Private and workplace charger promotion	Cost-sharing for charging infrastructure at housing cooperatives and public housing	Oslo
	Subsidies for home charging for taxi drivers	Oslo
	Outreach and education to help promote national government home charging subsidies	Stockholm
Curbside and lamppost charging	Dynamic demand assessment for curbside chargers	Amsterdam
	Add charging to lampposts in residential areas	London
EV-ready building codes	100% EV-ready requirement for new parking facilities	Oslo
	EV-ready requirements for retrofits and major modifications	Amsterdam
	Clear, streamlined permitting and guidelines for charging	London
EV charging interoperability requirements	Requirements for interoperability and open payment standards (OCPP) at all public chargers	Amsterdam

38 Policy examples in London come from: The Mayor's Electric Vehicle Infrastructure Taskforce, "London Electric Vehicle Infrastructure Delivery Plan" (London: Mayor of London, June 2019), http://lruc.content.tfl.gov.uk/london-electric-vehicle-infrastructure-taskforce-delivery-plan.pdf.; Mayor of London, "£4 Million Boost for More than 1,000 New EV Charging Points," London City Hall, December 20, 2019, https://www.london.gov.uk//press-releases/mayoral/4-million-boost-for-more-than-1000-new-ev-points.; Transport for London, "London's Electric Vehicle Charge Point Installation Guidance" (London, December 2019), http://lruc.content.tfl.gov.uk/london-electric-vehicle-charge-point-installation-guidance-december-2019.pdf.

39 Policy examples in Oslo come from: Bymiljøetaten, Oslo kommune, "Kartlegging av ladebehov i Oslo kommune" (Oslo, November 28, 2019), https://www.oslo.kommune.no/getfile.php/13354701-1576848117/Tjenester og tilbud/Gate, transport og parkering/Parkering/Kartlegging av ladebehov i Oslo kommune.pdf.; Ellen Viseth, "In Oslo People Are Installing Charging Points for Electric Cars at Record Speed," KlimaOslo, February 4, 2019, https://www.klimaoslo.no/2019/02/04/installing-charging-points-at-record-speed/.; "Tilskudd til ladestasjoner for el-drosjer," Oslo kommune, accessed May 21, 2020, https://www.oslo.kommune.no/tilskudd-legater-og-stipend/tilskudd-til-ladestasjoner-for-el-varebiler-og-el-drosjer/.

40 Policy examples in Amsterdam come from: City of Amsterdam, "Clean Air Action Plan" (Amsterdam, April 2019), https://www.amsterdam.nl/en/policy/sustainability/clean-air/.; Robert van den Hoed et al., "Emobility: Getting Smart with Data" (Amsterdam: Amsterdam University of Applied Sciences, June 2019), https://pure.hva.nl/ws/files/5796298/HvA_Emob_DIGI.pdf.; Gemeente Amsterdam, "Schone taxi's voor Amsterdam," Amsterdam.nl (Gemeente Amsterdam, March 23, 2020), https://www.amsterdam.nl/veelgevraagd/.; "Laadinfrastructuur voor elektrisch vervoer - EPBD III," Rijksdienst voor Ondernemend Nederland, March 10, 2020, https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/gebouwen/wetten-en-regels/nieuwbouw/epbd-iii/laadinfrastructuur-elektrisch-vervoer.

Conclusions

This investigation into charging infrastructure patterns and future needs yields the following conclusions regarding data-driven assessment of charging infrastructure needs for cities:

Tracking and measuring charging infrastructure is a key first step in achieving future electric vehicle targets. In order to plan for future charging infrastructure to support electric vehicle targets, it is critical for cities to first assess their existing charging infrastructure ecosystem. This includes quantifying the number of public chargers of different kinds (regular versus fast, and of different standards), as well as availability of private home and workplace charging, within each neighborhood of the city. Cities can track simple metrics such as electric vehicles per charger and also develop more advanced metrics to account for the energy provided by different types of charging stations, as identified in academic research. These metrics can be compared to those of similar cities at different stages of electric vehicle uptake to assess how much more charging and of what types may be needed.

Much more charging will be needed to accomplish cities' electric vehicle transitions. Cities are increasingly adopting strong electric vehicle policies, including zero-emission areas and targets for full phase-outs of combustion vehicles. The challenge of building sufficient infrastructure for an all-electric future will be substantial. For cities intending to transition to all zero-emission new car sales, such as Amsterdam or London, public charging availability may need to grow by 30% to 40% annually from 2020 to 2025 and expand by a factor of 6 to 10 from 2020 to 2030. Cities such as Berlin who wish to have half of all car sales be electric by 2030 would need to see their charging networks grow on average by 25% annually. This will include a combination of AC regular and DC fast charging, although the mix of technologies is dependent on local conditions and strategy.

Local factors dictate charging needs, making general international guidelines difficult. The unique characteristics of each city influence its charging needs. Notably, housing stock strongly influences how much charging is needed at the city and neighborhood level. As shown in the Netherlands, cities with more residents in multi-unit dwellings need more public charging to make up for the lack of private home charging. In the early stages of the transition, an important part of charging planning is providing spatial coverage; therefore, less-dense regions may require faster build-out in the early stages of the transition, and somewhat slower growth once that need is met. Other important factors include population density, renting patterns, public transit access, and parking patterns. The local vehicle mix also influences charging needs, with BEVs requiring more charging than PHEVs, and high-mileage applications such as taxis and private hire vehicles requiring more DC fast charging.

Cities have a menu of policy options to accelerate charging deployment. Based on emerging best practices, we identify a number of policies and actions that cities can adopt to encourage greater charging deployment. These range from adopting a charging infrastructure strategy, which most major European cities have done, to creating incentives for targeted private infrastructure applications, a policy adopted by only a few cities. While many cities have adopted smaller-scale programs and pilots, many actions could be greatly increased in scale as electric vehicle volumes grow, such as incorporating the best-practice elements listed in Table 3. Cities can track their implementation of policies from this list, providing an additional metric to evaluate a city's preparedness to meet future charging demands.