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CHARGING UP CHINA'S TRANSITION TO ELECTRIC VEHICLES

A dive into China's public charging infrastructure deployment and comparison with Europe and the United States

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About the ICCT: The International Council on Clean Transportation (ICCT) is an independent nonprofit organization founded to provide first-rate, unbiased technical research and scientific analysis to environmental regulators. Its mission is to improve the environmental performance and energy efficiency of road, marine, and air transportation to benefit public health and mitigate climate change.

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EXECUTIVE SUMMARY

China has made substantial progress in the transition to electric vehicles (EVs) but will have to accelerate EV adoption to meet the government's ambitious target of peaking carbon dioxide (CO_2) emissions by 2030 and achieving carbon neutrality by 2060. Despite government efforts to expand and improve the country's charging infrastructure, insufficient charging access remains among the major barriers to widespread EV uptake nationally.

This report examines the state of China's public charging infrastructure development, including the number, coverage, capacity, and utilization of public chargers installed in the country. We also compare public charger deployment in China with trends in Europe and the United States and provide recommendations on how to further enhance China's public charging infrastructure network. From this analysis, we draw the following main conclusions:

» China has established the world's largest public charging infrastructure network, with a public charger stock reaching 1 million—51% of the global total—and a total rated power exceeding 56 gigawatts as of 2022.

» China's public chargers were disproportionately concentrated in the most developed cities, with just 15 cities containing 57% of the country's public charger stock as of 2022.

» Highways are a particular weak spot of China's public charging infrastructure network. As of 2022, China's highway public charger density was six times lower than that of Norway.

» Several Chinese cities have established widely-distributed public charging networks in their urban cores, in which virtually 100% of EV drivers can find a public charger within 20 minutes of driving time. Public charger coverage in suburban and rural areas is much lower by comparison.

» Public chargers in the urban cores of leading cities have a relatively high average utilization rate, on par with rates in Amsterdam, while citywide averages are low.

We offer the following recommendations for China to further enhance its public charging infrastructure network:

» Localized near- and long-term plans on EV charging infrastructure deployment could be established at the provincial and city level based on data-driven EV charging needs assessments that account for local EV usage trends and charging demands.

» A comprehensive set of metrics could be leveraged to more accurately evaluate public charging infrastructure, including minimum drive time to reach a public charging pool, public power output installed per EV, and utilization rate of public chargers.

» Public charging infrastructure networks could be expanded beyond the urban centers of the most developed cities and charger availability on highways could be enhanced with dedicated policy and financial support.

» The establishment of an official national database on charging infrastructure would improve the comprehensiveness and quality of data on public chargers in China and enable more in-depth analysis to support policy design. A database should separately count chargers for heavy-duty vehicles, which have particular charging needs and account for a disproportionate share of emissions.

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INTRODUCTION

In many respects, China is leading the global transition to electric vehicles (EVs) (Chu & Cui, 2023). As shown in Figure 1, 6.3 million EVs—including battery electric vehicles and plug-in hybrid electric vehicles—were sold in China in 2022, representing 26% of China's total vehicle sales and 59% of EV sales globally. These 6.3 million EVs included 5.9 million passenger cars, 256,000 light-duty trucks, 62,000 buses and coaches, and 33,000 medium- and heavy-duty trucks. By the end of 2022, China's cumulative EV sales since 2013 reached 15.6 million, accounting for 54% of the global total (EV Volumes, 2023). Nevertheless, the adoption of EVs in China must accelerate if the country is to realize the government's ambitious target of peaking carbon dioxide (CO_2) emissions by 2030 and achieving carbon neutrality by 2060 (Jin et al., 2021).

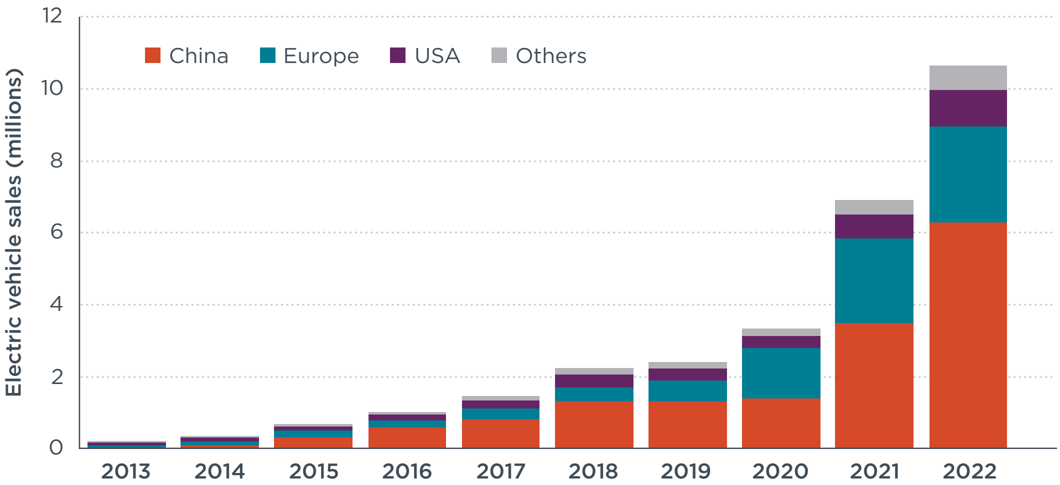

Figure 1. Annual electric vehicle sales by market from 2013 to 2022.

Insufficient access to chargers is among the major barriers to more widespread EV uptake in China, despite efforts by the government to expand and improve the country's public charging infrastructure (National Development and Reform Committee, 2022; General Office of China State Council, 2023). Also known as electric vehicle supply equipment, charging points, or charging ports, chargers are devices through which electricity is transferred from the grid to the EV. As illustrated in Figure 2, a charger typically has one connector, while a charging pool consists of one or more chargers. In markets where multiple charging standards coexist, such as Europe and the United States, a charger may consist of multiple connectors that each comply with different charging standards. In such cases, when one connector is being used, no power will be allocated to the other connectors of the same charger. In China, all chargers comply with one unified charging standard and one connector counts as one charger.

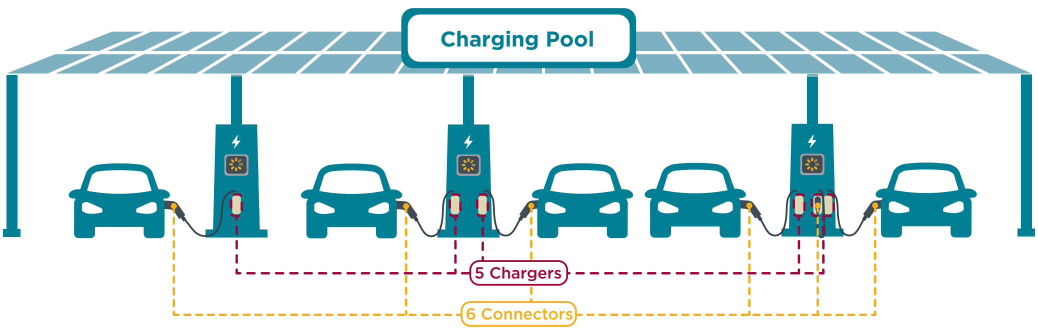

Figure 2. Concept chart of a charging pool with multiple chargers and connectors.

This report examines the state of China's deployment of public chargers, or wired stationary chargers that are accessible to the public, in comparison to that of Europe and the United States.[1] The following four sections analyze the number, coverage, capacity, and utilization of public chargers, respectively. The last section provides recommendations to enhance China's public charging infrastructure network. In this paper, charger deployment data are sourced from the China Automotive Technology and Research Center (for China), Eco-movement (for Europe), and the Alternative Fuels Data Center of the U.S. Department of Energy (for the United States).

1 Chargers that are only accessible to specific vehicle owners, such as home and depot chargers, are outside the scope of this analysis, as are emerging alternative charging solutions that remain at an early demonstration stage, such as battery swapping, wireless charging, and overhead catenary charging (Rajon Bernard et al., 2022).

NUMBER OF PUBLIC CHARGERS

China has installed more public chargers than any other country in the world. By the end of 2022, China's public charger stock had reached 1 million, a 25% increase from the previous year. This represented 51% of the global total and was almost twice the public charger stock of Europe and eight times that of the United States (Figure 3).[2] Public chargers are categorized as either alternating current (AC) or direct current (DC); DC chargers usually have a larger installed power output (i.e., maximum power that they can deliver to an EV) and thus are capable of recharging a vehicle faster than AC chargers. As of 2022, 47% of China's public chargers were DC, a significantly higher share than in Europe (13%) and the United States (21%). Of all public DC chargers installed worldwide by the end of 2022, 76% were in China. (On the power distribution of AC and DC chargers in China, see "Capacity of public chargers," below.)

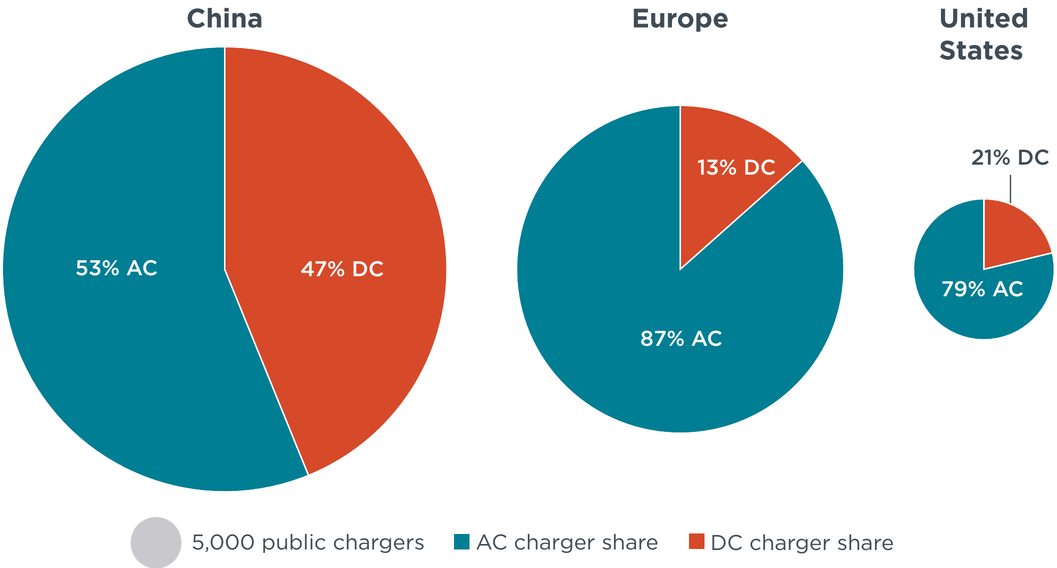

Figure 3. Public charger stock by type in China, Europe, and the United States as of 2022 (bubble size represents public charger stock).

Figure 4 compares the top 10 cities in China, Europe, and the United States in terms of public charger stock as of 2022, and the relative shares of AC and DC chargers in each city.[3] The top five cities in public charger stock globally were all in China. Shenzhen ranked first with 146,000 public chargers, followed by Shanghai (73,000), Guangzhou (57,000), Wuhan (41,000), and Beijing (35,000). Together, these cities accounted for 17% of global stock. Amsterdam ranked first in Europe, with 29,000 public chargers; two other Dutch cities, Rotterdam and Utrecht, also placed in the top five. In the United States, three of the top five cities by public charger stock were in California, led by Los Angeles, which ranked first among U.S. cities with 12,000 chargers.

The share of DC chargers in the top 10 Chinese cities ranged from 18% (Shenzhen) to 72% (Chengdu). Shares of DC chargers were generally much lower in Europe, where they ranged from 2% (Amsterdam) to 14% (Barcelona), and in the United States, where they ranged from 9% (Boston) to 22% (New York).

2 Europe here refers to the 27 European Union Member States, four European Free Trade Association (EFTA) Member States (Iceland, Liechtenstein, Norway, and Switzerland), and the United Kingdom.

3 In this paper, European and U.S. cities refer to metropolitan areas to allow more consistent comparison with China, where the official definition of a city is closer to the concept of a metropolitan area.

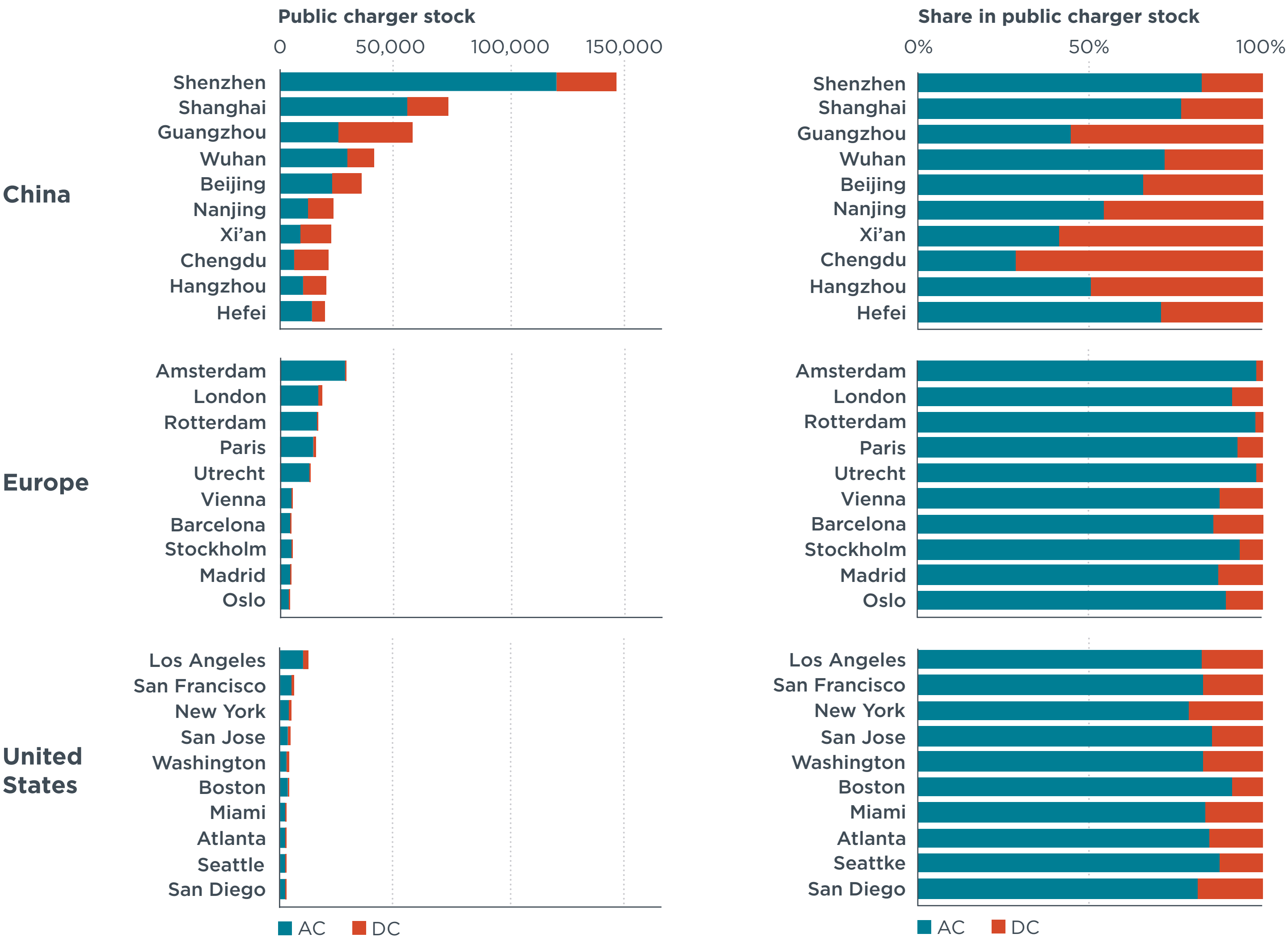

Figure 4. Public charger stock (left) and technology mix (right) of the top 10 cities in China, Europe, and the United States in terms of public charger stock in 2022.

Figures 5, 6, and 7 show the geographic distribution of public charger stock in these three markets. Cities in eastern and southern China generally had more public chargers in place than those in western and northern China, resembling trends in EV uptake in the country, which has been concentrated in the east and south (Chu & He, 2022). A similar concentration of both public charger stock and EV uptake was also seen in northern and western Europe (Rajon Bernard et al., 2021), and along the east and west coasts of the United States (Bui et al., 2021).

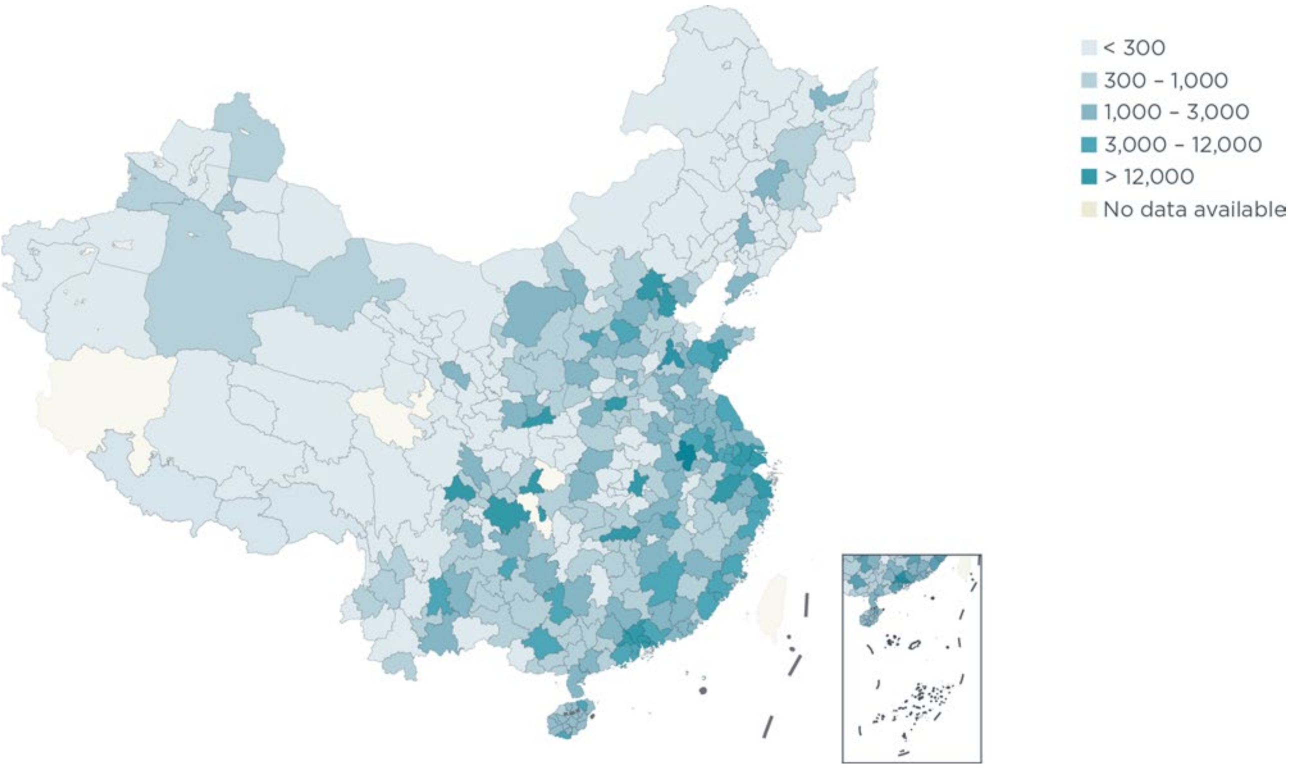

Figure 5. Public charger stock at the city level in China as of 2022.

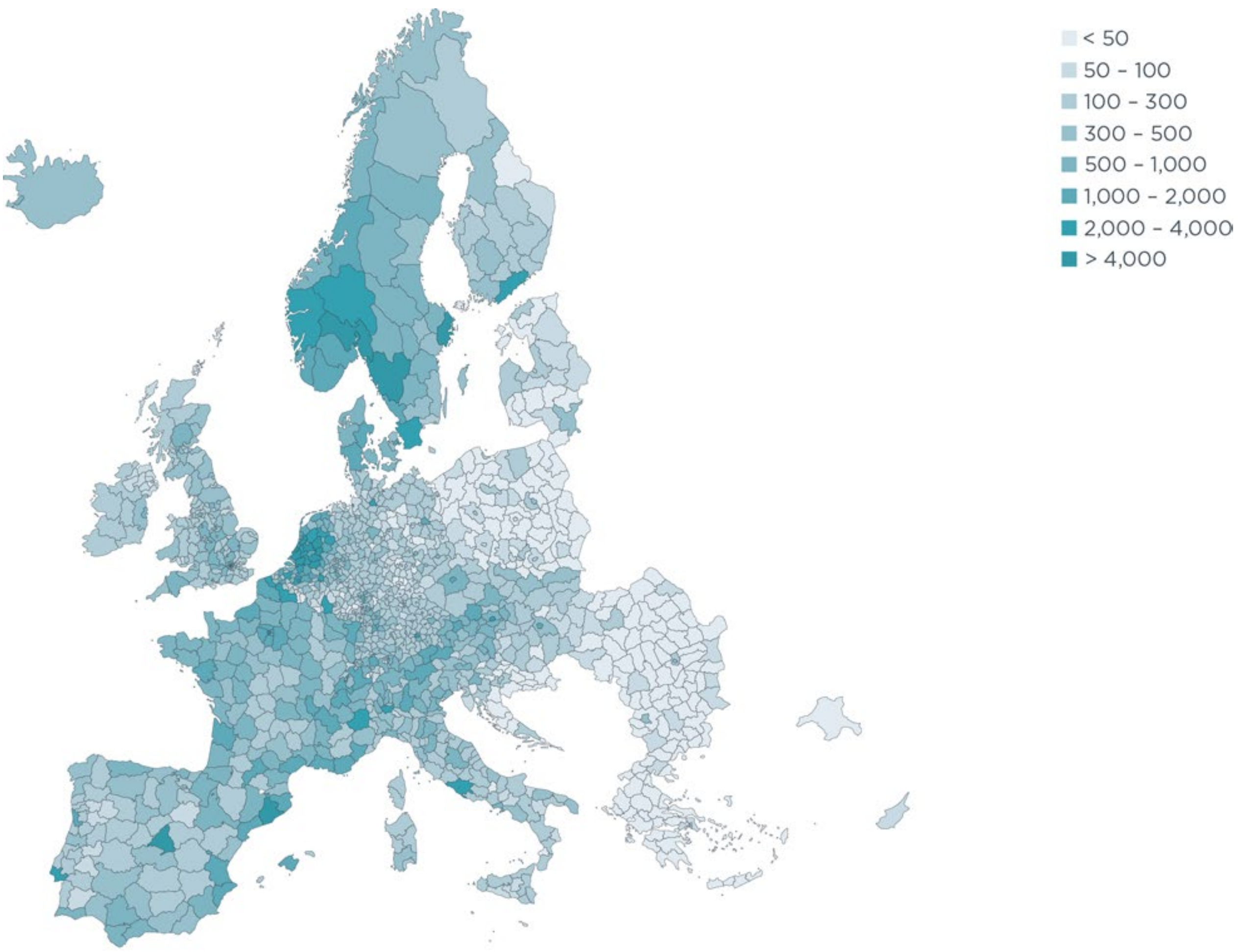

Figure 6. Public charger stock at the city (NUTS 3) level in Europe as of 2022.

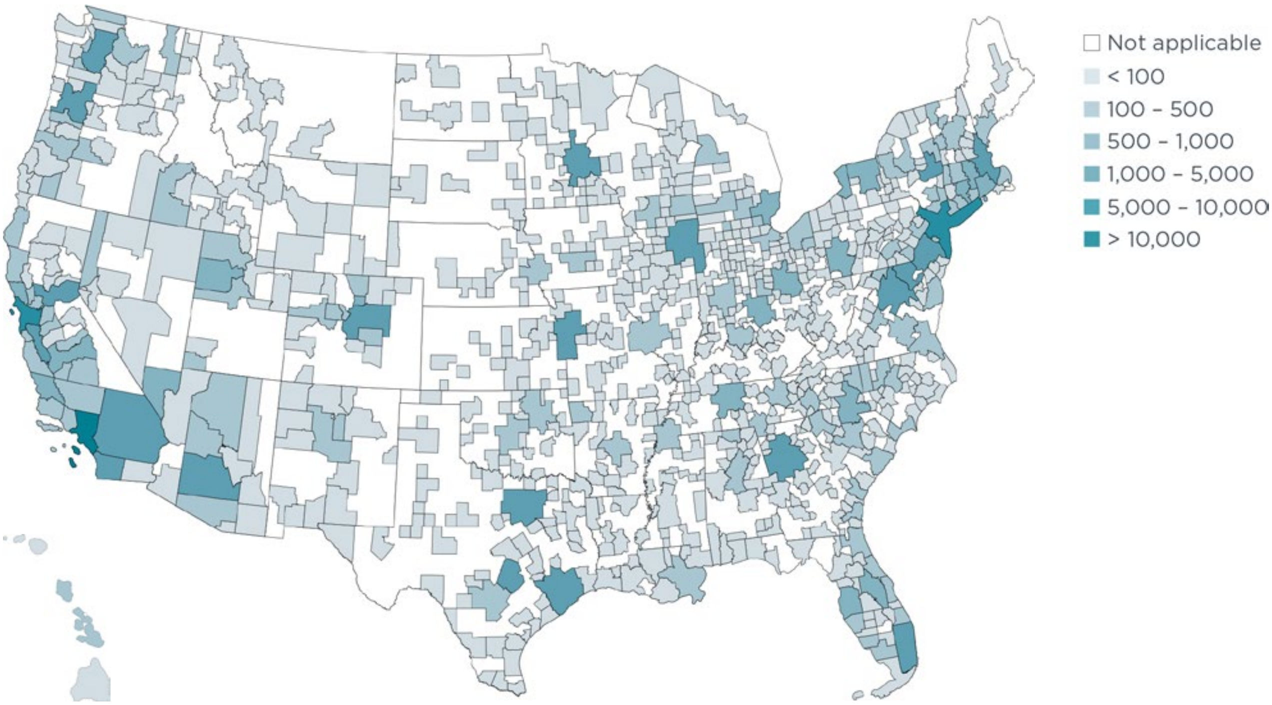

Figure 7. Public charger stock at the city (CBSA) level in the United States as of 2022.

Figure 8 further explores the variation in public charger stock between cities. In all three markets, public chargers were concentrated in a small number of more developed cities. China had the highest concentration in this regard, with 15 leading cities (out of 338 total cities designated as prefecture-level or higher) accounting for 57% of public charger stock. In Europe and the United States, the top 15 cities accounted for 23% and 47% of public charger stock, respectively.

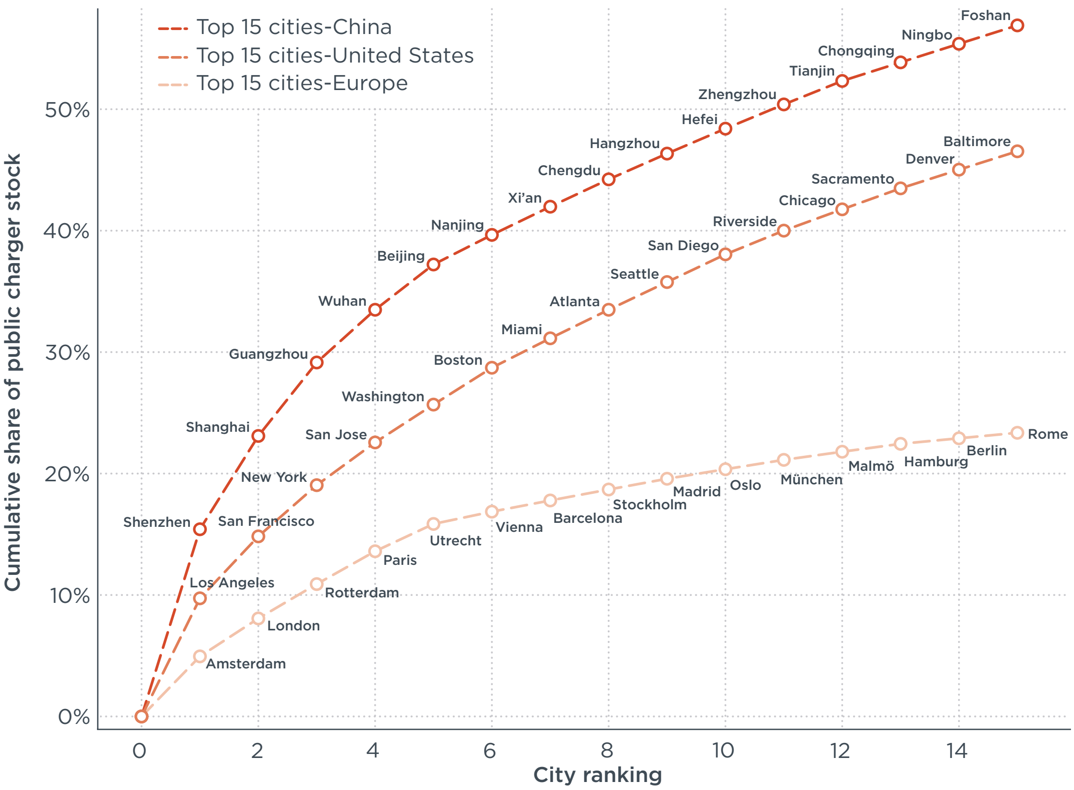

Figure 8. Cumulative share of public charger stock of the top 15 cities by public charger stock in China, Europe, and the United States as of 2022.

Public charger availability on highways is among Chinese EV drivers' greatest concerns on long-distance trips (Yao & Lin, 2023). Figure 9 compares highway public charger density—calculated by dividing the total number of public chargers alongside highways by total length of highways—in China and Norway, the countries with the highest EV penetration in the world. As of 2022, China's highway public charger density was 105 per thousand kilometers, compared with 654 in Norway. As of June 2023, according to data released by China's Ministry of Transport, China had installed 18,590 public chargers alongside highways, representing less than 2% of the nation's total public charger stock ("Nearly 90% of highway service centers," 2023).

We also conducted this analysis at the provincial and state level, using the province of Hainan in China and the state of California in the United States, which have the highest EV penetration among Chinese provinces and U.S. states, respectively. As shown in Figure 9, Hainan's highway public charger density was 115 per thousand kilometers, compared with 135 in California.

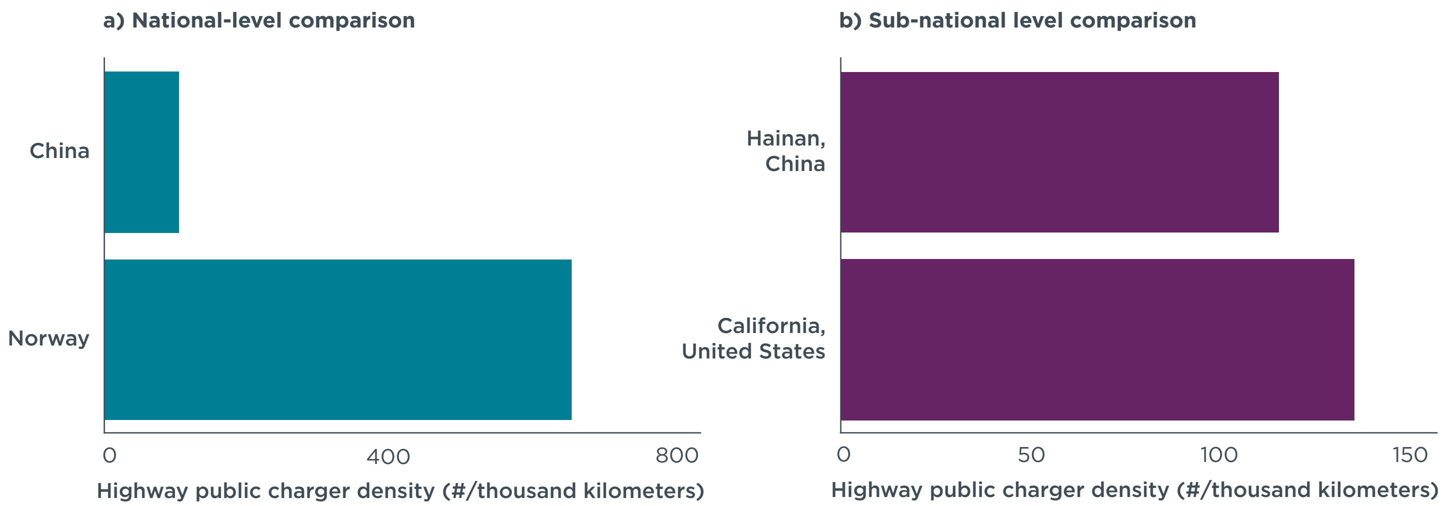

Figure 9. Highway public charger density in China and Norway (left) and in Hainan (China) and California (United States) (right) as of 2022.

COVERAGE OF PUBLIC CHARGERS

When measuring public charger availability, it is also essential to examine the coverage of public chargers—that is, how public chargers are geographically distributed within a given area. The straight-line distance to the nearest public charging pool is currently used in some Chinese cities to assess public charger coverage; however, this metric has obvious limitations, as straight-line distances often do not reflect the actual distance that an EV owner needs to drive to get to a charging pool.

Minimum drive time needed to reach a charging pool, measured in minutes, is a more accurate and straightforward measure of public charger coverage. Figure 10 explores the minimum drive time to reach public charging pools in Shanghai, Beijing, and Chengdu. Orange and purple regions represent areas where EV drivers could find a public charger within 5 minutes and 20 minutes of drive time, respectively, as of 2022.

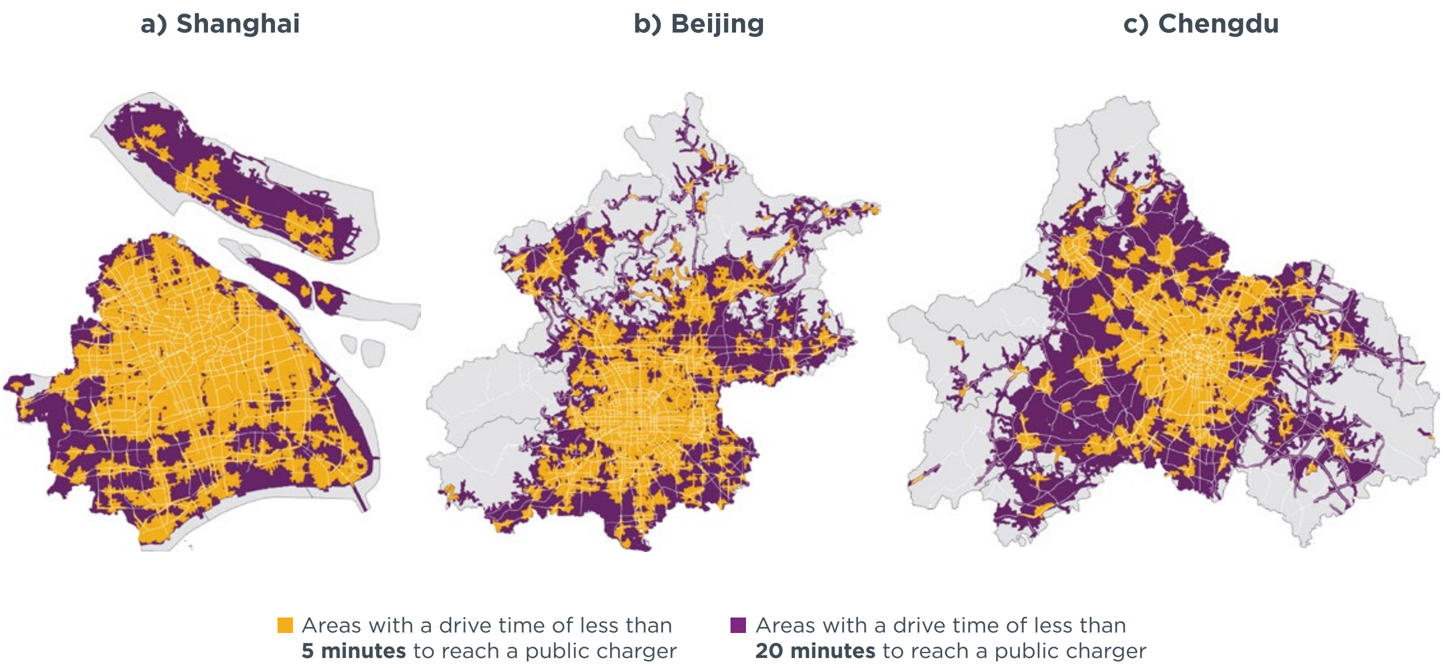

Figure 10. Minimum drive time needed to reach a public charging pool in Shanghai, Beijing, and Chengdu as of 2022.

As shown in Figure 10, 42% of the area of Shanghai falls within a five-minute drive from a public charger, while 82% is within a 20-minute drive. In Beijing and Chengdu, which are each more than double the area of Shanghai and are comparatively less urbanized, 20% and 15% of city area, respectively, falls within a five-minute drive of the nearest public charging pool, while 53% of both cities is within a 20-minute drive. If we only consider urban centers, five-minute coverage rates for Shanghai, Beijing, and Chengdu were 93%, 70%, and 81%, respectively, while the 20-minute coverage rate for all three was almost 100%.[4]

4 Urban centers here refer to areas in Shanghai within Outer Ring Road, the six inner-city districts in Beijing, and areas in Chengdu within Ring Highway.

CAPACITY OF PUBLIC CHARGERS

The capacity of public chargers, measured in power output, is another critical factor to consider when assessing charging infrastructure networks. The total rated power of China's public charging infrastructure network surpassed 56 gigawatts by the end of 2022, three times that of Europe. Public charging power installed per EV was 4.3 kW in China, compared with 2.4 kW in Europe.

As shown in Figure 11, China's public chargers were dominated by AC chargers with a rated power of 7 kW, which accounted for 51% of the country's total public charger stock in 2022, followed by DC chargers with a rated power of 120 kW (19%), 60 kW (7%), and 150 kW (5%). Among China's public AC chargers, 90% were 7 kW and 4% were 3.5 kW; among public DC chargers, 43% were 120 kW, 16% were 60 kW, and 11% were 150 kW.

In Europe, AC chargers with a rated power of 22 kW were the most common charger type, accounting for 37% of total public charger stock in 2022, followed by AC chargers with a rated power of 11 kW (20%) and DC chargers with a rated power of 50 kW (8%). Among Europe's public AC chargers, 46% were 22 kW and 25% were 11 kW; of its public DC chargers, 40% were 50 kW, 13% were 150 kW, and 8% were 300 kW.

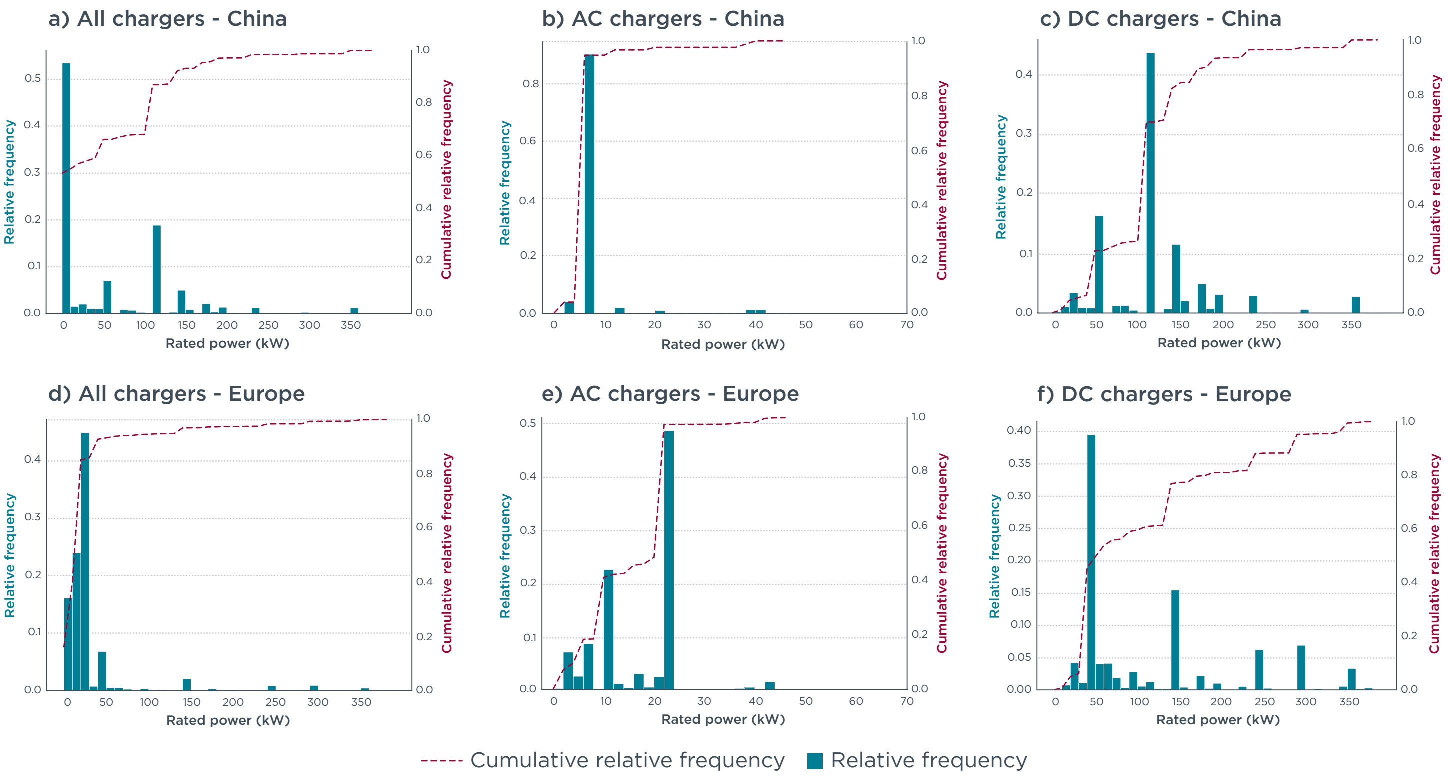

Figure 11. Rated power distribution of public chargers installed in China and Europe as of 2022.

Figure 12 compares the rated power distribution of public chargers among the 10 cities in China and Europe with the largest public charger stock as of 2022. As of 2022, the rated power of public AC and DC chargers in China averaged 9 kW and 129 kW, respectively. By contrast, Europe featured a much higher average rated power for AC chargers (16 kW) and a slightly lower average rated power for DC chargers (121 kW). At the city level, the power distribution of public chargers was generally more varied among European cities than Chinese cities; across both China and Europe, the rated power distribution of DC chargers was more varied than that of AC chargers.

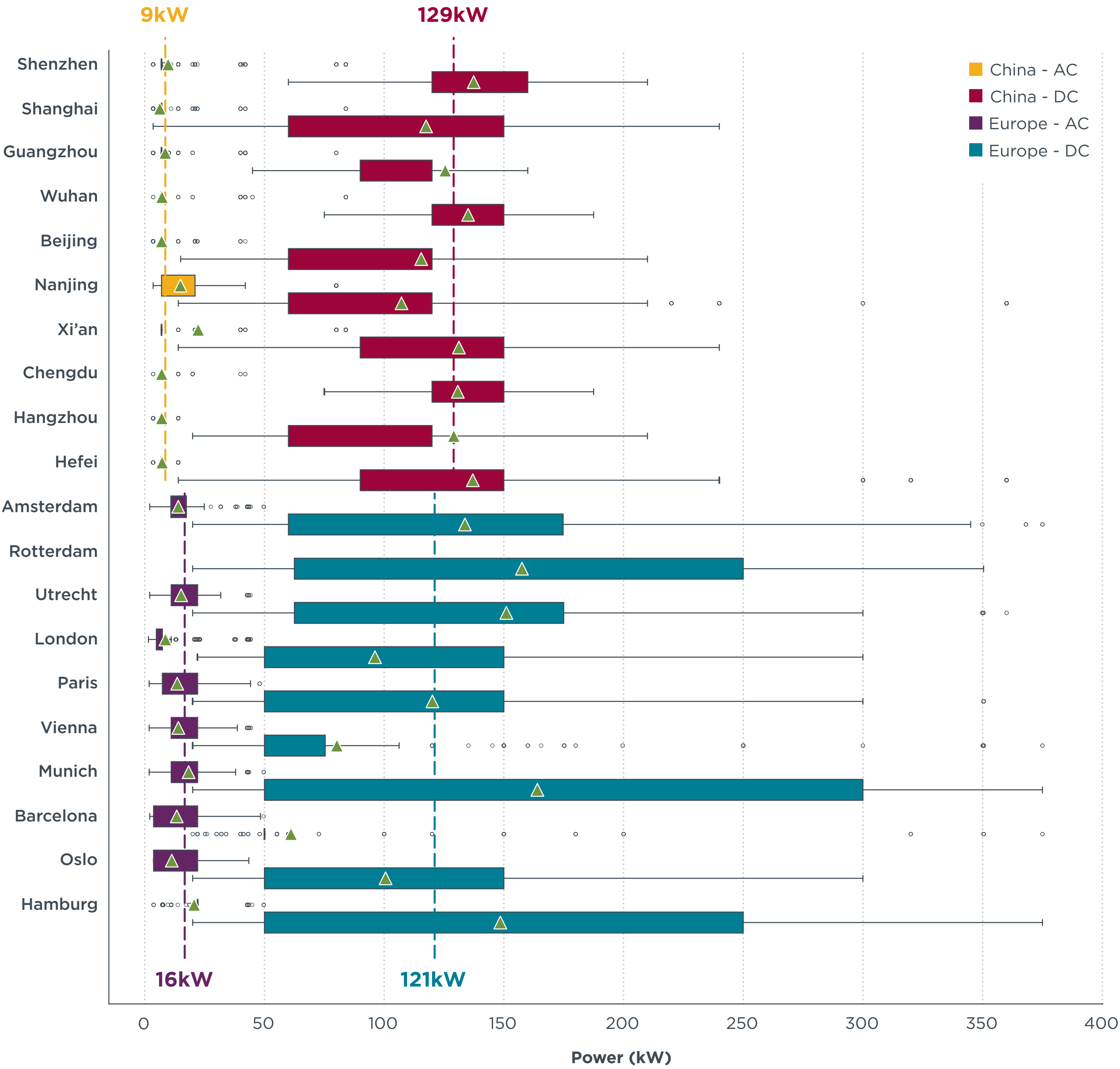

Figure 12. Rated power distribution of public chargers in the top 10 Chinese and top 10 European cities by public charger stock as of 2022. The green triangles represent the average rated power of public chargers in each city. The dashed lines show the average values across all cities in China and Europe.

In both China and Europe, policymakers view public charger-per-EV ratio as a key factor when evaluating and planning the deployment of charging infrastructure (National Development and Reform Commission, 2015; European Parliament, 2014); however, this metric risks overlooking differences in power output between chargers. With the adoption of the European Union Alternative Fuel Infrastructure Regulation (AFIR) in 2023, Europe has begun to emphasize the public power installed-per-EV ratio (Rajon Bernard, 2023), which better depicts how overall public charging capacity matches with EV charging needs in a given area.

Figure 13 shows the top 10 cities in China by public power installed-per-EV ratio as of 2022. Only cities with an EV stock of over 50,000 were taken into consideration. Kunming ranked first with a per-EV installed public power of 11.6 kW, 2.7 times the national average. The other cities in the top 10 were Quanzhou (10.7 kW), Fuzhou (9.8 kW), Xi'an (9.1 kW), Wuhan (8.8 kW), Nanjing (8.2 kW), Guangzhou (8.0 kW), Xiamen (7.8 kW), Taiyuan (7.5 kW), and Qingdao (7.4 kW). As discussed below, looking ahead, Chinese cities should consider emphasizing public power installed-per-EV ratios, instead of the traditional public charger-per-EV ratios, when evaluating and planning the deployment of public charging infrastructure.

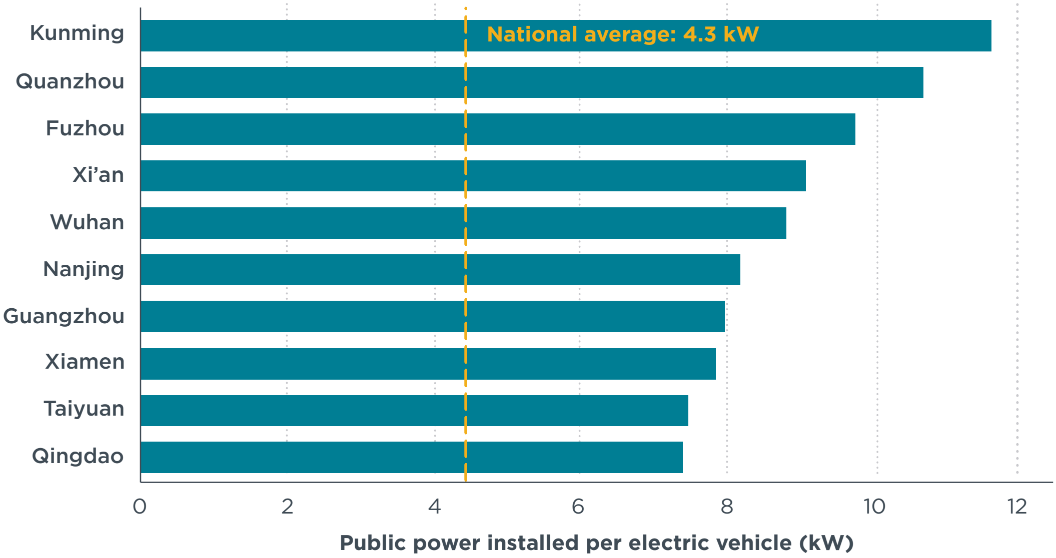

Figure 13. Top 10 Chinese cities by public power installed per electric vehicle as of 2022. Only cities with an electric vehicle stock of over 50,000 were taken into consideration.

UTILIZATION OF PUBLIC CHARGERS

Utilization rate, or the percentage of time that a charger is plugged into an EV, provides insights into the profitability and sustainability of a given area's charging infrastructure network. Figure 14 compares public charger utilization rates in 32 major Chinese cities with that of Amsterdam, which is a top tier city in Europe in terms of public charger utilization rate. Utilization rates in China were derived from a recent report by the China Academy of Urban Planning and Design (2023), while the rate in Amsterdam was calculated based on charging session data of 10,316 public chargers in April 2023 from Charging Radar (2023).

The utilization rates of public chargers in the 32 Chinese cities analyzed ranged from 4.1% (Shenzhen) to 17.4% (Xiamen), with an average value of 11%. This was much lower than Amsterdam, which had a utilization rate of 34%. Utilization rates vary within cities, however, and several Chinese cities have attained higher utilization rates in more densely populated urban cores. Based on June 2023 charging session data from Shenzhen, Shanghai, Guangzhou, Beijing, and Chengdu (China Automotive Technology and Research Center, 2023), we found that the utilization rates of public chargers in the urban cores of these cities were at roughly the same level as Amsterdam.[5] Chengdu ranked first among these cities with an average public charger utilization rate of 35% in its most densely populated areas, followed by Shenzhen (30%), Shanghai (29%), Guangzhou (28%), and Beijing (21%). Looking ahead, there is significant potential to further increase public charger utilization in China beyond the urban cores of leading cities through data-driven planning and deployment of public chargers.

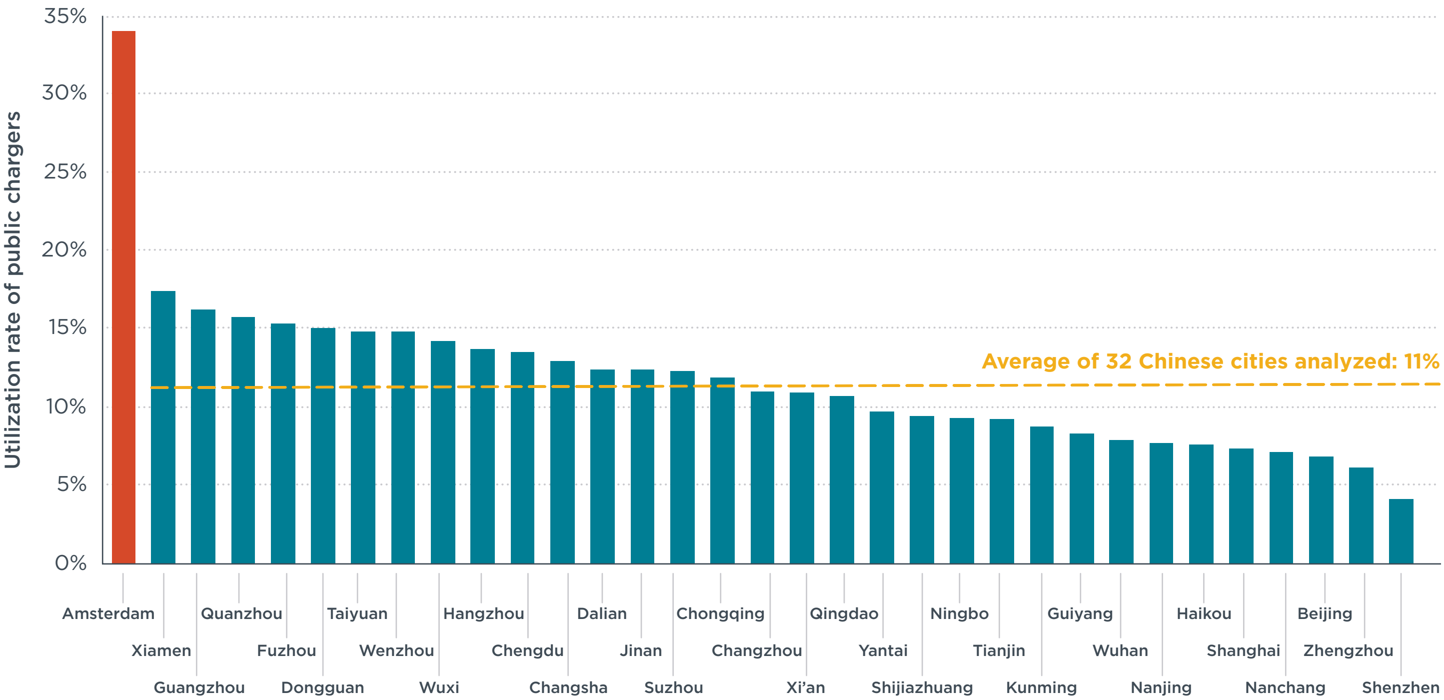

Figure 14. Average utilization rate of public chargers in major Chinese cities, compared with Amsterdam.

5 This analysis was based on charging session data from 1,968 public chargers in Shenzhen, 1,538 in Shanghai, 1,432 in Guangzhou, 1,552 in Beijing, and 1,564 in Chengdu.

CONCLUSIONS AND RECOMMENDATIONS

Based on our analysis of public charging infrastructure deployment in China, Europe, and the United States, we draw the following conclusions.

China has established the world's largest public charger infrastructure network. By the end of 2022, China's public charger stock reached 1 million. This represented 51% of the global total, and was almost double the public charger stock of Europe and eight times that of the United States. The total rated power of China's public chargers exceeded 56 gigawatts by the end of 2022, three times larger than the total public power in Europe. This corresponded with an installed public power of 4.3 kW per EV in China, compared with 2.4 kW per EV in Europe.

China's public chargers were unevenly distributed and were concentrated in the most developed cities. Cities in eastern and southern China generally had more public chargers than those in western and northern China. The top 15 cities in China, by number of public chargers, accounted for 57% of the country's total public charger stock as of 2022, while in Europe and the United States, the top 15 cities accounted for 23% and 47% of public chargers, respectively. There is, therefore, high potential for China to accelerate public charging infrastructure deployment beyond the most developed cities.

Highways are a weak link in China's public charging infrastructure network. Public charger availability on highways is among Chinese EV drivers' greatest concerns related to long-distance travel. As of 2022, China's highway public charger density was only 105 per thousand kilometers, compared with 654 in Norway. At the sub-national level, the highway public charger density in China's Hainan province was 115 per thousand kilometers, compared with 135 in the U.S. state of California. As of June 2023, China had installed 18,590 public chargers alongside highways, representing less than 2% of the nation's total public charger stock. This indicates a potential to further enhance deployment of public chargers along China's highways.

Leading Chinese cities have established a widely-distributed public charging network in urban centers but could improve public charger coverage in suburban and rural areas. As of 2022, virtually 100% of EV drivers in the urban cores of Shanghai, Beijing, and Shenzhen could find a public charger within 20 minutes of drive time, and large majorities could drive to their nearest charging pool in less than five minutes. On the other hand, public charger coverage in suburban and rural areas of these cities was still relatively low. This indicates that exurban areas could be more fully considered when planning and deploying public chargers in the future.

Public chargers in urban cores of leading cities have achieved a relatively high utilization rate while the citywide averages are still low. In Chengdu, for instance, public chargers in the urban core have a utilization rate of 35%, on par with rates in Amsterdam, which has one of the highest average utilization rates among European cities. Citywide average utilization rates of major Chinese cities are far lower, however, ranging from 4.1% to 17.4%. This indicates that public charger utilization could be further increased beyond urban centers of leading cities in China.

We offer the following recommendations on how China can further enhance the nation's public charging infrastructure network.

Localized near- and long-term plans for EV charging infrastructure deployment at the provincial and city levels could be established based on data-driven EV charging needs assessments. Several key shortcomings of the current charging infrastructure network in China, such as low utilization rates, may be attributable to a low understanding of EV owners' charging needs. When assessing charging needs of a province or a city, planners can use data-driven analysis and account for local factors such as EV stock by segment, EV technology mix, housing type, typical driving patterns, real-world performance of EVs, and charging speed requirements.

Consider leveraging a comprehensive set of metrics to evaluate public charging infrastructure. Traditionally, Chinese provinces and cities have emphasized the absolute number of public chargers and public charger-per-EV ratios when evaluating charging infrastructure deployment. Looking ahead, the coverage, capacity, and utilization of public chargers could be emphasized to ensure a user-friendly, convenient, and sustainable public charging infrastructure network. Minimum drive time to reach a public charging pool, public power output installed-per-EV, and utilization rate of public chargers are all important metrics that provinces and cities could take into consideration when evaluating their charging infrastructure networks.

Resources could be provided to expand public charging infrastructure networks beyond the urban centers of the most developed cities and enhance charger availability on highways. Though China has established the largest public charging infrastructure network in the world, over half of its public chargers are located in 15 cities. With dedicated policy and financial support for extending charging networks beyond developed urban centers, China's charging infrastructure network could be significantly improved, which will further unlock its vehicle electrification potential.

The establishment of an official national database on charging infrastructure would enable more in-depth analysis to support policy design. At present, there is no publicly accessible government database on EV charger deployment and use in China; a few unofficial sources seek to track such information, but their data is not comprehensive or consistent across databases. China's successful experience in improving statistics on EV uptake through the establishment of an official national EV database could serve as a model for an analogous database on nationwide charging infrastructure. In addition, amid accelerating efforts to electrify heavy-duty vehicles, which are responsible for a disproportionate share of air pollutants and carbon emissions, it is particularly important to understand the state of charging infrastructure development for heavy-duty vehicles. In the current unofficial databases, it is not possible to identify chargers that heavy-duty vehicles can use, which have a higher power and a larger associated parking space. Looking ahead, China could benefit from ensuring that its official national database on charging infrastructure separately counts chargers for heavy-duty vehicles, as this will enable more in-depth analysis to support policy design.

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