Electric vehicle charging guide for cities

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C40 CITIES

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INTRODUCTION

Electric vehicle sales and the associated charging infrastructure continue to expand around the world. The transition to electric vehicles is widely recognized as necessary for air quality and climate change mitigation, and governments at all levels have supported the early stages of the conversion with incentives, regulations, and supporting policy. Increasing the availability of charging infrastructure is critical for the growing market, as more private and public charging is key to making electric vehicles as convenient as conventional vehicles.

This paper analyzes research on the growth in light-duty electric vehicles and charging infrastructure to discern emerging best practices and future developments in charging deployment. The report summarizes research and trends in the top electric vehicle markets around the world, identifying opportunities for city governments to support the continued growth of their charging infrastructure and the electric vehicle market.

GLOBAL GROWTH IN CHARGING INFRASTRUCTURE

The increasing need for public charging infrastructure to support electric vehicle growth can be garnered from historical trends. Global electric vehicle uptake has grown an average of over 60% per year from 2013 to 2018, to about 5 million light-duty electric vehicles on roads around the world. Public charging infrastructure has also grown an average of over 60% annually over the same time period, reaching 600,000 charge points at the end of 2018.[1] The trends shown in Figure 1 are intertwined: More available public charging increases drivers' confidence to move to electric vehicles, and additional electric vehicle drivers put more demand on governments, automakers, and property owners to install charging stations. A robust public charging network assures consumers that electric vehicles are as convenient as conventional vehicles, and an expanded charging network increases electric vehicle drivers' confidence and their practical traveling range.

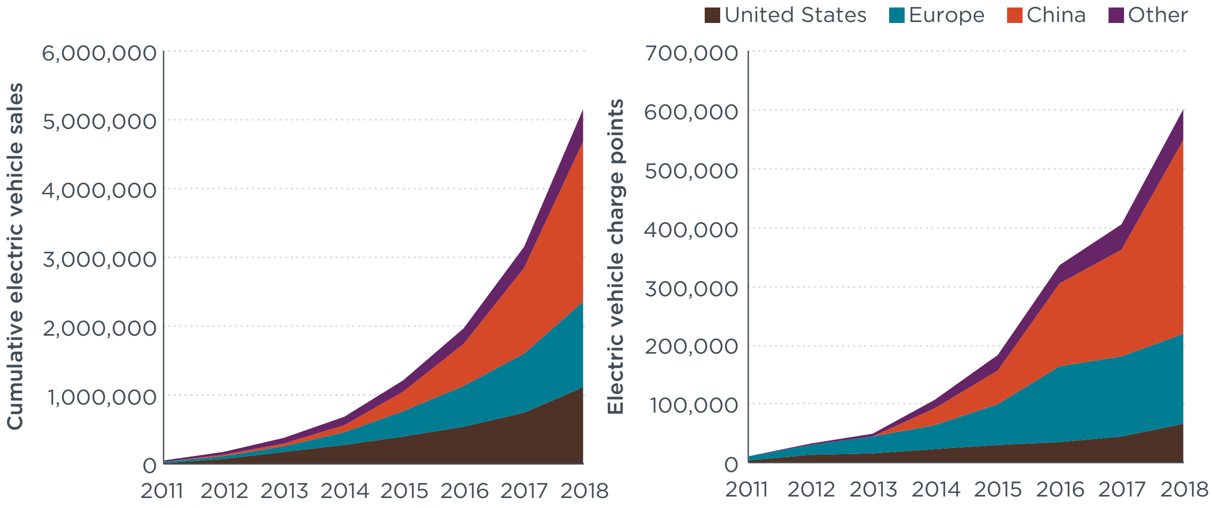

Figure 1. Global electric vehicles and public electric vehicle charging points.

Numerous market-specific studies establish a clear link between public charging infrastructure and electric vehicle uptake. These studies affirm that charging infrastructure is one of the keys to a successful transition to electric vehicles, alongside regulations, taxation policy, incentives, and consumer education measures. For example, a series of studies in the United States has shown a statistically significant relationship between the public charging infrastructure per capita and electric vehicle uptake for the country's 100 largest metropolitan areas.[2] This correlation has been validated for many other countries, although important differences in the amount and type of charging exist among the major markets.[3]

2 Pete 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.

3 Simon Funke, Frances Sprei, Till Gnann, and Patrick Plötz. "How much charging infrastructure do electric vehicles need? A review of the evidence and international comparison." Transportation Research Part D 77 (2019): 224-242, https://www.sciencedirect.com/science/article/pii/S136192091930896X.
Anastasios Tsakalidis, Andreea Julea, and Christian Thiel, *The Role of Infrastructure for Electric Passenger Car Uptake in Europe*, (European Commission, Joint Research Centre, Ispra, Italy: 2019), https://www.eafo.eu/news/23786/JRC%2520research%253A%2520The%2520Role%2520of%2520Infrastructure%2520for%2520Electric%2520Passenger%2520Car%2520Uptake%2520in%2520Europe.
Dale Hall and Nic Lutsey, *Emerging best practices for electric vehicle charging infrastructure,* (ICCT: Washington DC, 2017), https://theicct.org/publications/emerging-best-practices-electric-vehicle-charging-infrastructure.

THE ELECTRIC VEHICLE CHARGING ECOSYSTEM

Electric vehicle charging equipment is categorized according to its location, power capacity in kilowatts (kW), and plug type. Table 1 below illustrates the characteristics of common types of charging: regular, such as from a household outlet; alternating current (AC) fast, also called accelerated, which is typical for public chargers; and direct current (DC) fast, or rapid charging. Each electric vehicle model has different limits on the charging speeds it can accept from AC and DC, with longer-range vehicles typically able to accept more power. For example, no new electric vehicle models can accept AC charging over 22 kW, suggesting that high-power AC chargers may not be built in the future. Therefore, charging times can vary substantially based on vehicle.

Table 1. Characteristics of regular, fast, and rapid charging in Europe.

	Regular (240-volt AC, 2-7 kW)	AC fast (240-volt AC, 7-43 kW)	DC fast (rapid) (480+-volt DC, 50+ kW)
			
Hardware cost[a]	€200-€700, typically included with car	€2,500 for curbside	€15,000
Installation and grid connection cost[a]	€0-€500	€5,000 for curbside	€10,000
Time to charge[b]	8 hours to full charge	4 hours to full charge	45 minutes to 80% charge
Compatibility	Works with all EVs	Works with all EVs (speed varies with model)	Works only with select mostly long-range BEVs
Standard (Europe / North America)	Type 2 / J1772	Type 2 / J1772	Type 2 CCS / Type 1 CCS, CHAdeMO
Typical locations	Home, workplace, public locations such as lampposts	Public locations such as parking lots and curbside	Public locations such as highway exits and fueling stations

[a] Based on estimated average costs for Germany in 2020
[b] Based on a 2019 Nissan LEAF

Among electric vehicle early adopters, the majority of charging is done at home. In many places where people drive to work, workplace charging contributes the second-largest share of charging energy used. For drivers with reliable home or workplace charging, both AC and DC public charging may typically be used only for longer trips or in irregular circumstances. For those without home charging, such as those who live in apartment buildings in urban centers, and those with high daily mileage, however, public charging is a critical precondition to using an electric vehicle. Therefore, in denser cities with less home and workplace charging, more public charging is needed. For example, Amsterdam has as much charging per capita as Oslo, although the city has far fewer electric vehicles. Dense cities with more residents in high-rises, such as Beijing, will often need more public fast chargers. To support the growth of the electric vehicle market, much more charging of all types will be needed.

DIRECT CURRENT FAST CHARGING

Early DC fast charging installation deployments were designed to enable intercity driving on longer trips. In practice, DC fast charging has also been a popular alternative for regular charging for drivers without reliable home and workplace charging.[4] This trend, along with the popularity of fast charging among taxi, delivery, and ride-hailing drivers, is prompting a number of cities, including New York, Amsterdam, and London (see box) to build large fast charging hubs or plazas where up to ten or more electric cars can fast-charge simultaneously. Although more expensive to install and operate, these stations could potentially serve thousands of drivers each day, compared to building hundreds of home, workplace, and curbside stations to serve a similar population.

The introduction of ultra-fast charging, or charging at speeds above 50 kW, promises to further increase the usefulness of fast charging. However, there are a number of reasons why ultra-fast charging may remain a niche service. The hardware for 150-kW charging stations costs up to 3.5 times that of a 50-kW charging station, while a 350-kW station can cost 5.5 times that of a 50-kW station, although hardware costs are expected to decline over time.[5] A more substantial issue is that ultra-fast charging has a disproportionately greater impact on the power grid, meaning costly substation upgrades are much more likely to be needed. Grid operators may charge greater demand charges, or fees based on the maximum power drawn in a given period, increasing the operational costs and hindering the business case for commercial ultra-fast-charging services.

Most of the electric vehicle models that were available in 2019 cannot accept charging speeds over 50 kW. Because the amount of power a vehicle can accept is proportional to the number of battery cells, ultra-fast charging is expected to initially be available for vehicles with larger battery packs and may at first be deployed on higher-cost premium, luxury vehicle models. Therefore, in contrast to the growth of 50-kW and perhaps 150-kW charging in urban settings, ultra-fast charging in the 250-400 kW range is more likely to take root only for niche applications with high mileage, such as taxis and delivery fleets. Ultra-fast charging will also be important for medium- and heavy-duty vehicles with larger battery packs and higher energy consumption.

4 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.

5 Dale Hall and Nic Lutsey, *Estimating the infrastructure needs and costs for the launch of zero-emission trucks,* (ICCT, Washington DC: 2019), https://theicct.org/publications/zero-emission-truck-infrastructure.

CASE STUDY:
FAST CHARGING FOR ALL IN LONDON

London has high aspirations for electric vehicles, and especially so for its fleet of iconic black cabs: All *new* taxis must be zero-emission capable, and the *entire* fleet must be converted by 2033. Learning from challenges elsewhere, London is proactively expanding its rapid charge points. By late 2019, 74 of over 300 publicly accessible rapid charge points were dedicated for use by taxis.

The city is partnering with the private sector to expand charging for taxis, private-hire vehicles (PHVs), and others. In consultation with the power sector and charging providers, the EV Infrastructure Delivery Plan specifies policies to deploy rapid charging at public hubs, commercial hubs, and semi-public depots. It also identifies priority locations in a mapping exercise based on taxi driving patterns and electricity grid capacity. Businesses helping to fulfill the plan include Shell, which will add chargers at filling stations, and Qpark, which will construct them in their parking garages.

London's strategy for electrification creates a unique ingredient for success in the difficult case of fast charging. Taxis, as well as more PHVs and commercial vans in the future, will provide initial high-usage and relatively predictable anchors to ensure a viable business case. The shared stations increase the visibility of charging options and empower more drivers and fleets to purchase electric vehicles, creating a virtuous cycle of continuous EV adoption.

Sources: "Mayor-funded rapid charge points", Mayor of London, January 21, 2020, https://maps.london.gov.uk/ev-chargepoints/?intcmp=52680; The Mayor's Electric Vehicle Infrastructure Task Force, "London electric vehicle infrastructure delivery plan" (Mayor of London, 2019), http://lruc.content.tfl.gov.uk/london-electric-vehicle-infrastructure-taskforce-delivery-plan.pdf.

REGIONAL TRENDS IN CHARGING INFRASTRUCTURE

PRIVATE AND WORKPLACE CHARGING

As discussed, the largest shares of charging for most drivers occur at home and at workplaces. Home and workplace charging typically uses 208-240 volts of AC power in Europe or the standard 120 volts in markets such as North America, meaning that electrical upgrades are rare and installation costs are low. At home and the workplace are also the two locations where cars are parked most commonly and for the longest duration. For those reasons, governments are often focused on maximizing the availability of charging at homes and workplaces, although they may also have less authority over installations in these settings.

The availability of home and workplace charging is a key input in understanding public charging needs. Data on private charging at home and in the workplace are rare. Nonetheless, some pieces of data suggest that the availability of home charging varies widely among electric vehicle drivers in different contexts:

» In California, home to half of the electric vehicles in the United States, 83% of electric vehicle drivers use home charging. This share is higher for those who live in detached houses (90%) and much lower (about 35%) for those who live in apartments.[6]

» A 2017 survey of electric vehicle drivers in Germany found that two-thirds of battery electric vehicle drivers had access to home charging. For those drivers, 70% of charging happens at home.[7]

» In the UK, 85% of electric vehicle owners had access to off-street parking. Survey respondents indicated they would ideally like to do 61% of charging at home.[8]

Private workplace charging is similarly difficult to assess. However, in the United States, workplace charging appears to be increasingly common in some areas. The San Jose, California area has the highest electric vehicle uptake in the United States, with 21% of new sales, and also has the highest density of workplace charge points at close to 1,400 per million population, compared to closer to 100 per million population in most cities.[9] However, public charge points can also be used for charging at one's workplace—in fact, about 27% of charging at the workplace in the United States used public chargers.[10] In other regions, this share could be higher, depending on parking arrangements.

Going forward, local governments should attempt to collect data on private charging at home and at workplaces, as in the studies citied above for California, Germany, and the UK. These data collections can inform governments and other stakeholders about the largest gaps in charging infrastructure and effective solutions to bridge these gaps.

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6 Gil Tal, Jae Hyun Lee, and Michael Nicholas, *Observed charging rates in California,* (Institute of Transportation Studies, University of California, Davis: 2018), https://itspubs.ucdavis.edu/index.php/research/publications/publication-detail/?pub_id=2993.

7 Schaufenster Elektromobilität, "Bedarfsorientierte Ladeinfrastrukture aus Kundesicht [Demand-oriented charging infrastructure from the customer perspective]", (BMU, Berlin, 2017), http://schaufenster-elektromobilitaet.org/media/media/documents/dokumente_der_begleit__und_wirkungsforschung/EP35_Studie_LIS_online.pdf.

8 Alexander Lewis-Jones, Matti Kahola, and John Murray, "Who is the EV customer? 'Early adopter' customer segmentation", (Delta Energy & Environment: 2018).

9 Pete 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.

10 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.

PUBLIC CHARGING

While public charging accounts for a smaller share of total charging use, it is the most publicly visible component of the charging ecosystem and a crucial part of the transition to a mainstream electric vehicle market. It is also a part of the transition to electric vehicles where city governments have a key leadership role. As a result of the underlying demographic, geographic, and policy differences, leading electric vehicle markets have developed different charging infrastructure networks. The experiences of the highest-uptake electric vehicle markets reveal approximate benchmarks for charging infrastructure needs. To analyze the major trends, we look at the most developed electric vehicle local markets in the world, which are in China, Europe, and the United States.[11]

Figure 2 depicts the growth in electric vehicles in top electric vehicle-uptake metropolitan areas in Europe and the United States from 2015 to 2018 (left side), and for top China markets for 2016 to 2018 (right side). Note that there is a break in the horizontal axis due to higher charging availability in the China metropolitan areas. As indicated, the electric vehicle market and charging network grow in tandem for each case, but with differences across markets. The three markets in China reached 177,000 to 242,000 cumulative electric vehicles registered by the end of 2018, each with about 40,000 to 60,000 public charge points. Paris, London, and Amsterdam reached about 40,000 cumulative registered electric vehicles with 4,700, 5,800, and 9,100 charge points, respectively. Oslo reached 109,000 electric vehicles with 4,300 charge points. The three large California markets surpassed 100,000 electric vehicles, with 200,000 electric vehicles in the Los Angeles market, with 1,700 (San Jose), 2,700 (San Francisco), to 5,200 (Los Angeles) public charge points each.

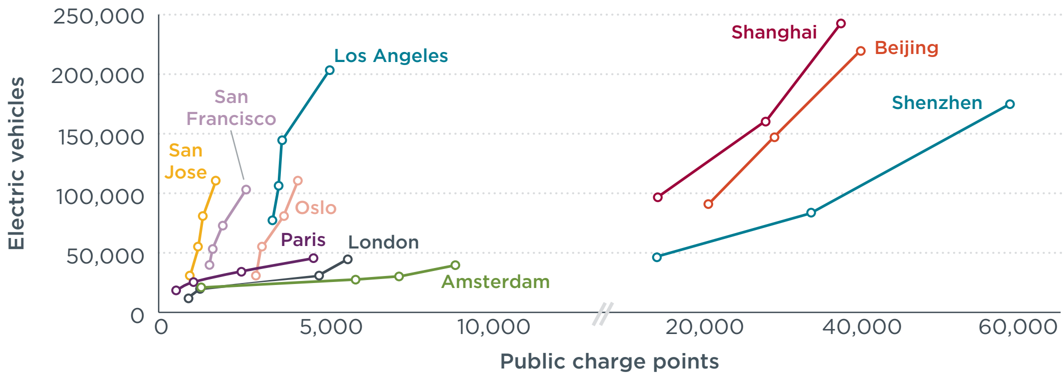

Figure 2. Global electric vehicles and public electric vehicle charging points in top electric vehicle metropolitan areas from 2015-2018.

11 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.
See detailed studies:
China: Hui He, Lingzhi Jin, Hongyang Cui, and Huan Zhou, *Assessment of electric car promotion policies in Chinese cities,* (ICCT: Washington DC, 2018), https://theicct.org/publications/assessment-electric-car-promotion-policies-chinese-cities.
Europe: Sandra Wappelhorst, Dale Hall, Mike Nicholas, and Nic Lutsey, *Analyzing policies to grow the electric vehicle market in European cities,* (ICCT: Washington DC, 2020), http://www.theicct.org/publications/electric-vehicle-policies-eu-cities.
United States: Pete 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.

The differences in the ratio of the number of vehicles to public charging points illustrates that there is no "one-size-fits-all" solution for charging infrastructure. However, there are trends that emerge within specific regions which can provide approximate guidelines for other cities when evaluating their own charging infrastructure construction. Table 2 provides key metrics for public charging networks and electric vehicle sales in several major electric vehicle markets.

Table 2. Key charging metrics in select metropolitan regions.

Metropolitan region	Public charge points per million population	Percent DC fast public charging	Electric vehicles per public charge point	2018 BEV sales share	2018 PHEV sales share
London	405	15%	7.6	1%	2%
Paris	307	8%	12	2%	1%
Oslo	3,000	10%	24	43%	18%
Stockholm	717	10%	23	2%	11%
Madrid	60	16%	39	1%	1%
Amsterdam	2,750	2%	4.3	7%	1%
Los Angeles	390	13%	39	4%	3%
Beijing	1,920	33%	5.3	14%	0.3%

Note: Each market is based on its metropolitan area rather than its city area with the exception of Beijing, which uses the city boundary. For European markets, this is based on the Metropolitan Region definition from Eurostat. Los Angeles refers to the Metropolitan Statistical Area from the U.S. Office of Management and Budget.

The table shows a wide disparity in sales share and charge points among the different markets. Oslo and Amsterdam have the highest concentration of public charging stations per million population, far higher than any other major city in Europe. The ratio of electric vehicles per charge point varies widely, from as low as 4 to 5 in Amsterdam, Beijing, and other Chinese cities, to as high as 39 in Los Angeles, with other cities in California show similar patterns. Most cities in Europe have in the range of 8 to 25 electric vehicles per charge point. In Beijing, a third of all public charging is DC fast charging, while in Amsterdam, the share is very low. In most other cities, between 10% to 20% public charging points are DC fast charging.

While cities may compare their own charging infrastructure to the patterns emerging in similar cities, these metrics should not be interpreted as targets for cities to strive for. Leading markets have a range of different infrastructure solutions, and yet every city is working to build more charging of all types to keep pace with electric vehicle sales. When assessing their own charging needs, cities will need to consider many local factors. Some of the most important factors influencing how much and of what type of charging a city will need, and therefore, the ratios of electric vehicles per charge point and the share of fast versus slow charging, include:

» **Housing stock:** A higher concentration of apartment buildings typically signifies less access to home charging, which means more of other charging types will be needed. *Example: In Amsterdam, the Netherlands, curbside public charging is the main charging source for central-city residents.*

- **Commuting patterns:** In places where many residents commute to work by private car, workplace charging can play a major role. Where active or public transportation is the norm, workplace charging will be less prevalent.
  Example: San Jose, California, where the vast majority of residents drive to work, has the highest density of workplace charging in the United States due to installations at large technology company campuses.
- **Vehicle mix:** Battery electric vehicles (BEVs) require fast charging, while plug-in hybrid vehicles (PHEVs) generally do not. PHEVs may benefit more from workplace and public regular charging.
  Examples: The Beijing market is almost exclusively BEVs and has more charging points, and a much higher fraction is DC fast charging than other cities. In comparison to Beijing, the Stockholm market has a higher share of PHEVs in its electric vehicle fleet, has a lower concentration of public charge points, and a lower percentage of these points are DC fast charging.
- **Typical driving patterns:** Where cars are driven more kilometers, more charging may be needed to provide more energy.
  Example: In Germany, where drivers typically drive more kilometers at higher speeds than in other European countries, more inter-city charging may be needed.
- **Amount of DC fast charging:** One DC fast charger can provide as much energy as many regular speed chargers, so places with a high ratio of fast charging may have a higher EV/charge point ratio.
  Example: Birmingham, UK, has a higher electric vehicle-per-public-charge-point ratio than other cities in the UK (48), but also has a much higher share of fast charging (29%).

Although charging infrastructure often comes at a substantial cost, governments typically need not bear the entire cost of the build-out. As electric vehicle uptake increases, utilization of public charging is expected to increase, making the business case for private operation of charging stations more viable. Recent charging network expansions in markets with high electric vehicle uptake, such as Norway and the Netherlands, have seen a shift to private sector operation with decreasing government support.

Models for successful private operation of charging have emerged based on applications that require consistent utilization. This includes taxis and ride-hailing or private-hire vehicles, which require fast charging to reduce downtime and often make trips from certain popular hubs or locations. Additionally, many businesses choose to install charging simply to increase customer draw without making money on the charging itself, as there is evidence that charging stations at retailers lead to more customers spending more money.[12]

12 Mike Nicholas and Gil Tal, *Survey and data observations on consumer motivations to DC fast charge,* (Institute of Transportation Studies: University of California, Davis, 2017), https://itspubs.ucdavis.edu/wp-content/themes/ucdavis/pubs/download_pdf.php?id=2799.

LOCAL POLICIES TO ACCELERATE CHARGING INFRASTRUCTURE

The data on top global electric markets indicate that more charging is needed to sustain electric vehicle market growth. But how can cities navigate the uncertainty of exactly how much charging, of what specific type, and what associated policies are needed? Based on cities' experiences growing the electric market so far, this section outlines a path to set and achieve charging infrastructure build-out goals that match electric vehicle growth expectations.

DEVELOPING A CHARGING INFRASTRUCTURE PLAN

The role that city governments take in providing charging infrastructure, and the specific policies that they use to achieve their goals, depend on the governments' authorities, budgets, geographies, and transportation patterns. Figure 3 offers a template for how cities can approach planning for charging infrastructure, as well as examples for how a city could implement each step:

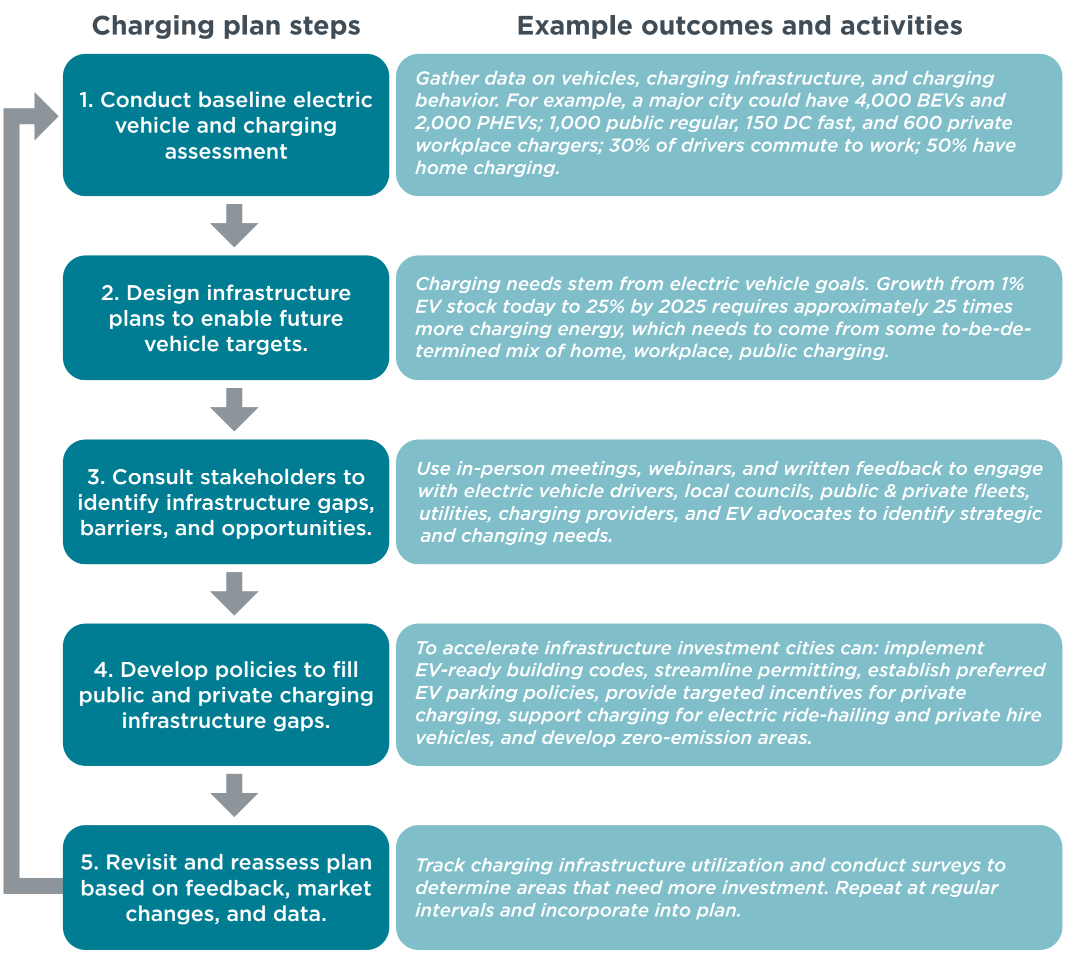

Figure 3. Template for creating a charging infrastructure plan.

Further details about each step of the process are provided below:

1. ***Conduct baseline electric vehicle and charging assessment.*** Rigorous infrastructure planning starts with rigorous data. The first step in planning charging is to find the best available data on the sales and stock of battery electric and plug-in hybrid electric vehicles, the distribution of vehicles by housing type (apartments versus attached or detached houses) and demographics (use of cars for commuting), existing charging infrastructure by type (home, workplace, public regular, public fast), and the relative use of charging by type in the area studied.

2. ***Design infrastructure plans to strategically match future electric vehicle growth targets.*** Many cities have set electric vehicle goals either by absolute number of electric vehicles, electric vehicle sales share, or stock percentage. Some cities may choose to create infrastructure targets aligned with these electric vehicle goals. One method for this analysis, described in detail below, consists of allocating future electric vehicles to different groups based on charging access and driving patterns, calculating the energy demand of each group, apportioning that energy across different locations, and then determining the number of stations required to provide that energy. This planning can be improved if it accounts for shifts in technology, such as from plug-in hybrids to more all-electric, and electric driver housing type, such as from more single-family homes to more multi-unit dwellings, although the timeframes of such plans are inherently limited by uncertainty. Such an assessment in the United States found that most local markets will typically need to increase their public charging infrastructure by a factor of 3-5 from the beginning of 2018 to 2025, or by at least 20% annually, to meet the growing electric vehicle demands.[13]

3. ***Consult stakeholders to identify infrastructure barriers.*** In the development of electric vehicle action plans, cities typically engage a community of interested stakeholders to determine policy gaps and opportunities, including electric vehicle drivers, public and private fleets, utilities and grid operators, new mobility companies, and charging providers. This includes collecting aforementioned data on driver preferences, electric vehicle usage, and charging availability, as well as gathering input on plans through virtual webinars or community workshops. Making these consultation processes highly inclusive can also broaden and strengthen the local coalitions supporting the shift to electric vehicles.

4. ***Develop policies that address charging infrastructure barriers.*** Once barriers and needs are understood, cities have a number of policy tools at their disposal to encourage private investments to fill in the prevailing charging gaps. Cities and their corresponding regional and national governments may provide subsidies for particularly difficult applications, such as multi-unit dwellings or taxi fleets. Incentives can also be provided in the form of making land available for charging points, such as public right-of-way or city-owned parking garages. Cities could also offer reduced parking fees for electric vehicles or dedicate electric vehicle-only spaces, as in Oslo, encouraging higher utilization and a strong business case for installing charge points in those locations.[14] Changing permitting policies can help accelerate private installation of charging, while building codes help to ensure

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13 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.

14 "Lade og parkere elbil [Charging and parking electric vehicles]," Oslo commune, accessed January 22, 2020, https://www.oslo.kommune.no/gate-transport-og-parkering/parkering/lade-og-parkere-elbil/#gref

long-term provision of charging at a lower cost (discussed in the following section). Policies to encourage the electrification of ride-hailing and private-hire vehicles along with linked charging infrastructure support can encourage high-utilization business cases for charging operators. Over the longer-term, city plans would also include a comprehensive charging infrastructure plan for the implementation of zero-emission-only areas.[15]

5. ***Revisit and refine charging infrastructure action plans.*** As the market grows, some parts of the electric vehicle market inevitably will be better served than others by the growing mix of home, workplace, and public charging infrastructure. Furthermore, new market trends, such as growth in ride-hailing vehicles, and technologies, such as ultra-fast charging, will influence how electric vehicles are used. Continually reviewing market changes, assessing data from previous charging installations, comparing progress with other markets, and soliciting stakeholder feedback at regular intervals allows cities to refine policies to address shifting needs over time.

ASSESSING CHARGING INFRASTRUCTURE DEMAND FOR THE GROWING MARKET

While most cities are working to create paths for more private investment in charging infrastructure, some cities may also seek to create targets for each type of charging infrastructure in order to meet specific electric vehicle goals. One method of conducting such analysis is summarized in Figure 4 below.[16] The blue boxes illustrate the calculations at each step, the grey ovals indicate the questions each step answers, and the gold trapezoids indicate key data inputs. A similar methodology has been used to create country-specific charging benchmarks for future charging growth, again using detailed data on driver behavior, vehicle mix, and housing stock.[17]

15 "Our commitment to green and healthy streets," C40 Cities, January 2020, https://www.c40.org/other/green-and-healthy-streets.

16 This approach was applied to assess U.S. metropolitan area-level charging needs and could be adapted to other geographies. See: 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.

17 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.

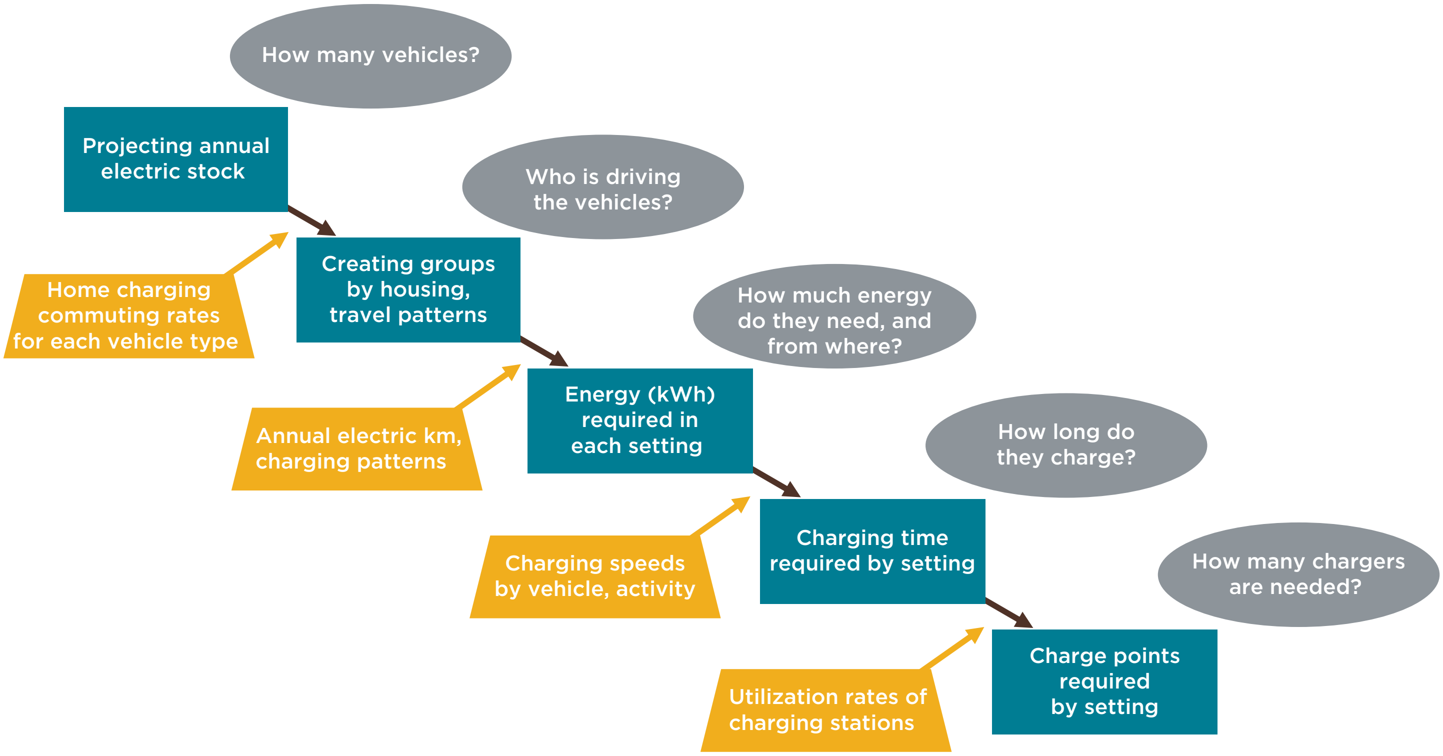

Figure 4. Illustration of process to estimate future charging demand.

A critical input into this process is detailed information about driving behavior, home charging feasibility, and charging preferences for drivers. Some of these data, such as charging preferences, can be estimated based on regional or national samples; others, such as distribution of cars by housing type, require city-level statistics. Surveys of electric vehicle drivers or telematics data can provide the best information about the fraction of charging performed at home, workplaces, in public destinations, and at DC fast charging stations.

These distributions will change over time based on attributes of the mainstream market and technological improvements. For example, the share of electric vehicle drivers living in multi-unit buildings will likely increase year-over-year, and electric range is also likely to increase. Charging models could take such shifts into account in order to not base future policy solely on early adopters' behavior. Ideally, regular updates with new data could be performed to gradually expand projections. Governments can also influence behavior through broader transportation policy (e.g., congestion pricing, public transport, and private hire vehicle licensing), so it is important to align the analysis's assumptions on driving behavior with other goals, such as parking reduction, mode shift, or development patterns.

After evaluating the amount and type of public charging needed, cities can optimize the locations of new charging infrastructure. Important factors to consider include the availability of sufficient electrical capacity, especially for DC fast charging, traffic patterns, dwell time, and proximity to residences without home charging. For example, Oslo has mapped the areas where charging will have the greatest impact on enabling private electric vehicle uptake by considering housing stock, parking availability, survey data, and charging utilization.[18] Governments, research institutions, and companies have created many charging location optimization models in markets around the world.[19]

CASE STUDY: GUIDING PRIVATE INVESTMENT IN STOCKHOLM

Even in markets with high electric vehicle growth, bureaucratic processes and delays related to site selection, permitting, and grid connection can discourage investment. Stockholm is tackling this challenge in its Charging Master Plan, which aims to deliver 4,000 public charge points by 2022. The goal is to make it as easy as possible for companies to install charging stations, while also ensuring high utilization of each station.

As part of the plan, the city has mapped priority areas for public charging investment through consultation with the grid operator Ellevio, the municipal planning department, and local businesses. Each site will have room for 4-10 charge points, intended either for overnight resident charging or rapid charging for taxis or commercial vehicles. These sites are "pre-approved" for the charging installation and made available on an online, public map showing the number and type of chargers approved, the electrical connections, and conditions (see colors on the example map, above).

Private operators can submit statements of interest for specific sites. To increase competition, each operator can only apply for up to 30 sites per round. Once formally approved, the operator is connected with the grid operator to encourage speedy installation. As a result, Stockholm is accelerating the growth of an efficient public charging network without direct subsidies. Other cities, such as Amsterdam and Rotterdam in the Netherlands and Denver and Portland in the United States, are also taking similar steps to prioritize and streamline charging, so a trend appears underway.

Source: "Ansök om att etablera nya laddplatser för elbil," Stockholms stad, accessed February 12, 2020, https://tillstand.stockholm/tillstand-regler-och-tillsyn/parkering/ansok-om-att-etablera-nya-laddplatser-for-elbil/

18 Bymiljøetaten, Oslo commune, "Kartlegging av ladebehov i Oslo kommune [Survey of charging needs in Oslo municipality]" (2019), https://www.oslo.kommune.no/getfile.php/13354701-1576848117/Tjenester%20og%20tilbud/Gate%2C%20transport%20og%20parkering/Parkering/Kartlegging%20av%20ladebehov%20i%20Oslo%20kommune.pdf.

19 Raphaela Pagany, Luis Ramirez Camargo, and Wolfgang Dorner. "A review of spatial localization methodologies for the electric vehicle charging infrastructure." International Journal of Sustainable Transportation 13, no. 6, (2019): 433-449. https://www.tandfonline.com/doi/full/10.1080/15568318.2018.1481243.

STREAMLINING THE INFRASTRUCTURE PLANNING PROCESS

Typical planning requirements and permitting processes can hinder the timely deployment of charging infrastructure to meet electric vehicle market growth. Local governments have explored a number of policies to streamline and expedite the permitting and installation of charging infrastructure. Ideally, such policies enable faster charging installation and improve the business case for private construction.

Expedited permitting for charging. While cities recognize the urgency of adding more charging infrastructure, regulations around the installation of high-powered electrical appliances can often delay and add cost to installations. Therefore, a number of governments have created special regulations to reduce permitting or inspection requirements or prioritize the approval of permits for charging stations. A California state law requires that all cities adopt streamline permitting processes for charging infrastructure; a number of other U.S. cities and states also have these provisions. The city of Vienna, Austria reduced restrictions and permitting requirements for charging infrastructure as part of their building code updates.[20] The European Union, as part of their 2018 Energy Performance in Buildings directive, requires all member states to adopt legislation simplifying permitting and approval procedures for charge points by 2025.[21]

Right to install private charging. While home charging is typically the most convenient and affordable option for charging, many drivers, especially those renting their homes or living in multi-unit dwellings, face hurdles getting approval to install a charging station. A solution is a "right-to-install" ordinance, meaning that tenants can install charging without seeking the permission of the building owner. Such laws have been adopted at the state level in California, Colorado, Florida, and Oregon in the United States, and in the province of Ontario, Canada.[22] Norway has a similar nationwide policy for all residential buildings.[23]

ELECTRIC VEHICLE-READY BUILDING CODES

If the vehicle fleet is to transition fully to electric vehicles, charging capacity will eventually be needed at most locations where vehicles are parked for an extended period of time. It is much less costly to install charging infrastructure at the time of construction or during a major renovation than to add it later. Building codes requiring that parking spaces be fitted with charge points, or the wiring to support future charge points, are an increasingly popular tool to accelerate the installation of charging infrastructure at a lower cost than building the charging infrastructure in older buildings.

Table 3 below summarizes key elements of selected electric vehicle-ready building codes. Although governments are taking different approaches due to local authority and

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20 Landesgesetzblatt für Wien, 69. Gesetz, Rechtsinformationssystem des Bundes, December 21, 2018, https://www.ris.bka.gv.at/Dokumente/LgblAuth/LGBLA_WI_20181221_69/LGBLA_WI_20181221_69.pdfsig.

21 "Questions & Answers on Energy Performance in Buildings Directive," European Union Directorate-General for Energy, accessed January 22, 2020, https://ec.europa.eu/info/news/questions-answers-energy-performance-buildings-directive-2018-apr-17_en.

22 Lyuba Wolf, "EV Charging for Condos: Get your HOA to Say 'Yes.'", *ChargePoint,* November 2, 2017, https://www.chargepoint.com/blog/ev-charging-condos-get-your-hoa-say-yes/.

23 Pierpaolo Cazzola, Marine Gorner, Sacha Scheffer, Renske Schuitmaker and Jacopo Tattini, *Nordic EV Outlook 2018.* (International Energy Agency: Paris, 2018), https://www.nordicenergy.org/wp-content/uploads/2018/05/NordicEVOutlook2018.pdf.

building stock, recently adopted building codes are generally setting higher levels, some up to 100%, of electric vehicle readiness for new parking facilities.[24]

Table 3. Example building codes supporting electric vehicle charging infrastructure.

Jurisdiction	Year taking effect	Construction type	Percent of spaces with charge points required	Percent of spaces "EV-ready" required	Other notes
London	2016	New residential	20%	20%	
		New retail	10%	10%	
		New workplace parking lots	20%	10%	
European Union	2020	New residential with >10 spaces, or major renovation	-	100%	Directive requires Member States to implement their own policies by 2025
		New non-residential with >10 spaces, or major renovation	1 space	20%	
Guangzhou	2019	New residential	-	100%	Some specific applications require charge points to be installed
		New public parking lots	-	30%	
		New highway service stations	-	50%	
San Francisco	2018	All new construction and major renovation	-	100%	One fast charger can substitute for 5 EV-ready spaces

Notes: Building code information from: "Chapter 6: London's Transport" in *The London Plan* (Greater London Authority: 2017), https://www.london.gov.uk/what-we-do/planning/london-plan/current-london-plan/london-plan-chapter-six-londons-transport-0;
"Questions & Answers on Energy Performance in Buildings Directive," European Union Directorate-General for Energy, accessed January 22, 2020, https://ec.europa.eu/info/news/questions-answers-energy-performance-buildings-directive-2018-apr-17_en; "Views on accelerating the innovation and development of new energy vehicle industry [广东省人民政府关于加快新能源汽车产业创新发展的意见]," Guangdong provincial government, accessed January 22, 2020, http://www.gd.gov.cn/gkmlpt/content/0/146/post_146920.html; San Francisco Green Building and Environment Codes - Requirements for Installation of Electric Vehicle Chargers, San Francisco Board of Supervisors, Ordinance No. 92-17, April 17, 2017, https://sfbos.org/sites/default/files/o0092-17.pdf.

Cities may also adopt requirements for open standards for charging and standards enabling smart charging, such as using the Open Charge Point Protocol (OCPP) or ISO 15118. While these are often mandated at a national level, such as in the Netherlands, or state level, such as in California, cities outside of jurisdictions with existing requirements may adopt such standards. Oslo is one such example, requiring OCPP and open payment standards for all stations that receive public funding.

COORDINATION WITH UTILITIES

Electric power companies and grid operators are critical partners in building out charging infrastructure in an efficient, safe, and cost-effective manner. However, complex regulatory and business structures can hinder coordination between governments and

24 Hongyang Cui, Dale Hall, and Nic Lutsey, *Electric vehicle capitals: Accelerating the global transition to electric drive,* (ICCT: Washington, D.C., 2018), https://theicct.org/publications/ev-capitals-of-the-world-2018.

CASE STUDY: EV-READY BUILDING CODES IN SAN FRANCISCO AND CALIFORNIA

California has used building codes to promote sustainability since 1978. The Green Building Code first included electric vehicle charging as a voluntary measure in 2008; local governments across the state are now enacting more ambitious standards and influencing similar building codes developments outside California.

San Francisco set a new bar for EV-ready building codes in the United States with its 2017 update. The regulation requires that 100% of parking spaces in all new commercial and residential buildings be "EV ready." Ten percent of those must be "turnkey ready" with outlets and full panel capacity; the remainder must have wiring or conduit in place to reduce the cost of future installation. There must be sufficient electrical capacity to charge electric vehicles simultaneously at 20% of spaces. To provide flexibility, the code also allows for the installation of a DC fast charging station to substitute for five EV-ready parking spaces. The same requirements also apply to buildings undergoing major alterations, an important consideration in a city with relatively little new construction. Research for this new building code was funded by the California Energy Commission, further illustrating the synergistic relationship between state and local governments on this issue.

San Francisco remains the largest city in the United States with a 100% EV-ready ordinance, but many other cities have adopted codes that go even further by requiring energized outlets or actual charging points. This includes Vancouver, British Columbia and nearby cities, where 100% of residential spaces are required to have outlets and panel capacity, and several major cities in China, including Beijing, Guangzhou, and Qingdao, where 100% of residential spaces are required to have outlets or charge points.

Sources: San Francisco Green Building and Environment Codes - Requirements for Installation of Electric Vehicle Chargers, San Francisco Board of Supervisors, Ordinance No. 92-17, April 17, 2017, https://sfbos.org/sites/default/files/o0092-17.pdf; C2MP and Fraser Basin Council, "Residential Electric Vehicle Charging: A Guide for Local Governments" (City of Richmond, 2019), https://www.richmond.ca/__shared/assets/Residential_EV_Charging_Local_Government_Guide51732.pdf; "广州市工业和信息化委 广州市财政局关于印发广州市电动汽车充电基础设施补贴资金管理办法的通知," Guangzhou Industrial and Information Commission, Guangzhou, June 7, 2018 ,https://www.gz.gov.cn/gzswjk/2.2.11/201810/b8a0c6319fd44c9bb48587021e6b8634.shtml;
"北京市城市管理委员会关于印发实施《2019年度北京市单位内部公用充电设施建设补助资金申报指南》的通知," Beijing Urban Management Committee, May 9, 2019, http://www.beijing.gov.cn/zhengce/gfxwj/201908/t20190805_102886.html.

the private sector. City governments can work with utilities in a number of ways to accelerate charging infrastructure construction, as shown in these three examples:

» In Amsterdam, the electric power companies Nuon and Vattenfall install curbside charging stations based on estimated demand for residential charging. Nuon also helps to coordinate smart charging programs at these public stations to encourage more charging when there is excess grid supply.[25]

» In Vienna, the Wiener Stadtwerke utility constructed and managed DC fast charging infrastructure for the electric taxi fleet, and supported trial projects integrating electric mobility with the public transit network.[26]

» New York City is partnering with local utility ConEd to build fast charging hubs throughout the city, with a goal of 50 such hubs in 2020. The utility is helping to select sites and build grid-friendly infrastructure.[27]

Coordination with distribution system operators (DSOs) is especially important for fast and ultra-fast charging. DSOs have the clearest understanding of where there is available grid capacity for installing new stations, and where upgrades would be needed. Working with these DSOs to increase transparency and access to such data on grid capacity without sacrificing privacy or data security can help to accelerate and reduce the cost of constructing more fast charging infrastructure.

TARGETED SUBSIDIES AND INCENTIVES

A number of local governments provide incentives for charging infrastructure for particular applications with high costs, or where the private market is less likely to invest. For example, Paris provides incentives for 50% of the installation and labor costs to install charging infrastructure in apartment buildings, and also provides a 50% subsidy for home charging for taxi drivers.[28] Berlin provides a 50% subsidy for the construction of public AC charging stations for small- and medium-sized businesses.[29] In China, major cities with high electric vehicle shares, including Beijing and Guangzhou, offer subsidies for public chargers, often scaling the subsidy amount to the power in kilowatts.[30] Oslo

25 Doede Bardok, Art van der Giessen, Carla van der Linden, and Bart Vertelman, "Plan Amsterdam: The Electric City" (Gemeente: Amsterdam, 2018), https://issuu.com/gemeenteamsterdam/docs/plan_amsterdam_4-2018_the_electric.

26 "E-mobility on demand," Wiener Stadtwerke, accessed January 22, 2020, https://www.wienerstadtwerke.at/eportal3/ep/programView.do/pageTypeId/71282/programId/73024/channelId/-51285.

27 "Leading the Charge: Mayor Announces Fast-Charging EV Hubs in All 5 Boroughs," Office of the Mayor of New York, New York City, accessed on January 22, 2020, https://www1.nyc.gov/office-of-the-mayor/news/600-17/leading-charge-mayor-fast-charging-ev-hubs-all-5-boroughs.

28 "Les aides financières pour inciter à des mobilités propres [Financial aid to encourage own mobility]," City of Paris, accessed on January 22, 2020, https://www.paris.fr/services-et-infos-pratiques/deplacements-et-stationnement/deplacements/lutte-contre-la-pollution-les-aides-a-la-mobilite-5373.

29 "Wirtschaftsnahe Elektromobilität (WELMO) [Economical Electric Mobility]," Investitionsbank Berlin, accessed on January 22, 2020, https://www.ibb.de/de/foerderprogramme/wirtschaftsnahe-elektromobilitaet.html.

30 "广州市工业和信息化委 广州市财政局关于印发广州市电动汽车充电基础设施补贴资金管理办法的通知 [Notice of the Guangzhou Municipal Bureau of Industry and Information Technology of the Guangzhou Municipal Finance Bureau on Printing and Distributing the Measures for the Administration of Subsidy Funds for Electric Vehicle Charging Infrastructure in Guangzhou]," Guangzhou Industrial and Information Commission, Guangzhou, June 7, 2018 ,https://www.gz.gov.cn/gzswjk/2.2.11/201810/b8a0c6319fd44c9bb48587021e6b8634.shtml;
"北京市城市管理委员会关于印发实施《2019年度北京市单位内部公用充电设施建设补助资金申报指南》的通知 [Notice of the Beijing Municipal Administration on Printing and Distributing the Guidelines for the Application of Subsidies for the Construction of Public Charging Facilities in Beijing Units in 2019]," Beijing Urban Management Committee, May 9, 2019, http://www.beijing.gov.cn/zhengce/gfxwj/201908/t20190805_102886.html.

subsidizes home charging for taxi drivers and in garages at housing cooperatives, finding it more cost-effective than building additional public charging.

State and national governments also offer incentive programs for charging infrastructure. City governments can help residents take advantage of these programs and advocate for the introduction of national-level programs. While the Swedish government provides incentives for charging stations in apartment buildings, the city government in Stockholm hosts public workshops and information sessions to help tenants and community groups successfully navigate these programs.[31] London, Milton Keynes, Bristol, and Nottingham were selected as winners of the UK national government's Go Ultra Low Cities Challenge to create innovative electric vehicle promotions. The London project has so far resulted in 1,700 charge points installed through the summer of 2019. London also conducted its own "Neighbourhoods of the Future" competition, through which several boroughs are testing innovative infrastructure and incentive schemes.[32]

STAKEHOLDER OUTREACH

When planning charging infrastructure, it is critical to understand neighborhood-level dynamics in addition to relying on data and modeling exercises. Extensive stakeholder outreach—with drivers, community organizations, fleets, and charging companies—can ensure that charging is well-utilized and convenient and that the investments engender community goodwill.

London offers two examples of stakeholder outreach. The Mayor's Office has funded Low Emission Neighbourhood programs in nine boroughs since 2016, each of which includes several specially tailored programs to support ultra-low emission vehicles and the related charging infrastructure. This program has encouraged boroughs to consult their communities and businesses, set high aspirations for electric vehicles, and develop innovative solutions to fit their own needs, rather than depend on top-down planning from the Greater London Authority. Simultaneously, the Mayor's office convened the EV Infrastructure Task Force of local and national agencies, power companies, distribution network operators, and trade associations to accelerate charging infrastructure build-out. The Task Force published a Delivery Report with private commitments to build charging infrastructure and suggestions for policies to lower barriers (see box on page 5).[33]

31 "Fix a Charging Station," Energy Office of Greater Stockholm, accessed on January 22, 2020, http://energiradgivningen.se/projekt/fixa-laddplats-till-flerbostadshus.

32 "Go Ultra Low City Scheme," London Councils, accessed on January 22, 2020, https://www.londoncouncils.gov.uk/our-key-themes/transport/roads/gulcs.

33 "Electric vehicles and charge points," Transport for London, accessed January 22, 2020, https://tfl.gov.uk/modes/driving/electric-vehicles-and-rapid-charging.

CONCLUSIONS

Cities are taking an active role in advancing the electric vehicle market, with benefits for air quality and the climate. Building the charging infrastructure to support this growing market as part of a full suite of supporting policies will be an ongoing challenge in this transition. This guide provides key lessons for cities on building out their charging infrastructure system, based on the activities in leading markets. Among the principle findings are the following:

Much more charging of all kinds is needed to enable a full transition to electric vehicles. To meet ambitious electric vehicle goals and ensure flexibility for all drivers, cities will need many more charging points in public, at homes, and at workplaces; up to a 20% growth in charge points each year. In general, charging infrastructure would grow approximately proportional to the electric vehicle stock, but additional public charging, including DC fast charging, can also fill in gaps when private home and workplace charging is infeasible in particular settings. While some charging stations may experience low utilization today, they will be used more over time, as most parking sites with electrical capacity and parking demand will one day benefit from having charging.

Each city can plan for its unique charging needs. The mix of a city's charging needs, such as public and private points, or regular and fast charging options, would ideally be assessed based on each city's local factors, including housing stock, commuting patterns, vehicle mix, electric vehicle growth expectations, and the electrical grid. Although charging metrics like electric vehicles per charge point can be useful for city comparisons, these metrics should not serve as universal one-size-fits-all targets for future deployment. Through its own data-driven assessment, a city can determine how much charging of what type is needed, consult with stakeholders, and ultimately develop policies that promote private sector investments. Such assessments would ideally be refined and updated with changing market conditions, user feedback, and technological improvements. Over the longer-term, city plans could include a comprehensive charging infrastructure plan to enable zero-emission-only mobility.

Many policies can accelerate the pace of charging deployment. Although long-term planning is important, cities have a number of tools that they can implement now to accelerate the construction of infrastructure by a range of different charging providers. Electric vehicle-ready building codes are critical for ensuring the long-term build-out of charging in a cost-effective manner. Streamlined permitting processes and pre-approval of sites can help to spur private investment in charging infrastructure and reduce delays; open charging standards can also help to increase competition and improve user experience. Targeted, easy-to-access incentives, both from local and national governments, can fill in gaps in the private charging space. Policies to encourage the electrification of ride-hailing and private-hire vehicles, linked with charging infrastructure support, can encourage high-utilization business cases for charging operators. Working closely with electric utilities and grid operators will be crucial for constructing charging in a grid-friendly, cost-effective way, especially as fast charging continues to grow in importance.

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