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ELECTRIC VEHICLE CAPITALS OF THE WORLD

DEMONSTRATING THE PATH TO ELECTRIC DRIVE

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EXECUTIVE SUMMARY

Many cities around the world see the transition to electric vehicles as key to improving local air quality and mitigating climate change. Electric vehicles reduce greenhouse gas emissions, improve air quality, and lessen dependence on oil, enabling a transition to renewable energy and sustainable transportation. Large, high-profile cities can play a special leadership role developing and testing innovative policy actions before more widespread adoption. By examining some of the world's preeminent electric mobility cities, or "electric vehicle capitals," in this report, we look to glean lessons on the critical first steps to accelerate a global transition to electric drive.

This report assesses major cities that are leaders in promoting electric vehicles around the world, quantifies their market successes to date, and discusses the underlying contributing factors for each. We identify 14 major metropolitan areas in North America, Europe, and China that led their respective countries in electric vehicle uptake or sales shares in 2015. Only metropolitan areas with a population over 1 million residents are included in this analysis. For each city, we summarize the policy, infrastructure, and consumer awareness actions that have been put in place to grow the market in these world-leading electric vehicle markets. The markets are evaluated at the metropolitan area level to incorporate the urban center and the surrounding commuting area. We compare electric and conventional vehicle life-cycle emission data to assess the new technology's relative climatic impact in these pioneering electric vehicle markets.

Figure ES-1 illustrates electric vehicle sales and sales shares of the 14 electric vehicle capital cities. These are the foremost major markets in terms of their relatively rapid deployment of electric vehicles at the early stage of electric vehicle market growth in 2015. The data points show the share of new passenger vehicles that are plug-in electric vehicles, and the vertical bars summarize new electric vehicle registrations in 2015 to indicate the overall size of the market.

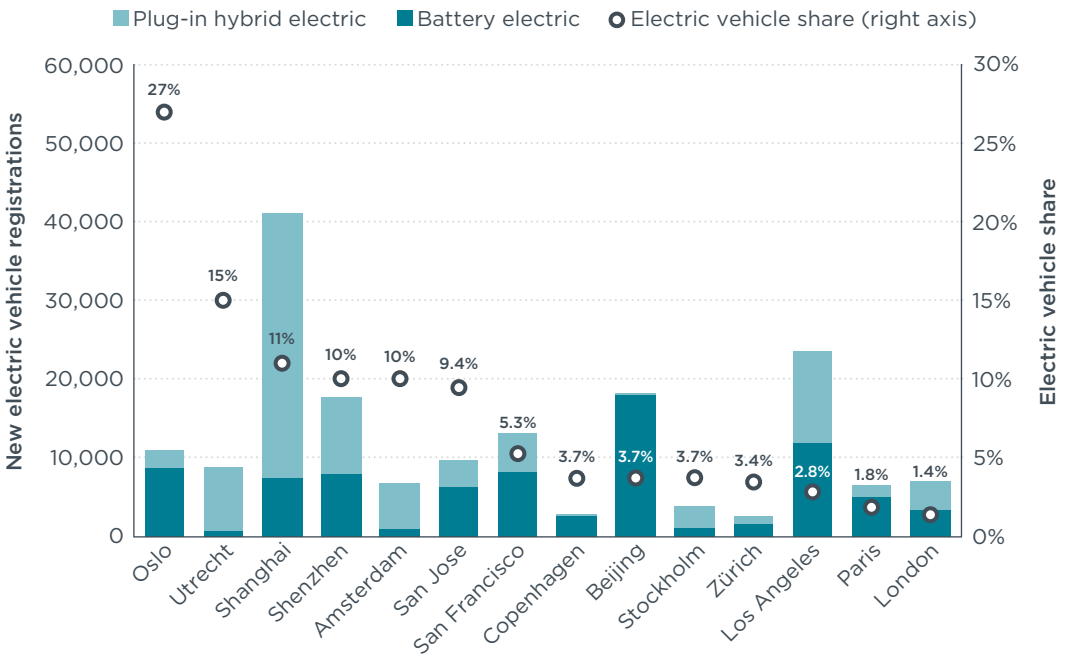

Figure ES-1. Electric vehicle new registrations and share of new vehicles in 2015 in high electric vehicle uptake markets. (*New vehicle registration data from IHS Markit and IHS Automotive*)

Based on this analysis, the top markets by electric vehicle share of new passenger vehicles are Oslo (27%), Utrecht (15%), Shanghai (11%), Shenzhen (10%), Amsterdam (10%), and San Jose (9.4%). For comparison, only 0.8% of new passenger cars sold worldwide in 2015 were electric vehicles (i.e., plug-in hybrid and full battery electric). In terms of total volume, the highest annual sales markets are Shanghai, Los Angeles, and Beijing, which recorded between 18,000 and 42,000 new electric vehicle registrations in 2015. Overall, the 14 electric vehicle capitals presented in this study have from two to over 30 times the global electric vehicle sales rate.

We highlight the following three findings:

Nearly a third of global electric vehicle sales are in just 14 electric vehicle capitals. Fourteen metropolitan areas, representing only about 1.5% of the global population, accounted for 32% of new electric vehicles in 2015. These hot spots for electric vehicle growth are demonstrating the first major steps toward the mainstream deployment and integration of new electric vehicle technologies. The foremost 2015 markets within China, Europe, and the United States have annual electric vehicle sales that are in the tens of thousands per year or make up at least one in every 10 new passenger vehicles sold.

Electric vehicle capital cities use a comprehensive suite of electric vehicle promotion actions to spur the market. High electric vehicle uptake markets address the prevailing electric vehicle consumer barriers of cost with incentives, convenience with extensive charging infrastructure, and consumer awareness with promotional campaigns. At the same time, these markets' policy actions are tailored to unique local conditions, for example, to their geography (e.g., waiving tunnel tolls in Norway), city layout (e.g., congestion zones in London, carpool lanes in Los Angeles), incentive options (e.g., tax exemption in Europe), or vehicle licensing policies (e.g., exemption from registration lotteries in Beijing and Shanghai).

Electric vehicles deliver a low-carbon transport option. Cities that are accelerating the transition to electric drive are achieving significant carbon emission reductions in their transportation sector. Even after incorporating upstream emissions, electric vehicles provide carbon emission reduction benefits of 30% to more than 98% compared to conventional vehicles across the China, Europe, and U.S. markets. Further improvements are expected as the electric grids continue to decarbonize.

These cities demonstrate many best-practice electric vehicle support policies and can act as models for other cities that seek to accelerate their transition to electric vehicles. Many of these policies could be more universally applied around the world, if tailored to a local policy context. Future work would continue to examine questions related to the effectiveness of individual policies, the diffusion of electric vehicle uptake beyond these capital cities, charging infrastructure benchmarks as markets grow, and the prospects for increasingly powering electric vehicles from renewable electricity sources. The importance of the various policy approaches could also shift as lower cost and higher range electric vehicles enter the market. In addition, future work would ideally assess the electrification opportunities more broadly—including increasingly electric-powered car-sharing, transit, and freight movement—as the technology advances.

I. INTRODUCTION

Cities are an important focal point for culture, commerce, and our daily travel patterns. Many cities around the world have struggled to thrive and grow while developing sustainable transportation systems. Some of these cities are seeing the transition to electric vehicles as a key to improving local air quality, mitigating climate change, and growing the economy. Capital cities—be they the formal seat of policymaking or informal leader in a particular market development—play a special role in developing, implementing, and testing innovative policy actions before more widespread adoption of emerging best practices.

Are there "electric vehicle capital" cities emerging, where cutting-edge electric vehicle actions are taking root and broadening the market? This idea of electric vehicle capitals has been introduced in the statements and ambitions of many mayors around the world. The mayors of Oakland, San Francisco, and San Jose, California, have established a joint goal to make the Bay Area region the electric vehicle capital of the United States. The mayor of Los Angeles also has announced the city's intention to compete for the same title (Office of the Mayor of San Francisco, 2011; Office of the Mayor of Los Angeles, 2010). Other U.S. mayors and industry leaders have expressed similar ambitions for their respective cities to become electric vehicle market leaders, including Houston, Texas, and Portland, Oregon (Green Houston, 2010; Adams, 2009).

Several policymakers in Europe have aspired to lead the world in electric mobility. In 2009, the mayor of London launched a plan to make the city the electric car capital of Europe (Jha, 2009), and subsequent mayors have reiterated this commitment (Greater London Authority, 2015 and 2016). Oslo, Norway's numerous electric vehicle activities often put the city front and center in global electric vehicle discussion, and its mayors have committed and reaffirmed the city's pioneering role as the electric vehicle capital of the world (Grundberg & Rolander, 2013; Bymiljøetaten Oslo, 2015). Amsterdam has proclaimed that no other city in the world is as far ahead in the transition to electric transport (Gemeente Amsterdam, 2016). Stockholm also shares the ambition to be the world leader in clean vehicles, envisioning that electric vehicles will play an important role (City of Stockholm, 2012)

The rapid growth of electric vehicles in China suggests that some of the major hubs there are greatly outpacing electric vehicle sales in prominent U.S. and European markets. The Beijing municipal government has launched an action plan to make the city a globally leading electric vehicle market. Electric vehicles are seen as a promising solution to reduce vehicle pollution while sustaining personal mobility and economic growth in many cities in China. Shanghai in particular was declared an international electric vehicle demonstration city by the central government, and this has led to many local policies and promotion activities. Others see Hong Kong as a special beacon city for electric vehicle growth in Asia (Ng, 2016). Pioneering policymakers are working hard to establish their cities as electric vehicle hubs, creating a "race to the top" that could lead to benefits for all.

By examining the cities with the highest electric vehicle uptake around the world, we seek to glean lessons on what it might take to start the global transition to electric drive. In particular, we have collected information on national, state, and local policies and how they have created a favorable policy environment to accelerate electric vehicle adoption. In addition, we investigated the extent of public charging infrastructure and

any actions that have helped build out those networks. In the rapidly changing electric vehicle market, these cities demonstrate private and public promotion activities that can be emulated elsewhere.

This paper identifies and analyzes "electric vehicle capitals" around the world that could provide examples of the types of actions that could be more widely embraced to further grow the electric vehicle market. We analyze the top North America, Europe, and China markets that accounted for well over 90% of global electric vehicles sales. To focus the study, we limited our analysis to metropolitan areas with at least 1 million residents and over 1% electric vehicle sales share in 2015. Based on these criteria, we identified high electric vehicle uptake cities by their high electric vehicle sales share and sales volume in major markets, and assessed the prevailing promotional actions in place in each. Additional cities are presented in the Annex, and other markets could be included in future work as the applicable data become available.

The data in this report come from many sources. Vehicle registration data are from IHS Markit for Denmark, Germany, the Netherlands, Sweden, Switzerland, the United Kingdom; Council for Information on Road Traffic for Norway (2016); IHS Automotive for the United States; and EV100 for China. These sources are based on new vehicle registrations, which we consider equivalent to new vehicle sales for this analysis. Although analysis of German vehicle data was included, a comparably high electric vehicle market city was not identified there. Data sources for carbon emissions and charging infrastructure vary by country and are provided in the Annex. Each region is assessed at the metropolitan area level to incorporate the urban center and the surrounding commuting area, as geographic definitions vary widely among countries. Metropolitan area definitions are given in the Annex. In each metropolitan area, we analyzed the vehicle data and reviewed policy, infrastructure, and consumer awareness actions in place.

II. DRIVERS FOR ELECTRIC VEHICLE UPTAKE

Extensive research has shown that high electric vehicle uptake is correlated with a variety of supporting policies and activities. The cities discussed in this paper all have implemented a number of such actions to achieve their electric vehicle goals. These electric vehicle support actions tend to address the prevailing electric vehicle barriers of cost (typically with incentives, exemptions from fees and tolls), convenience (with charging infrastructure, parking, and preferential local access), and consumer awareness (promotional campaigns, fleets, public-private initiatives, and trial projects). For each of the selected cities in this paper, we highlight notable actions in the following five categories.

Financial incentives. Financial incentives are found to be important drivers of electric vehicle sales, and are present in almost every major electric vehicle market (Yang et al., 2016; Vergis, Turrentine, Fulton & Fulton, 2014; Mock & Yang, 2014). There are a number of ways in which governments financially incentivize electric vehicles. The United States offers an income tax credit of up to $7,500 for purchasing an electric vehicle, which is not received by consumers until the end of the tax year. More commonly, governments, such as Sweden and Japan, offer upfront rebates to reduce the purchase price of electric vehicles. Additionally, many jurisdictions offer tax and fee exemptions, both for vehicle purchase taxes and for annual circulation taxes or registration fees. Subsidies vary based on a number of criteria, including vehicle battery capacity or range, and in some cases only battery electric vehicles (BEVs), not plug-in hybrid electric vehicles (PHEVs), are eligible. Additionally, company and private vehicles may be ineligible for different incentive levels. Additional restrictions may help to target funding toward the most hard-to-reach market segments. For example, income and vehicle price thresholds are increasing being used (e.g., DeShazo et al., 2016). Federal or state governments are most commonly responsible for incentive programs, but some city governments provide their own subsidies, and utility companies sometimes provide subsidies for home charging stations and vehicles (Salisbury & Toor, 2016).

Nonfinancial incentives. Beyond financial incentives, many other electric vehicle promotion actions also are linked to electric vehicle uptake. Common forms include special benefits for electric vehicle drivers, such as free parking, access to high-occupancy vehicle (HOV) lanes, access to Low Emission Zones, and exemption from fees for tunnels or congestion areas. By offering and publicizing such programs, governments at all levels can increase electric vehicle uptake (Lutsey et al., 2016; Haugneland & Kvisle, 2013). Sales mandates and government quotas also can lead to greater electric vehicle availability and uptake. California is a prominent example of this policy (Reichmuth & Anair, 2016; Searle et al., 2016). The range of actions depends on the physical and policy context of each city. For example, the rugged terrain in Norway allows for the popular tunnel and ferry fee exemptions for electric vehicle owners, and the vehicle quota system in Shanghai enables the government to give preferential registration to electric vehicles (Dansk Elbil Alliance, 2016; Wang & Liu, 2015). Cities around the world continue to explore various policies in these areas as programs are created and modified and electric vehicles reach mainstream markets.

Charging Infrastructure. The availability of charging infrastructure is linked to electric vehicle uptake around the world. Greater charging availability helps address key consumer barriers regarding the range and the convenience of electric vehicles.

Charging of vehicle batteries tends to be largely done at home, and several studies have shown that availability of home charging infrastructure can increase interest in electric vehicles (Bailie et al., 2015). The deployment of public charging infrastructure has been found in a variety of studies to help encourage electric vehicle purchases (e.g., Bakker & Trip, 2013; Li et al., 2016; Lutsey et al., 2015; Sierzchula et al., 2014; Vergis & Chen, 2014). Expanded charging infrastructure increases electric vehicle user confidence and makes greater range and functionality possible. Charging networks also elevate the visibility of electric vehicle use and can offer broader grid benefits. For these reasons, a number of governments have subsidized and encouraged the construction of public charging infrastructure by private companies and electric utilities. As the market matures, there are a number of models for the future development of public charging networks (e.g., Bakker & Trip, 2015; van Deventer et al., 2015).

Research and campaigns. Electric vehicles are a quickly evolving technology, and governments at the federal and local levels can play a role in steering electric vehicle research, market development, and campaigns to promote electric vehicles. Several countries, such as China and Germany, have designated certain areas as electric vehicle pilot or model regions where best practices in consumer outreach, charging infrastructure deployment, and vehicle-grid integration can be determined (Wang & Liu, 2015; Vergis et al., 2014). Universities also can play a major role in advancing electric vehicle technologies and studying consumer and driver behavior. In the rapidly growing field of vehicle-grid integration, electric power utilities around the world have launched research projects and trials regarding smart charging, the impacts of electric vehicle charging, and new charging infrastructure (Hall & Lutsey, 2017). Additionally, government-run consumer awareness campaigns can be very important in informing consumers about the benefits of electric vehicles and the presence of incentive programs, while also helping to inform the design of new technologies and policies (Greene & Ji, 2016). Research projects and consumer campaigns help support market growth by engaging various stakeholders and promoting awareness and education related to electric vehicle developments and model availability.

Transit and fleets. Another avenue for increasing the number of electric vehicles and their visibility in a city is the electrification of a city's transit and fleets. Electric buses have attracted growing interest in recent years – these buses can significantly reduce noise and localized pollution in addition to promoting clean transportation (Adheesh et al., 2016). Likewise, taxis are a prominent fixture of the transportation landscape in many cities and have duty cycles that could correspond well with electric vehicles; some cities, such as Amsterdam, are working to electrify their entire taxi fleet (City of Amsterdam, 2015). Electrified taxi fleets, as well as electric car-sharing programs, could have the effect of exposing people to electric vehicles and normalizing the technology, in addition to providing immediate environmental benefits.

III. ANALYSIS OF TOP ELECTRIC VEHICLE MARKETS

This section includes profiles of each of the 14 identified high electric vehicle uptake cities around the world and their efforts to promote electric vehicles. The analyses include electric vehicle sales figures, data on electric vehicle charging infrastructure, and the associated emissions from power generation in the respective countries. Furthermore, we summarize government and public-private programs in the categories of financial incentives, nonfinancial incentives, charging infrastructure, research and campaigns, and transit and fleets. In addition to profiling these top electric vehicle uptake cities, we discuss policies and programs in place at the national level that play a significant role in the local market. In the summary tables for each city, we include a qualitative ranking based on how extensive the electric vehicle support activities are in each area. Further details on the data sources and assumptions underlying the analyses are provided in the Annex.

CHINA

The approximately 200,000 new electric passenger cars sold in China represented about 35% of 2015 global electric vehicle sales and accounted for almost 1% of all new passenger vehicles sold in China in that year. The country has a variety of national policies and promotional actions in place that have supported the development of the electric vehicle market. These programs include central government incentives that are valued at up to 54,000 Chinese yuan ($8,000) for the purchase of new electric vehicles (Yang et al., 2016). China is developing a plan to promote additional electric vehicle sales in upcoming years through a New Energy Vehicle credit system or a New Energy Vehicle carbon quota system (Cui et al., 2016).

The central government encourages municipalities to support the advancement of public charging infrastructure by providing policy support, subsidizing construction of charging stations, and issuing guidelines for charging technology standards, city planning, land use policy, and electricity pricing (State Council, 2014). China's state-owned electric utility State Grid Corporation is working to build national networks of fast charging stations (Mitchell, 2015). In 2015, the State Council set the targets of having at least one charging station per every 2,000 electric vehicles and by 2020 achieving a charging infrastructure to support 5 million electric vehicles (Office of the State Council, 2015).

Many cities in China offer additional consumer fiscal rebates and other actions for electric private cars as well as for buses. From 2009 to 2012, the original Ten Cities, Thousand Vehicles program expanded to 25 cities, and the pilot city programs have themselves grown in scope. These pilot cities have used incentives, charging infrastructure, and other promotion activities to increase their electric vehicle readiness (Wang & Liu, 2015). In addition, several major cities in China have restrictions on vehicle registrations and use to help curb congestion and pollution, and electric vehicles sometimes are exempted from such restrictions. The many pilot cities have had varying levels of success, and three markets in China stand out. Shanghai, Shenzhen, and Beijing, which are profiled below, have the highest electric vehicle sales, with these cities accounting for approximately 41% of all electric vehicle sales in China in 2015. Some smaller pilot cities, such as Hangzhou and Wuhu, had sales far above the national average, with electric vehicles accounting for 7.5% and 5.7% of total vehicle sales in 2015 respectively.

SHANGHAI, CHINA

Metropolitan population	**24 million**	**Total electric vehicle sales**	**41,179**
Public electric vehicle charge points per million people	**146**	**Electric vehicle share of new vehicles**	**11%**
Grid CO_2 emissions (gCO_2/kWh)	**740**	**Electric vehicle sales share relative to country average**	**12x**

The Shanghai metropolitan area, where 11% of new vehicles were electric in 2015, has the highest electric vehicle uptake in China. With more than 41,000 new electric vehicles sold in 2015, the Shanghai area had the highest total electric vehicle sales among all metropolitan areas in the world. Shanghai provides additional regional electric vehicle purchase subsidies of up to 30,000 yuan renminbi ($4,400), reduced from up to 40,000 yuan at the beginning of 2016. Electric vehicles are also exempted from the expensive and restrictive license plate auction system where the cost is around 80,000 yuan per license plate (Yang et al., 2016).

Shanghai was declared an International EV Demonstration City by the federal government. An important part of Shanghai's electric vehicle promotion is the EV Demonstration Zone in the city's Jiading District, where the city and federal government help auto companies reach and engage with more consumers and collect consumer electric vehicle data. The Zone includes an electric vehicle rental plan, an electric vehicle service center, and the ability to import with limited customs procedures. The Zone also and includes the promotion of electric vehicles through a car sharing service, a network of charging stations, and free electric vehicle test drives.

Table 1. Summary of electric vehicle support actions in the Shanghai metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal subsidies of up to 54,000 CNY and tax exemptions • Regional subsidies of up to 30,000 CNY	++
Nonfinancial incentives	• Subsidies for a reserved parking space in Jiading District • Exemption from restrictive license plate auctions (80,000 CNY savings)	+
Charging infrastructure	• 21,700 charging points (16,500 private, 3,200 company charging, 800 bus and logistic vehicle) • Estimated 3,513 publically available charge points • State Grid Corp. constructing network of fast charging stations • Up to 30% grant for the installation of charging infrastructure (expired in 2014) • Government plans to build 28,000 public charging points (at least 1:7 ratio of public charging points to NEVs) by 2020 • Goal to build 210,000 charging points by 2020 • 30% capital subsidy for businesses to establish special and public charging infrastructure, integrated PV charging infrastructure, and new charging technology (until 2020)	+
Research and campaigns	• Jiading District EV Demonstration Zone	+
Transit and fleets	• EVCARD: China's first electric car sharing service • Electric buses and taxis are given priority to operate in the city • Pure electric public buses received a 165,000 CNY operation subsidy per year from 2013 to 2015 • Commercial vehicle passing permits to allow purely electric commercial vehicles to operate in urban areas	+

Public charge point data from EVCIPA (2016)

SHENZHEN, CHINA

Metropolitan population	**11 million**	**Total electric vehicle sales**	**17,699**
Public electric vehicle charge points per million people	**—**	**Electric vehicle share of new vehicles**	**10%**
Grid CO_2 emissions (gCO_2/kWh)	**740**	**Electric vehicle sales share relative to country average**	**12x**

The Shenzhen metropolitan area had a 9.9% electric vehicle sales share in 2015, the second highest among China markets, and it had the third highest total electric vehicles sales among all metropolitan areas in China with more than 17,000 passenger cars sold. Shenzhen is the headquarters of BYD, the manufacturer with the second-highest 2015 worldwide electric vehicle sales. Shenzhen is seen as a "first level city" in terms city readiness for electric vehicle adoption, with a number of local programs implemented and significant advancements in charging infrastructure (Shenzhen Municipal People's Government, 2015). Between 2009 and 2015, the Shenzhen government provided 500 million yuan (nearly $74 million) per year of financial subsidies for electric vehicle purchases (Wang & Liu, 2016). In addition to the financial incentives for electric vehicle purchases, the Shenzhen government provides parking benefits and subsidies for tolls, car insurance, and charging infrastructure (Liu, 2015). In 2015, the city of Shenzhen stated that it will spend up to 5 billion yuan for the development of charging infrastructure, subsidies for the purchase of electric vehicles, and policies to increase the overall uptake of electric vehicles (Liu, 2015).

Table 2. Summary of electric vehicle support actions in the Shenzhen metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal subsidy of up to 54,000 CNY and tax exemptions • Regional subsidy up to 60,000 CNY for purchase of passenger vehicles and taxis and purchase tax exemptions • Discounts on tolls and car insurance • Subsidies for the operation of electric public buses	++
Nonfinancial incentives	• One hour of free parking each day • Exemption from vehicle registration lottery	++
Charging infrastructure	• 30% grant for the installation of charging stations • One-time charging subsidy up to 5,000 CNY • Low regulated prices guaranteed for public charging	+
Research and campaigns		
Transit and fleets	• Electrification of city buses, with hundreds of electric buses in operation in 2016, goal of 100% electric vehicles by 2017 • 70% of new fleet taxis must be NEVs • Company cars and government vehicle fleets transitioning to NEVs • Minibus: connects the "last-mile" between homes and normal bus/metro stations (currently 33 routes and 150 buses with the goal of 38 routes and 196 buses by the end of 2016) • e-Bus: An electric bus service that maximizes the efficiency and effectiveness of buses by allowing individuals to book the service and initiate new routes (if there is enough demand, a new route will be added) using an online tool (currently 410 routes with 22,000 passengers per day; 100 new routes planned before the end of 2016)	++

BEIJING, CHINA

Metropolitan population	**22 million**	**Total electric vehicle sales**	**18,065**
Public electric vehicle charge points per million people	**313**	**Electric vehicle share of new vehicles**	**3.7%**
Grid CO_2 emissions (gCO_2/kWh)	**740**	**Electric vehicle sales share relative to country average**	**4.1x**

Electric vehicle sales in Beijing surpassed 18,000 in 2015, accounting for a 3.7% share of new vehicle sales. The Beijing electric vehicle market is promoted through a city-level subsidy worth more than 50,000 yuan for battery electric vehicles. The city's electric vehicle market is unique with more than 99% of its electric vehicle sales being battery electric vehicles, as the Beijing incentives were not provided for plug-in hybrid vehicle models. Electric vehicles are exempt from the traffic restrictions that ban conventional vehicles from the roads of Beijing one day per week based on license plate numbers (Yang et al., 2016). The city of Beijing has implemented a license plate lottery system to greatly limit the number of new vehicles registered in the city. Electric vehicles are exempt from the lottery, and up to 60,000 license plates were reserved for electric vehicles in 2016; in contrast, only about 0.03% of those with conventional vehicles who participated received license plates in the June 2016 lottery (Guo, 2016).

A number of consumer awareness programs complement these incentive and registration policies. Beijing has a New Energy Vehicle Experience Center, supported by the Ministry of Science and Technology and Beijing Municipal Science and Technology Commission, that educates individuals on new energy vehicles and provides test drives in BAIC electric vehicles (China Ministry of Science and Technology, 2014). In addition, from May to November of 2015, the Beijing New Energy Vehicle Promotion Center and the Beijing Auto Museum organized 36 electric vehicle test drive events. Beijing also has several electric vehicle fleet programs, including government programs and private car-sharing programs.

Table 3. Summary of electric vehicle support actions in the Beijing metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal subsidy of up to 54,000 CNY and tax exemptions • Regional subsidies of 31,500-54,000 CNY in 2015, 25,000-55,000 CNY in 2016, and 20,000-44,000 CNY in 2017 for BEV passenger cars based on electric range • Regional subsidies of up to 50,000 CNY for taxis • Electric taxis exempt from fuel tax • Regional subsidies of 300,000-500,000 CNY for BEV buses	++
Nonfinancial incentives	• Exempt from traffic restrictions • Separate license plate quota for electric vehicles, exempt from lottery	+
Charging infrastructure	• 21,000 charge points (3,700 for special use, e.g. buses; 12,000 for private use) • Estimated 6,789 publically available charge points • State Grid Corp. constructing network of fast charging stations • Upper limit on public charging rate of 15% of 1L gasoline market rate per kWh	++

Type of Program	Description	Grade
Research and campaigns	• Consumer awareness campaign: "Electric Vehicle into Community" • Beijing New Energy Vehicle Experience Center allows people to gain insight into new energy vehicles and test drive BAIC electric vehicles • 36 electric vehicle test drive events organized by Beijing New Energy Vehicle Promotion Center and Beijing Auto Museum organized from May to November 2015	++
Transit and fleets	• Electric buses and taxis are given priority to operate • LeShare electric car sharing service	+

Public charge point data from EVCIPA (2016)

DENMARK

In Denmark, the southernmost and smallest of the Scandinavian countries, electric vehicles accounted for 2.3% of the total vehicle sales with more than 4,700 sales in 2015. Denmark has prioritized creating a green and sustainable society with the goal of achieving complete independence from fossil fuels by 2050 (Danish Government, 2016). With the transportation sector's dependence on fossil fuels accounting for approximately one-third of the total fossil fuel use in the country, Denmark's goal of independence from fossil fuels would require an extensive transformation of the sector (Danish Government, 2011).

The national government of Denmark has pushed the adoption of electric vehicles by exempting electric cars from the green tax ("Grønne Afgifter"), additional car taxes, and, until the end of 2015, vehicle registration fees (Danish Government, 2011). Starting in 2016, electric cars will incrementally be charged registration taxes, with full taxes (150% the value of the car) implemented in 2020. In order to ensure that electric vehicle sales do not stagnate with the introduction of registration taxes, a condition of the legislative agreement is that 24,100 electric vehicles are sold by 2020 and sales will be monitored for progress (International Energy Agency [IEA], 2016). The 2015 fourth quarter sales of electric vehicles in Denmark experienced a 280% increase from the third quarter, (Insero, 2016), in advance of the onset of registration taxes on electric vehicles beginning at the start of 2016.

Electric vehicle incentives in Denmark include free parking in certain cities, support of electric vehicle partnerships and tests, tax exemptions on electricity for electric vehicle operators, subsidies for businesses and municipalities for the purchase of electric vehicles, and tax discounts for the installation of charging stations up to 4,000 kroner (Dansk Elbil Alliance, 2016). The Danish Electric Vehicle Alliance (Dansk Elbil Alliance) helps to push the implementation of electric vehicles by bringing together the energy and electric vehicle sectors. Until the end of 2015, the Danish Energy Agency (DEA) administrated extensive funding, at a level of 30 million kroner ($4.4 million) in 2015, for projects to familiarize companies, public bodies, and private consumers with electric vehicles, support charging infrastructure, and develop relevant partnerships (IEA, 2016).

COPENHAGEN, DENMARK

Metropolitan population	**1.7 million**	**Total electric vehicle sales**	**2,793**
Public electric vehicle charge points per million people	**492**	**Electric vehicle share of total vehicle sales**	**3.7%**
Grid CO2 emissions (gCO2/kWh)	**375**	**Electric vehicle sales share relative to country average**	**1.6x**

Copenhagen, the capital of Denmark, had an electric vehicle share well above the national average, with 3.7% of vehicles sold in 2015 being electric vehicles. With approximately 2,800 new electric vehicles, nearly 60% of Denmark's electric vehicle sales were in the Copenhagen metropolitan area. In 2009, Copenhagen released an extensive climate plan with the intention of becoming, by 2025, the world's first carbon neutral capital. To achieve the overall goals, the climate plan set the aim of making public transit carbon neutral and 20%-30% of all light-duty vehicles and 30%-40% of heavy-duty vehicles using alternative fuels (City of Copenhagen, 2009). Copenhagen has supported the transition toward sustainable mobility by providing free and designated parking, pushing the development of charging infrastructure, purchasing only electric or hydrogen powered vehicles for municipality use, and electrifying public transit.

Table 4. Summary of electric vehicle support actions in the Copenhagen metropolitan area

Type of Program	Description	Grade
Financial incentives	Federal Incentives: • Exempt from vehicle registration taxes (up to 180%) until 2016; partially exempt until 2020 • Exempt from annual car tax • Tax refunds on electricity used to charge electric vehicles	+
Nonfinancial incentives	• Designated free parking	+
Charging infrastructure	• 850 total charge points and 60 fast charge points • By 2025: 500-1,000 public charging stations and 5,000 restricted public access charging stations • Tax rebate of up to 18,000 DKK ($2,646) for the installation of a home charger	++
Research and campaigns	• "Meet the electric vehicle" – 12-day trial for businesses to test electric vehicles • "Rent an electric vehicle" – employees of companies in Copenhagen can rent electric vehicles for two weeks to assess their practicality • Financial subsidies for builders and tradesman purchasing electric vans in return for their experiences • "Vehicle X" – using electric vehicles to charge and operate tools and equipment • Two electric buses at the Copenhagen Airport to gain practical experience with electric buses	++
Transit and fleets	• More than 20,000 electric bikes sold in 2014 • DriveNow – car sharing service with a fleet of 400 BMW i3's • Entire bus fleet to be replaced by electric buses starting in 2019 • Municipality only purchasing zero emission vehicles starting in 2011 • 85% of government vehicles must be zero emission by 2015	++

Charge point data from E.ON (2016) and Clever (2016) as of October 31, 2016; may not include some smaller charging networks

FRANCE

Although electric vehicles accounted for only approximately 1.2% of France's total vehicle sales in 2015, France has one of the most efficient new vehicle fleets. France has made great strides to mitigate climate change and improve air quality, especially in urban areas, aiming to achieve a four-fold reduction in greenhouse gas emission by 2050. The transportation sector was the largest emitter of greenhouse gases in France in 2013, emitting 28% of France's total emissions (Ministère de l'Environnement, de l'Énegie et de la Mer, 2015). The development of clean transportation is a main pillar of France's climate policy. France's low-carbon electricity makes it an ideal location for electric vehicle penetration.

With the generous incentive increases in 2016, France has seen a significant uptick in electric vehicle purchases: 15,068 new electric vehicles were registered in the first half of 2016, a 49% increase from 2015, ahead of Norway's 12,216 (AVERE-France, 2016a). The bonus-malus system grants low-emission vehicles up to 6,300 euros and increases the purchase price of high emitting vehicles up to 8,000 euros (Ministère de l'Environnement, de l'Énegie et de la Mer, 2017). In addition, there is up to a 3,700 euro bonus for the scrappage of an old diesel car (AVERE-France, 2016b). The national government offers company tax exemptions for electric vehicles and a 30% tax credit with the installation of a charging station (City of Paris, 2016). Regions have the option to provide 50% to 100% registration tax exemptions for alternative fuel vehicles. At least 50% of the vehicles purchased by the national government and at least 20% of the vehicles purchased by local authorities must be low emission vehicles beginning in 2025. By 2030, France aims to have 7 million charge points installed and by 2017, the country aims to have a charging station every 50 kilometers (Ministère de l'Environnement, de l'Énegie et de la Mer, 2015; AVERE, 2015). The French Environment and Energy Management Agency (ADEME) has provided 50 million euros for the installation of public charging infrastructure since 2013 (AVERE-France, 2015).

PARIS, FRANCE

Metropolitan population	**12 million**	**Total electric vehicle sales**	**6,587**
Public electric vehicle charge points per million people	**106**	**Electric vehicle share of new vehicles**	**1.8%**
Grid CO2 emissions (gCO2/kWh)	**71**	**Electric vehicle sales share relative to country average**	**1.5x**

Paris is the capital and most populous city in France. In 2015, electric vehicles accounted for 1.8% of total vehicle sales in Paris, placing it above the national average but below other European electric vehicle capitals. As transportation is the area's largest source of air pollution and greenhouse gas emissions, the Paris Climate and Energy Action Plan aims for a 60% reduction in greenhouse gas emissions from inner-city transport and a 35% reduction for all transport in outer Paris between 2001 and 2020 (City of Paris, 2012).

To achieve these goals, Paris has implemented new policies to reduce vehicle use by 25% in 10 years, increase and improve public transit, and promote pedestrian and electric vehicle travel (City of Paris, 2012). In addition, the city has set extensive vehicle bans and road closures to improve air quality and reduce harmful greenhouse gas emissions, particularly in the city center. The city provides free parking for electric vehicles, charging station grants, bus electrification, and electric car sharing.

As of September 30, 2016, the Métropole du Grand Paris has provided a subsidy of 25% of the purchase price of low-emission vehicles with the replacement of older vehicles, up to 5,000 euros for cars, 1,000 euros for electric two-wheelers, and 500 euros for electric bikes. (Métropole du Grand Paris, 2016). Autolib', one of the world's largest electric car sharing services, began in Paris in 2011 and in 2016 had more than 3,900 cars, more than 5,900 charge points, and more than 126,000 subscribers (Autolib', 2016). Autolib' cars have access to free parking, are exempt from road and registration tax, and are granted access to bus lanes. Residents of Paris willing to sell or scrap their old, conventional vehicles or motorized two-wheelers receive financial aid for the enrollment to the Vélib bike sharing service or Autolib' or the purchase of a bicycle or electric bike (City of Paris, 2016).

Table 5. Summary of electric vehicle support actions in the Paris metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal incentives: Bonus-malus system (up to 6,300 euros grant for electric vehicles), bonus for diesel car scrappage (up to 3,700 euros), company tax exemptions • 25% subsidy for the purchase price of low-emission vehicles, electric mopeds, or electric bikes • 15% subsidy for companies replacing a diesel/gasoline vehicle with an electric vehicle (up to 3,000 euros for light commercial vehicles, 6,000 euros for vans, and 9,000 euros for trucks)	++
Nonfinancial incentives	• Free parking • High polluting vehicles banned from city streets on weekdays	+
Charging infrastructure	• 1,367 total charge points and 32 fast charge points • Federal incentives: tax deduction for installing a charging station • Grants for the installation of a private charging station in apartment complex	++
Research and campaigns	• Electric bus trials by transport operator RATP using 16 BYD buses	+
Transit and fleets	• All 4,500 buses in the Greater Paris network will be clean buses with 80% of them electric by 2025 • Sogarus and SEMPARISENE partnered to provide 30 delivery rounds in the 15th arrondissement using electric vehicles • Autolib', an electric car sharing program • At least 20% of local authority vehicle fleet must be low CO_2 and air pollutant emissions when renewing their fleet • All new public transit buses and coaches acquired after 2025 must be low-emission vehicles • At least 10% of car rental firms and taxi operators fleets must be low-emission vehicles when renewed	++

Charge point data from Etalab (2016), as of September 9, 2016

NETHERLANDS

The Netherlands has been a leader in electric vehicle promotion and deployment, with more than 43,000 new electric vehicle sales. These sales accounted for 9.7% of the country's total new vehicle sales in 2015, second in the world only to Norway. Despite being a relatively small country with a small population, the electric vehicle sales here accounted for more than 8% of the global electric vehicle sales in 2015.

The national government of the Netherlands has taken a comprehensive set of actions to achieve their ambitious national goals of 75,000 privately owned electric vehicles on the country's roads by 2020, and 50% of all new cars sales plug-in electric—with at least 30% of these vehicles fully electric—by 2025 (Dutch Government, 2015). To achieve these national targets, the government has published a series of action plans. The first action plan was published in 2009 and outlined the government's threefold course of action and its contribution of up to 65 million euros to make "the Netherlands the guide and international laboratory for electric driving" (Dutch Government, 2009). These action plans have led to the formation of the Formula E-Team, a national public-private platform that unites and advises businesses, academia, non-profit organizations, and the government to stimulate the development of charging infrastructure and new zero-emission mobility policies. The Formula-E Team has supported the implementation of field trials and demonstration projects and stimulated the development of charging infrastructure and electric vehicle and parts manufacturing.

Zero-emission vehicles in the Netherlands have been exempt from registration and road taxes, and have had reduced taxes for the private use of company cars. The Netherlands has a very extensive public charging network, with 0.8 public charging points per electric passenger vehicle at the end of 2015, and has recently developed the Open Charge Point Interface (OCPI) protocol to support the national agreement on interoperability of charge points (IEA, 2016). The Netherlands has several projects, coalitions, and agreements to support the uptake of electric driving. Among these projects are Project A15, which ran from 2012 through 2015 to promote electric driving powered by locally generated green energy along the A15 motorway; the National Knowledge Platform for Charging Infrastructure, consisting of research and innovation projects to bring down the cost of public charging infrastructure; and the Green Deal to increase publicly accessible electric charging infrastructure, including 5.7 million euros for the installation of charging points.

While the national government has implemented a wide variety of programs to incentivize electric vehicles, local governments also have played a major role in promoting these vehicles. In this analysis, we focus on Amsterdam, the capital of the Netherlands, and Utrecht, a major city with an electric vehicle sales share that is 50% above the national average. We note that additional cities such as Eindhoven, The Hague, and Rotterdam also have similar electric vehicle sales shares of 10.3%, 8.6%, and 7.3% respectively, placing them among the top cities for electric vehicle penetration in the world.

AMSTERDAM, NETHERLANDS

Metropolitan population	**2.4 million**	**Total electric vehicle sales**	**6,645**
Public electric vehicle charge points per million people	**561**	**Electric vehicle share of total vehicle sales**	**9.7%**
Grid CO2 emissions (gCO2/kWh)	**565**	**Electric vehicle sales share relative to country average**	**1.0x**

The electric vehicle share of new vehicle sales in Amsterdam was 9.7% in 2015, placing it among the highest in the world. As the capital and most populous city of the Netherlands, Amsterdam is a model for the transition to sustainability for other cities in the Netherlands and abroad. Amsterdam has set aggressive sustainability targets, aiming to become the first zero-emission European city and to reduce its overall CO_2 emissions by 45% in 2025 relative to 2012 levels (City of Amsterdam, 2015). A significant portion of Amsterdam's air pollution, estimated at up to 50%, stems from motorized traffic (Gemeente Amsterdam, 2016). To achieve its overall emission reduction targets, the city has created a strategy to stimulate, support, and regulate the transition to clean mobility. The city has a widespread public charging network powered by locally generated wind energy. The city encourages further development of the charging infrastructure by accepting applications for the installation of additional public charging stations in desired areas and providing subsidies for the installation of private and semi-private charging stations. Among other programs, there is residential parking permit priority for electric vehicle owners, subsidies for electric taxis and company owned vehicles, a fleet of 350 electric vehicles for car sharing (Car2Go), and extensive deployment of electric taxis (IEA, 2016). Even Amsterdam's Schiphol airport has started the deployment of 35 electric buses charged with solar energy from the largest charging station for electric buses in Europe.

Table 6. Summary of electric vehicle support actions in the Amsterdam metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal incentives: electric vehicles exempted from registration and road taxes, reduced tax for the private use of a company car, investments in electric vehicles and charging points that are partially deductible from corporate and income taxes • 5,000 euros for fully electric taxis or company owned passenger and small delivery vehicles • 20% off the purchase price (up to 40,000 euros) per vehicle for large vans, trucks, or buses	++
Nonfinancial incentives	• Priority for electric taxis • Priority for electric vehicles in Low Emission Zones (current for trucks, delivery vans in 2017, taxis and coaches in 2018) • Residential parking permit priority • Free floating parking permits for car sharing companies with fully electric fleets	++

Type of Program	Description	Grade
Charging infrastructure	• 1,341 total charge points and 36 fast charge points • 4,000 charge points planned by 2018 • Public charging stations are powered by locally generated wind energy • Residents/ employees can submit application for new public charging station • 500 euro subsidy for private charging point • 1000 euro subsidy for semi-private charging point	++
Research and campaigns	• Part of European FREVUE Program • EU Sustainable Energy Electric Vehicles for the City (SEEV4City) – storage of sustainable energy using electric vehicles • Part of the Dutch Living Lab Smart Charging • Municipality of Amsterdam and the University of Applied Sciences of Amsterdam performed a study to analyze the most efficient way to install charging infrastructure	+
Transit and fleets	• Car2Go – car sharing company with 350 electric vehicles • All taxis fully emission free by 2025 (Clean Taxis for Amsterdam Covenant) • Currently more than 400 electric taxis • Plans to make public transit system emission free by 2025 • 35 electric buses at Amsterdam Airport Schiphol (largest charging station for electric buses in Europe)	++

Charge point data from Open Charge Map (2016), as of September 9, 2016

UTRECHT, NETHERLANDS

Metropolitan population	**1.3 million**	**Total electric vehicle sales**	**8,791**
Public electric vehicle charge points per million people	**781**	**Electric vehicle share of total vehicle sales**	**14.7%**
Grid CO_2 emissions (gCO_2/kWh)	**565**	**Electric vehicle sales share relative to country average**	**1.5x**

Utrecht is the fourth largest city in the Netherlands and the capital of the province of Utrecht, the smallest of the country's 12 provinces. Although Utrecht is relatively small, more electric vehicles were sold there in 2015 than in any other metropolitan area in the Netherlands. In 2015, Utrecht had the second highest electric vehicle share of the world's large metropolitan areas at 14.7%, second only to Oslo, Norway. The city of Utrecht published its Clean Transport Action Plan in 2015 for 2015-2020 outlining a comprehensive set of actions to become climate neutral by 2030 including a goal to become the city with the highest number of electric cars per inhabitant in the Netherlands (City of Utrecht, 2015). Over the past couple of years, Utrecht has been a hotspot for the development of clean, smart charging networks and vehicle-to-grid integration through various pilot projects and government subsidies.

Table 7. Summary of electric vehicle support actions in the Utrecht metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal incentives: electric vehicles exempted from registration and road taxes, reduced tax for the private use of a company car, investments in electric vehicles and charging points that are partially deductible from corporate and income taxes • 5,000 euros for electric taxis and delivery vans (until end of 2015) • 10.7 million euros in subsidies for vehicle replacement	++
Nonfinancial incentives	• Environmental zone • Free parking while charging • Bus lane access for clean taxis	++
Charging infrastructure	• 987 total charge points and 46 fast charge points • All charging points will supply only green energy (Utrecht Energy Deal) • 500 euros subsidy for private charging point • 1,500 euros subsidy for semi-public charging points • 160 new charging stations planned in 2017	++
Research and campaigns	• Smart Grid Consortium development of V2G energy storage system • Solar Smart Solar Charging Network Project: deployment of 150 Renault ZOE, installation of 1,000 smart solar-charge stations powered by 10,000 photovoltaic panels, implementation of car sharing program, and development of V2G ecosystem • Part of the Dutch Living Lab Smart Charging	++
Transit and fleets	• Emission free freight transport in the city center by 2020 and the entire city by 2025 (Zero Emission Urban Distribution Green Deal) • 3 all electric buses • 20 electric taxis for transporting school children	+

Charge point data from Open Charge Map (2016), as of September 9, 2016

NORWAY

Norway is widely viewed as the world leader in electric mobility. With approximately 34,000 electric vehicles sales in 2015, more than 22% of Norway's total vehicle sales in 2015 were electric. Almost all of the electricity consumed in Norway is generated from hydropower, making electric vehicles a core part of the country's actions to reduce overall carbon emissions. By 2020, Norway aims to cut greenhouse gas emissions 30% relative to 1990 emission levels and to achieve total carbon neutrality by 2050 (Transportøkonomisk Institutt [TØI], 2013). By 2020, Norway aims to achieve an average CO_2 emission rate of new passenger vehicles below 85 g/km (TØI, 2013). To achieve these ambitious emissions reduction goals, the national government has implemented the world's most generous program of electric vehicle incentives. Among the benefits are exemption from the 25% VAT on purchase or leasing, no import or purchase taxes, no charges on tolls or ferries, low annual road tax, 50% reduced company car tax, no fuel taxes for hydrogen or electricity, free access to bus lanes, free municipal parking, and free charging station use (AVERE, 2012; Norsk elbilforening, 2016). In addition, the government is financing at least two multi-standard charging stations every 50 kilometers on all main roads in Norway by 2017 to allow for long distance trips using electric vehicles (Norsk elbilforening, 2016).

Norway is home to several major electric vehicle markets. The capital, Oslo, stands out and is profiled below. Aside from Oslo, the second-largest metropolitan area of Bergen has a regional population around 500,000 and had the world's highest share of electric vehicle sales with more than 4,600 electric vehicle sales, accounting for 38% of the total vehicle sales in 2015. As many of the surrounding suburbs are on islands, the national incentives of toll exemptions or reductions for the use of bridges, tunnels, and ferries provide a substantial incentive for the inhabitants of the Bergen metropolitan area to purchase electric vehicles. Overall, Norway's urban areas especially benefit, due to the incentives of access to bus lanes and free access to the "toll rings" (Tietge et al., 2016).

OSLO, NORWAY

Metropolitan population	**1.2 million**	**Total electric vehicle sales**	**10,920**
Public electric vehicle charge points per million people	**2,295**	**Electric vehicle share of total vehicle sales**	**26.6%**
Grid CO_2 emissions (gCO_2/kWh)	**9**	**Electric vehicle sales share relative to country average**	**1.2x**

Oslo has the highest electric vehicle share of any major metropolitan area in the world, with electric vehicles accounting for 21% of new passenger vehicles in 2015. Although the Oslo metropolitan area accounts for approximately one-fourth of Norway's population, 40% of Norway's electric vehicles in 2015 were sold in Oslo. Oslo has recently tightened its emission reduction goals, aiming to reduce greenhouse gas emissions in half relative to 1990 levels by 2020 and by 95% by 2030 (Oslo Kommune, 2016). As over 60% of emissions come from transportation, the transformation of the transportation sector is a main pillar of Oslo's plan to cut emissions, as outlined in Oslo's Climate Budget (Oslo Kommune, 2016). To achieve an emissions reduction from transportation of more than 40%, Oslo plans to continue to push electric mobility by electrifying public transportation and the municipality and taxi fleets, freight electrical vehicles, craft and service vehicles, while also increasing charging infrastructure and implementing low-emission and environmentally differentiated congestion zones (Peters & Torvanger, 2016). In terms of passenger traffic, Oslo seems to have shifted its focus from promoting electric vehicles to reducing overall passenger traffic by raising tolls for vehicles entering the city, increasing public transit use, improving bicycle infrastructure, introducing parking restrictions, facilitating carpooling, and encouraging pedestrian traffic with the aim of having a car free city center by 2019 (Tønnesen et al., 2016).

Table 8. Summary of electric vehicle support actions in the Oslo metropolitan area

Type of Program	Description	Grade
Financial incentives	• No purchase or import taxes • Exempt from 25% VAT on purchases and leases • 50% reduction on company car taxes • No fuel taxes for electricity or hydrogen • Low annual road taxes • Exempt from road and ferry tolls	++
Nonfinancial incentives	• Planning low-emission zones • Free municipal parking • Free electricity for normal charging (3.6kW) • Discounted quick- and semi-quick charging for prioritized vehicles (e.g., EL-Taxis and Electric Freight Vehicles (FEV)) • Bus lane access	++
Charging infrastructure	• 2,973 total charge points, 161 fast charge points • Grants for up to 60% (up to 10,000 kroner) of the cost of the installation of additional charging point • 2 million euros for the installation of 400 charging points between 2008-2011, 200 new charging points per year from 2013, 1,200 total by of the end of 2016, and 200 new ones in 2017 • Free public charging for normal charging (3.6 kW) • Cooperation with private quick charging companies to deploy quick charging stations (three deployed in 2016 with many more to come) • Building "a center of excellence for professional users of electric vehicles" in cooperation with the private real estate company Aspelin Ramm • Building dedicated quick and semi-quick charging stations for EL-Taxis together with the taxi industry • Building two large parking garages for electric vehicles	++
Research and campaigns	• Part of European FREVUE, SEEV4, BuyZET, ELAN, and REMIND Programs	+
Transit and fleets	• Zero emissions municipality fleet and public transportation by 2020 • Green purchase of transport services	++

Charge point data from Open Charge Map, 2016, as of September 9, 2016

SWEDEN

Sweden has worked to promote electric vehicles in recent years, and in 2015 it ranked third in new electric vehicle sales percentage in Europe, with electric vehicles accounting for 2.5% of vehicle sales, behind only Norway and the Netherlands. Sweden has adopted a variety of programs to incentivize electric vehicles, including an upfront subsidy of 40,000 kroner (about $4,540) and exemption from circulation taxes (Mock & Yang, 2014). Greater financial incentives for those replacing old, high-polluting vehicles, as well as free parking, have led to high electric vehicle sales in urban areas. In addition to the capital of Stockholm, the city of Gothenburg, home of the Swedish Electric and Hybrid Vehicle Centre, has seen success through its Green Gothenburg campaign and its efforts to electrify 95% of the city's fleet. Sweden is also pushing the frontiers of electric vehicle technology, including working with Siemens to electrify a major highway through the country in order to advance electrification of heavy-duty vehicles (Weller, 2016).

STOCKHOLM, SWEDEN

Metropolitan population	**2.2 million**	**Total electric vehicle sales**	**3,727**
Public electric vehicle charge points per million people	**257**	**Electric vehicle share of new vehicles**	**3.7%**
Grid CO_2 emissions (gCO_2/kWh)	**22**	**Electric vehicle sales share relative to national average**	**1.5x**

The capital of Sweden has seen higher electric vehicle sales than the average of Europe and Sweden, likely stemming from numerous electric vehicle promotion programs over more than a decade. The city has ambitions of becoming the world's leading clean vehicle city and making the city center fossil-free by 2030, with electric vehicles playing an important role in the transformation (City of Stockholm, 2012). The city has partnered with a number of organizations, such as the utility Vattenfall, to transform public and company fleets and to provide public charging stations using clean energy. Furthermore, the city awards electric vehicles free parking permits in the city center, which normally cost 5000 kroner (more than $560) per year (van der Steen et al., 2015). Stockholm will continue to push electric vehicle adoption into mainstream markets and fulfill its ambitious goals.

Table 9. Summary of electric vehicle support actions in the Stockholm metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal incentive of 40,000 kroner ($4,400) • Exemption from annual circulation taxes	+
Nonfinancial incentives	• Free central city parking permits	+
Charging infrastructure	• 565 total charge points, 82 fast charge points • Numerous free chargers with 100% renewable energy	+
Research and campaigns	• Vattenfall inductive charging demonstrations and research • Clean Cars campaign with OEMs and fuel companies to promote zero-emission vehicles	+
Transit and fleets	• Clean Fleets case study – City of Stockholm and 296 organizations purchasing up to 5,000 electric vehicles	+

Charge point data from Open Charge Map (2016), as of September 9, 2016

SWITZERLAND

The small, mountainous country of Switzerland has worked for a number of years to reduce its greenhouse gas emissions and make its transportation sector more environmentally friendly. Switzerland has adopted increasingly stringent emission standards for imported vehicles, and has announced that electric vehicles will cover 50% of vehicle miles traveled by 2050 as part of its New Energy Policy (Swiss Federal Office of Energy [SFOE], 2016; IEA, 2016). The federal government waives the standard 4% car import tax for electric vehicles, but offers no additional financial incentives, leaving such programs to individual cantons. Nonetheless, other actors in Switzerland have been active in promoting electric vehicles. For example, the E'mobile coalition, organized by automakers, utilities, and research institutions, organizes events and publications to support low-emission vehicle uptake (E'mobile, 2016). Additionally, some of Switzerland's picturesque mountain villages, such as Zermatt and Wengen, allow electric vehicles into their otherwise car-free centers.

ZÜRICH, SWITZERLAND

Metropolitan population	**1.6 million**	**Total electric vehicle sales**	**2,496**
Public electric vehicle charge points per million people	**121**	**Electric vehicle share of new vehicles**	**3.4%**
Grid CO_2 emissions (gCO_2/kWh)	**11**	**Electric vehicle sales share relative to national average**	**1.7x**

Switzerland's largest city, Zürich, is known for its innovative transportation solutions, including an extensive tram network and a system that limits traffic volumes in the city center. The city is working to incorporate electric vehicles into its sustainability plans, boasting the highest electric vehicle sales in the country. Zürich's utility, EKZ, also has played a major role in promoting electric mobility in the region and has worked to maximize the environmental benefits of electric vehicles by linking charging with renewable energy. Zürich may not match the sales or programs of larger European capitals, but its transportation electrification programs are pushing the country toward cleaner mobility.

Table 10. Summary of electric vehicle support actions in the Zürich metropolitan area

Type of Program	Description	Grade
Financial incentives	• Exemption (for BEVs) and 80% reduction (for PHEVs) from vehicle taxes in Canton of Zürich	+
Nonfinancial incentives		
Charging infrastructure	• 190 total charge points, 12 fast charge points • National charging station registry LEMnet • Utility EKZ operates fast charging stations in city powered by renewable energy	+
Research and campaigns	• Utility EKZ partnering with IBM to research charging and consumer outreach practices • Research on electric vehicle powertrains, purchasing behavior at ETH Zürich • EKZ Ökostrom-Vignette program guarantees green power for all electric vehicle driving	++
Transit and fleets	• Ongoing electrification of taxi fleet through private-sector initiatives • eMotion Zürich electric car-sharing trial • Replacing diesel trolleybuses with electric buses	+

Charge point data from Open Charge Map (2016), as of September 9, 2016

UNITED KINGDOM

Electric vehicles represented 1.1% of all vehicle sales in 2015 in the United Kingdom, putting the country above the European average. This was approximately double the figure for 2014, and strong growth has continued into 2016 (Society of Motor Manufacturers and Traders, 2016a, 2016b). In recent years, the United Kingdom has initiated a suite of programs to promote electric vehicles, including a subsidy of up to 4,500 pounds and the pioneering Go Ultra Low consumer awareness campaign (Office for Low Emission Vehicles [OLEV], 2016d). The Office for Low Emission Vehicles (OLEV) is investing more than 600 million pounds between 2015 and 2020 to advance

the government's goal of making the UK's light-duty fleet fully zero-emission by 2050 (OLEV, 2016a; International Zero Emission Vehicle Alliance, 2015).

Major priorities in the United Kingdom's transportation electrification scheme include the deployment of public and private electric vehicle charging equipment and the electrification of bus and taxi fleets. OLEV offers grants of up to 500 pounds toward the cost of home chargers, provides grants towards workplace charge points, and is working with Highways England to complete an extensive nationwide rapid charge network, a 15 million pound project to ensure there are rapid chargers every 20 miles on the United Kingdom's Strategic Road Network—however, interoperability between private charge networks remains a concern (OLEV, 2016b; Blythe et al., 2015). Recently the government has proposed taking regulatory action to make the provision of electric vehicle charge points mandatory at suitable public locations, simplify the electric vehicle charging equipment usage process for consumers, and introduce smart charging capability to enable future balancing of electricity supply and demand. As with other countries, electric vehicle uptake has been concentrated in specific regions—in addition to the capital of London, the districts of Gloucestershire, Peterborough, and Birmingham have seen electric vehicle sales shares above the national average in 2015, at 9.1%, 4.1%, and 1.5% respectively.

LONDON, UNITED KINGDOM

Metropolitan population	**15 million**	**Total electric vehicle sales**	**7,037**
Public electric vehicle charge points per million people	**112**	**Electric vehicle share of new vehicles**	**1.4%**
Grid CO_2 emissions (gCO_2/kWh)	**428**	**Electric vehicle sales share relative to national average**	**1.3x**

As the capital of the United Kingdom and largest city in the European Union, London is an international center of finance and culture. Increasingly concerned with climate change, air pollution and sustainability, the city has made promotion of electric vehicles a major piece of its environmental policy, including plans to help London become the Ultra-Low Emission Vehicle (ULEV) capital of Europe (Greater London Authority, 2015, 2016). The UK government has given London 15 million pounds as part of the Go Ultra Low City program, with the goal of having 250,000 ultra-low emission vehicles on the road by 2025 (OLEV, 2016a). The city has in turn launched a number of programs to accomplish this ambitious goal, including the ongoing electrification of the taxi and bus fleets; the creation of an Ultra Low Emission Zone in the city center beginning in 2020, although a revised start date of 2019 is under consultation; and planning requirements for charge points at all new developments (Transport for London [TfL], 2016).

Table 11. Summary of electric vehicle support actions in the London metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal grant up to 4,500 pounds at electric vehicle purchase • Electric vehicles exempt from annual circulation tax • Federal grant of an additional 3,000 pounds for zero emission capable taxi (mid-2017-2020)	+
Nonfinancial incentives	• Exemption from congestion charges • Free or reduced parking costs in some boroughs • Central Ultra Low Emission Zone planned for introduction by 2020 (revised start of 2019 under consideration)	+
Charging infrastructure	• 1,652 charge points and 134 fast charge points • City-wide Source London network accessible for small annual fee • Charging point planning requirements for all new developments	++
Research and campaigns	• UK Power Networks grid assessment and demand response trials • Go Ultra Low "Neighborhoods of the Future" project • Go Ultra Low national communications campaign	++
Transit and fleets	• Electrification of bus routes • All single-deck buses will be ZEV by 2020 • All new taxis required to be ZEV capable by 2018 • LoCITY program to encourage cleaner commercial vehicles	++

Charge point data from Office for Low Emission Vehicles (OLEV, 2016c), as of September, 2016

UNITED STATES

More than 115,000 new electric vehicles were sold in the United States in 2015, representing about a quarter of global electric vehicle sales. Although this is a substantial fraction of the global market, electric vehicles represented only 0.7% of all light-duty vehicle sales in 2015 in the United States. The United States has a variety of national policies and promotion actions in place that have supported the development of the market for electric vehicles. These programs include federal tax credits up to $7,500 for the purchase of new electric vehicles, vehicle efficiency standards through 2025 with explicit incentives for electric vehicles, funding for public charging infrastructure, and a program to encourage workplace charging infrastructure deployment. With the goal of making electric vehicles cost competitive and as convenient as conventional vehicles by 2022, the U.S. Department of Energy launched EV Everywhere, an initiative combining research and development, outreach, and education. In addition, many states and cities offer additional consumer fiscal rebates, access to high-occupancy vehicle lanes, exemptions from fees, and preferential parking, among many different actions.

Several major U.S. vehicle markets greatly outpaced the national average electric vehicle uptake in 2015. These markets include many throughout California that were well above the national average. In addition, the areas of Seattle, Washington, Portland, Oregon, Atlanta, Georgia, and Honolulu, Hawaii, had about 2% electric vehicle sales shares in 2015. These high electric vehicle uptake markets tended to have a combination of vehicle and fuel policy, state consumer incentives, local support actions, more extensive public charging infrastructure, and utility actions in place to support electric vehicles (Lutsey et al., 2016). In addition, California's Zero Emission Vehicle regulation has greatly increased electric vehicle model availability in the state, and the policy requires greater electric vehicle penetration over time, up to 15% of new vehicle sales by 2025. The three California metropolitan areas of San Jose, San Francisco, and Los Angeles that are profiled below account for 40% of all United States electric vehicle sales.

SAN JOSE, CALIFORNIA, UNITED STATES

Metropolitan population	**2.0 million**	**Total electric vehicle sales**	**9,753**
Public electric vehicle charge points per million people	**379**	**Electric vehicle share of new vehicles**	**9.4%**
Grid CO_2 emissions (gCO_2/kWh)	**296**	**Electric vehicle sales share relative to country average**	**13x**

The San Jose metropolitan area stands apart as the top electric vehicle uptake market in the Unites States with over 9% electric vehicles share—13 times the national average. New electric vehicle sales in 2015 were about 9,700, a 7% increase over 2014. Encompassing Silicon Valley, the headquarters for many global high-tech companies, the San Jose area has demonstrated that it is a highly attractive early market for electric vehicles (Searle et al., 2016). Along with the standard rich portfolio of California state-level policies, the San Jose area has a variety of local promotion actions to help spur electric vehicle uptake. Local support includes access to multiple high-occupancy vehicle highway lanes, city-owned charging, and free parking for electric vehicles. The city also has a goal for 100% alternative fueled vehicles in its municipal fleet by 2020. The local electric utility, Pacific Gas & Electric, has many supportive actions, including lower electric vehicle charging rates, information and cost tools to assist electric vehicle users. The area has the most extensive public charging infrastructure network in the U.S. with 379 charge points per million residents, which is 4.5 times the national average. The area also includes a much greater amount of workplace electric vehicle charging than elsewhere in the United States.

Table 12. Summary of electric vehicle support actions in the San Jose metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal tax credit up to $7,500 per electric vehicle • State rebate up to $2,500 per electric vehicle	++
Nonfinancial incentives	• City parking benefit • Preferential access to high-occupancy vehicle lanes • Preferential utility electric vehicle charging rate	++
Charging infrastructure	• 955 charge points and 71 fast charge points • Extensive workplace charging network: More than 1400 workplace charge points available to employees • Low-carbon fuel regulation • State private charging infrastructure incentives and streamlined local charging permitting process	++
Research and campaigns	• State manufacturing incentive • “National Drive Electric Week” city outreach information and events • Utility outreach information and events	+
Transit and fleets	• State electric vehicle fleet programs • Goal to power 100% of municipal fleet with alternative fuels by 2022 (currently 41%)	+

Charge point data from Alternative Fuels Data Center [AFDC] (2016), as of October 19, 2016

SAN FRANCISCO, CALIFORNIA, UNITED STATES

Metropolitan Population	**4.6 million**	**Total electric vehicle sales**	**13,081**
Public electric vehicle charge points per million people	**339**	**Electric vehicle share of new vehicles**	**5.3%**
Grid CO_2 emissions (gCO_2/kWh)	**296**	**Electric vehicle sales share relative to country average**	**7.5x**

The San Francisco metropolitan area is a major electric vehicle hub in the United States, with over 5% electric vehicles share—more than 7.5 times the national average. New electric vehicle sales in 2015 were more than 13,000, a 7% increase over 2014, and the second highest sales fraction among U.S. markets. Along with the many California state-level policies to support, the San Francisco area has a variety of local promotion actions to help spur electric vehicle uptake (Searle et al., 2016). Local support includes access to high-occupancy vehicle highway lanes, city-owned charging, and multiple city outreach and awareness activities for electric vehicles. The city also operates programs to increase the use of electric vehicle in their city and private car-sharing fleets. The local electric utility, Pacific Gas & Electric, has many supportive actions, including reduced electric vehicle charging rates and information and cost tools to assist electric vehicle users. The area has one of the most extensive public charging infrastructure networks in the United States, with 339 charge points per million residents, which is four times the national average.

Table 13. Summary of electric vehicle support actions in the San Francisco metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal tax credit up to $7,500 per electric vehicle • State rebate up to $2,500 per electric vehicle	++
Nonfinancial incentives	• City parking benefit • Preferential access to high-occupancy vehicle lane • Preferential utility electric vehicle charging rate	++
Charging infrastructure	• 1,916 charge points and 175 fast charge points • Low-carbon fuel regulation • State private charging infrastructure incentive	++
Research and campaigns	• State manufacturing incentive • “Best.Ride.Ever” and “National Drive Electric Week” outreach and awareness events • City information materials and events • Utility outreach information and events	+
Transit and fleets	• More than 300 electric trolley buses and additional hybrid buses • State and city electric vehicle fleet programs • Electric car sharing program	++

Charge point data from AFDC (2016), as of October 19, 2016

LOS ANGELES, CALIFORNIA, UNITED STATES

Metropolitan population	**13 million**	**Total electric vehicle sales**	**23,653**
Public electric vehicle charge points per million people	**208**	**Electric vehicle share of new vehicles**	**2.8%**
Grid CO_2 emissions (gCO_2/kWh)	**296**	**Electric vehicle sales share relative to country average**	**4.0x**

The Los Angeles metropolitan area has the highest electric vehicle sales among metropolitan areas in the United States. With more than 23,000 new electric vehicles in 2015, Los Angeles had an approximate 3% electric vehicles share—more than 4 times the national average. Along with the many California state-level policies to support, the Los Angeles area has a variety of local promotion actions to help spur electric vehicle uptake. Local support includes access to multiple high-occupancy vehicle highway lanes, city-owned charging, and multiple city outreach and awareness activities for electric vehicles. The city also has programs to increase the use of electric vehicles in its city, police, and private car-sharing fleets. The city also has enacted an EV-ready building code requirement whereby new buildings are equipped to enable charging infrastructure. The local utilities offer many supportive actions, including lower electric vehicle charging rates, consumer information, home charger incentives, extensive research into smart charging programs. In addition, there is a major utility pilot plan to deploy $22 million in electric vehicle public charging infrastructure (Edison International, 2016). The area also has an extensive public charging infrastructure network with about 2.5 times the charge points per capita of the U.S. average.

Table 14. Summary of electric vehicle support actions in the Los Angeles metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal tax credit up to $7,500 per electric vehicle • State rebate up to $2,500 per electric vehicle	++
Nonfinancial incentives	• City parking benefit • Preferential access to high-occupancy vehicle lanes • Preferential utility electric vehicle charging rate	++
Charging infrastructure	• 3,473 charge points and 226 fast charge points • Low-carbon fuel regulation • State private charging infrastructure incentive • Electric vehicle-ready building codes • Streamlined local charging permitting process	+
Research and campaigns	• State manufacturing incentive • “Drive the Dream,” “Best.Ride.Ever,” and “National Drive Electric Week” city outreach and awareness events • City information materials and events • Utility outreach information and events	+
Transit and fleets	• State and city electric vehicle fleet programs • Growing municipal and police electric vehicle fleets • Electric car sharing program	++

Charge point data from AFDC (2016), as of October 19, 2016

IV. SUMMARY COMPARISON OF ELECTRIC VEHICLE MARKETS

This section summarizes data on electric vehicle sales, public charging infrastructure, policy actions, and carbon emissions across the cities. The electric vehicle sales data in all countries except for Norway are estimated from new vehicle registration data. The charging infrastructure data presented come from multiple sources. The policy action data are qualitative, based on original collection for this report. The carbon emission data include comparisons of lifecycle emissions from electric and conventional vehicles in the regions examined. Further information, underlying data sources, and additional assumptions are presented in the Annex. In several cases data were not available for particular cities.

ELECTRIC VEHICLE UPTAKE

Figure 1 shows the electric vehicle uptake—in new registrations and share of new vehicles in 2015—for the 14 metropolitan areas identified in this study. These 14 markets represented 32% of global electric vehicle sales in 2015. As shown, the top 2015 electric vehicle markets within China, Europe, and the United States have annual electric vehicle sales that are in the tens of thousands per year or that make up about one in every 10 new vehicles. Oslo had the highest electric vehicle share at 27%, followed by Utrecht at 15%, and Shanghai at 11%. Shenzhen, Amsterdam, and San Jose complete the top six in sales share with 9%-10% of new vehicles being electric. The top six cities by electric vehicle share are distributed across four countries on three continents. In terms of total annual new electric vehicle volume, Shanghai leads by a wide margin with 41,179 electric vehicles sold in 2015. Los Angeles, with 23,652 sales, and Beijing, with 18,065 sales, had the next most new electric vehicles being deployed.

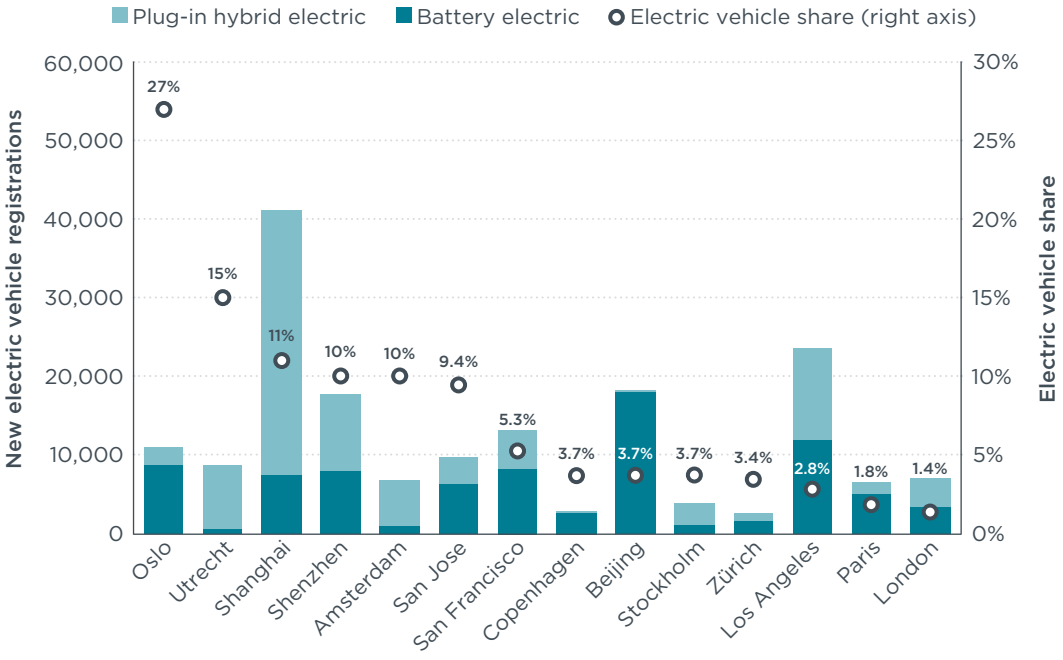

Figure 1. Electric vehicle new registrations and share of new vehicles in 2015 in high electric vehicle uptake markets. (*new vehicle registration data from IHS Markit and IHS Automotive*)

Although Figure 1 shows electric vehicle sales relative to the other capital cities, these cities have varying performances relative to their own countries. The city of Oslo has very high uptake, for example, but its sales fraction is only slightly higher than Norway's national average of 22%. Meanwhile, San Jose has an electric vehicle share more than 13 times that of the United States (and three times that of California), and Shanghai sold electric vehicles at 12 times the rate of China's national average.

Beyond total sales volume and sales fraction, there are additional differences between these cities. In some cities, such as Copenhagen and Beijing, almost all electric vehicles sold were pure battery electric vehicles, while in other cities, like Amsterdam and Utrecht, the vast majority were plug-in hybrid electric vehicles, and in cities such as San Jose and Stockholm, there is a mixture of electric vehicle types. This is reflective of differences in subsidy programs that prioritize the two plug-in electric vehicle types, availability of models in each market, the availability of charging infrastructure, and commuting patterns.

CHARGING INFRASTRUCTURE

As noted in the introduction, public charging infrastructure can be an important component of electric vehicle market growth, and each of the cities examined have substantial electric vehicle charging networks. Figure 2 shows the number of charge points (both total and fast) per million people in most of the metropolitan regions examined in Europe and North America. As shown, Oslo has much more substantial charging network than others, with more than 2,400 total charge points per million people with about 130 fast chargers per million people, with others having less charging available. Detailed, comprehensive data were not publicly available for the China cities; based on best available data, we approximate that the total charge points per million people for Shanghai is 146 and for Beijing is 313. Oslo and Utrecht, the top two cities in electric vehicle sales share, also lead in the availability of public charging infrastructure. Overall, the cities with the greatest electric vehicle uptake tended to have greater charging infrastructure, providing additional evidence that charging infrastructure is a crucial part of a supportive electric vehicle environment.

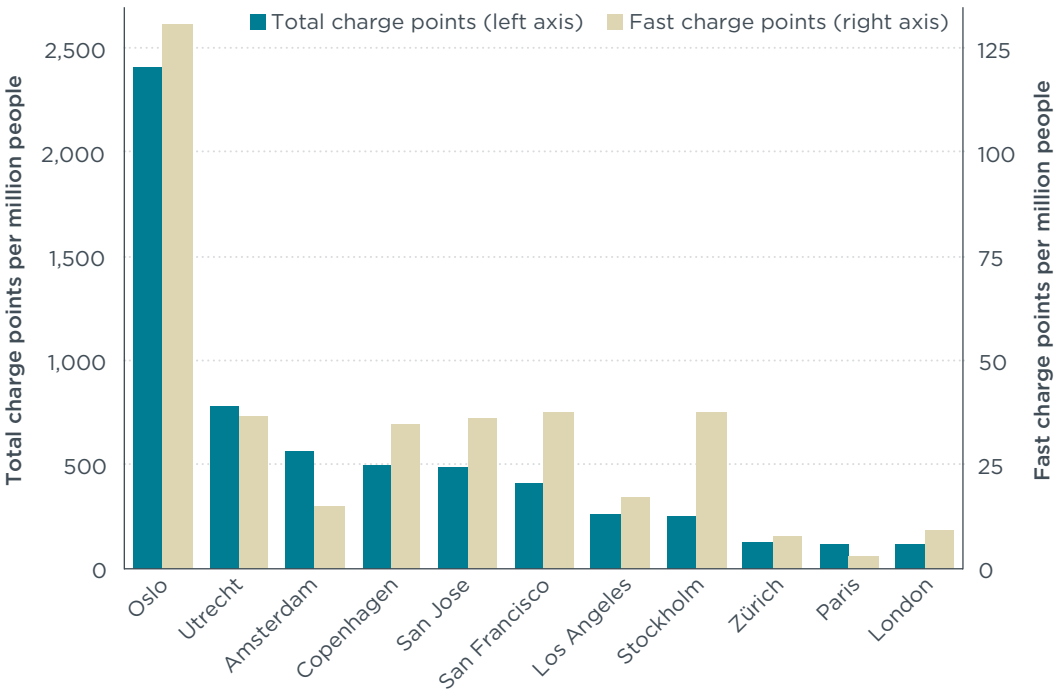

Figure 2. Total electric vehicle charge points and fast charge points per million population.

In each city, the number of Level 2 (AC) charging far exceeded the number of fast chargers, which are defined as having a charging power of 40 kW or greater. Although we use 40 kW for consistency in this analysis, different jurisdictions use anywhere from 22 to 50 kW to define fast charging. However, the ratio varies from more than 20 level 2 chargers for every fast charger in Utrecht and London to about six level 2 chargers for every fast charger in Stockholm. With its large population, Los Angeles leads the 11 metropolitan areas analyzed here in terms of total charge points with 3,473, followed by Oslo (2,829), San Francisco (1,916), and London (1,652). Although detailed comprehensive data were not publicly available for China, one government source states that there are 6,789 publicly available charge points in Beijing and 3,513 in Shanghai (Electric Vehicle Charging Infrastructure Promotion Alliance [EVCIPA], 2016).

ELECTRIC VEHICLE PROMOTIONAL ACTIONS

All of the cities in this assessment have extensive actions and policies in place to further the deployment of electric vehicles. Table 15 shows a breakdown of the extent to which each of the respective cities has implemented actions and policies based on five main categories: financial incentives, nonfinancial incentives, charging infrastructure, research and campaigns, and transit and fleets. Each of the categories is given a ranking of + or ++ based on the extent of action the city has taken for the respective category, with a blank indicating no known policy or action, +, some action, and ++, extensive action. As indicated, each of these metropolitan areas with high electric vehicle uptake has many policies and promotion activities in place.

Table 15. Qualitative evaluation of electric vehicle support actions for high electric vehicle uptake markets

Country	City	Financial incentives	Nonfinancial incentives	Charging infrastructure	Research and campaigns	Transit and fleets
China	Shanghai	++	+	+	+	++
	Shenzhen	++	++	+		++
	Beijing	++	+	+	++	+
Europe	Copenhagen	+	+	++	++	++
	Paris	++	+	+	+	+
	Amsterdam	++	++	++	+	++
	Utrecht	++	++	++	++	+
	Oslo	++	++	++	+	++
	Stockholm	+	+	+	+	+
	Zürich	+		++	+	+
	London	+	++	+	++	++
United States	San Jose	++	++	++	+	+
	San Francisco	++	++	++	+	++
	Los Angeles	++	++	+	+	++

A blank indicates no known policy or action, + some action, and ++ extensive action. Additional details on evaluations are provided in the Annex.

GRID CO_2 EMISSIONS FROM ELECTRIC VEHICLE CHARGING

Electric vehicles, due to their much higher on-road efficiency and use of lower-carbon energy sources, have the potential to offer much lower carbon emissions than conventional vehicles. Figure 3 shows real-world life-cycle carbon dioxide (CO_2) emissions on a per kilometer basis in each of the countries discussed in this paper, including both the vehicle exhaust emission and the fuel cycle emissions to extract and process the energy sources into useful vehicle energy. This figure compares the emissions from the world's most popular electric vehicle, the 2015 Nissan Leaf, charged using electricity from the country's average electricity generation portfolio, with emissions from an average internal combustion engine-powered passenger car sold in 2015 in each of these countries. The conventional vehicles are shown as passenger car averages for China, U.S., and Europe, based on the latest available regulatory CO_2 data. These include an adjustment to account for higher real-world emissions (e.g., International Council on Clean Transportation, 2015; U.S. Environmental Protection Agency and Department of Transportation, 2012). Electric vehicles in all markets analyzed delivered substantially lower carbon emissions than the average conventional vehicle. In some regions (e.g., Amsterdam and Zürich), electric vehicles are more frequently charged using dedicated "green" electricity sources; although the benefits of these programs are not reflected in Figure 3, dedicating clean electricity to fuel electric vehicles would result in even lower carbon transport. Further details on the underlying assumptions are provided in the Annex.

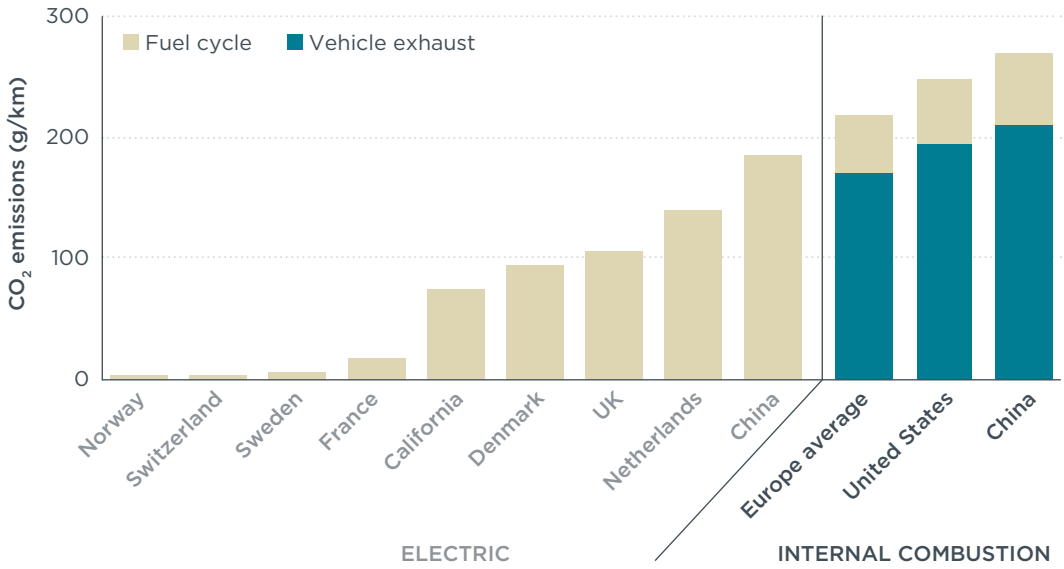

Figure 3. CO_2 emissions from electric and internal combustion engine vehicles in the jurisdictions analyzed assuming the country's average generation portfolio is used to charge electric vehicles.

As shown in the figure, electric vehicles produce fewer emissions than an average internal combustion engine vehicle in every jurisdiction considered. However, the magnitude of this difference varies significantly. Markets like Norway, France, Sweden, and Switzerland that have greater electricity generation from low-carbon renewable and nuclear energy sources result in much lower carbon emissions—more than a 90% benefit compared with average conventional cars in Europe. In California, an electric vehicle produces at least 75% lower CO_2 emissions per kilometer driven than an average conventional car in the U.S. The same electric vehicle produces 50%-60% lower carbon emissions in Denmark and the United Kingdom. In the cases of China and the Netherlands, electric vehicles delivered 30%-40% lower carbon emissions than the average conventional vehicle in those markets. The Netherlands has led efforts to ensure electric vehicles are charged using low-carbon energy, with public chargers being supplied by renewable energy instead of grid electricity (Verbeek et al., 2015). As the electricity supply around the world continues to become steadily cleaner over time, electric vehicles are expected to offer even greater emission reductions in the future (IEA, 2015).

V. CONCLUSION

As electric vehicle technology continues to improve, policymakers seek to mitigate climate change concerns and see electric vehicle uptake as part of the solution. Although global electric vehicle sales are modest at less than 1% of new car sales, many major markets have seen relatively high uptake (ranging from 2 to more than 30 times the global average) due to a variety of supportive policies and extensive charging infrastructure networks. Although these "electric vehicle capitals" each have different market context and differ in their policy approaches, their success today offers a number of lessons, providing valuable information to other governments planning their own transition to electric drive.

Global electric vehicle sales are heavily concentrated in certain metropolitan areas—the 14 metropolitan areas accounting for just 1.5% of the global population and only 5% of annual global passenger vehicle sales represent about a third of the global electric vehicle market. The metropolitan areas with the highest electric vehicle sales in 2015 were in Shanghai (41,179 electric vehicles), Los Angeles (23,652), Beijing (18,065), and Shenzhen (17,699). The metropolitan areas with the highest share of electric vehicles sold in 2015 relative to total passenger vehicle sales were Oslo (27%), Utrecht (15%), Shanghai (11%), and Shenzhen (10%). These electric vehicle capitals are paving the way for the broader global adoption of electric vehicles. Together, they provide clear examples of the set of actions needed for electric vehicles to reach beyond market innovators and early adopters to the mass market.

The 14 electric vehicle capitals discussed in this paper demonstrate how the pathway to increased penetration of electric vehicles includes a wide range of actions, including financial and nonfinancial incentives, charging infrastructure build out, research and development, promotional campaigns to enhance consumer awareness, electrification of public transit and government vehicle fleets, car sharing services, and others. In essence, the common strand among these cities' electric vehicle activities is that they all are actively addressing the key prevailing barriers of cost, convenience, and consumer information.

Although there are similarities in the policy approaches, each of the progressive electric vehicle capitals has a unique approach to increasing electric vehicle adoption, providing numerous examples for other cities to learn from. In Norway, major incentives are implemented by the national government and regional governments and provide strongly supportive policies and programs. The national government's polluter-pay tax system heavily taxes high-emitting conventional vehicles and exempts zero-emission vehicles. The tax system, paired with other electric vehicle incentives (e.g., low annual road taxes, no fuel taxes, no purchase or import taxes, free parking, bus lane access, free charging, extensive public charging network, exemption from road and tunnel tolls), has effectively placed Norwegian cities at the forefront of electric vehicle deployment and integration. The Netherlands has strong national electric vehicle subsides paired with additional regional subsidies in select locations, widespread electric charging infrastructure and development, extensive public transit and taxi electrification, and a broad range of pilot projects and consumer awareness campaigns. In China, there are federal subsidies and tax exemptions in addition to many local registration limitation policies that greatly favor electric vehicles. The United States federal government implements tax credits, and many regional and local governments, like the state of

California, offer electric vehicle rebates, preferential lane access, developed charging infrastructure, and consumer outreach and awareness.

Future work could include a deeper analysis into each of the markets and the relative importance of charging infrastructure, policy, and other promotion actions. Region-specific analysis, for example, isolating China, Europe, and U.S. markets, could use consistent comprehensive datasets to analyze relative effectiveness of the policy actions and charging infrastructure benchmarks over time. Also, beyond the capitals identified here, there are numerous smaller metropolitan areas that also could provide further insight into electric vehicle deployment. Other cities include Bergen, Norway, where electric vehicles are 38% of total vehicle sales; Eindhoven, Netherlands (10%); Gloucestershire, United Kingdom (9.1%); and Hangzhou, China (7.5%). Bergen's numerous islands made bridge, tunnel, and ferry toll exemptions a major driver for uptake. Analysis of Norway in general might be especially helpful in understanding how northern climates in China and North America might overcome potential issues with electric cars in colder climates. Although no German cities are identified here as capitals, they could hold lessons in the future, especially now that Germany has incentives in place and lower-cost, higher-electric range vehicles are entering the market. For example, Cologne and Frankfurt had approximately 1% electric vehicle sales in 2015 before the major mid-2016 Germany incentive program was implemented. Other cities elsewhere in Europe, Canada, and Japan, could also provide further lessons as data become available on the electric vehicle market development in those regions.

Many cities actively work in many ways to shift the transport system to lower carbon modes, and to decarbonize vehicles with new technology. Among these various strategies, it is clear that electric vehicles deliver a low-carbon transport option. The major electric vehicle hubs assessed here are accelerating the transition to electric drive and therefore realizing significant emissions reductions and air quality benefits. Upstream CO_2 emissions from electric vehicles vary substantially across the cities studied in this paper, from essentially zero in hydropower-rich Norway and Switzerland to more than 150 g/km in relatively coal-heavy China. Even after incorporating upstream emissions from electricity production, electric vehicles emit less CO_2 compared to conventional cars in each of markets evaluated. CO_2 reduction benefits range from 30%-40% China and the Netherlands; 50%-75% in the United Kingdom, Denmark, California; and over 90% in France, Norway, Sweden, and Switzerland. Furthermore, electric vehicles are expected to offer even greater emission reduction benefits in the future as electricity grids become cleaner and new initiatives continue to integrate electric vehicle and renewable energy deployment.

During the early stages of market growth, electric vehicle capitals have charted unique paths and emerged as global leaders in terms of electric vehicle promotion actions and uptake. Although electric vehicle policies and actions must be tailored to each region, the metropolitan areas discussed in this analysis provide models for other cities as they transition toward electric mobility. These electric vehicle capitals of the world are already realizing the benefits of their investment in clean transportation. This type of leadership, if continued and expanded, will help accelerate the global deployment of electric vehicles in coming years.

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ANNEX

This section includes additional data sources, as well as information and criteria regarding the qualitative scoring of the electric vehicle support actions and the quantification of the fuel cycle electric vehicle carbon emissions.

COMPARISON OF ADDITIONAL METROPOLITAN AREAS

Although we limited our primary analysis to select metropolitan areas in the United States, Europe, and China with populations over 1 million, there are a number of additional metropolitan areas with substantial electric vehicle sales in 2015, as shown in Figure A1 below. These 29 metropolitan areas represent approximately 44% of world electric vehicle sales in 2015. Although many of these cities were not included in this analysis, further comparison of this broader array of cities is a possible area for future research.

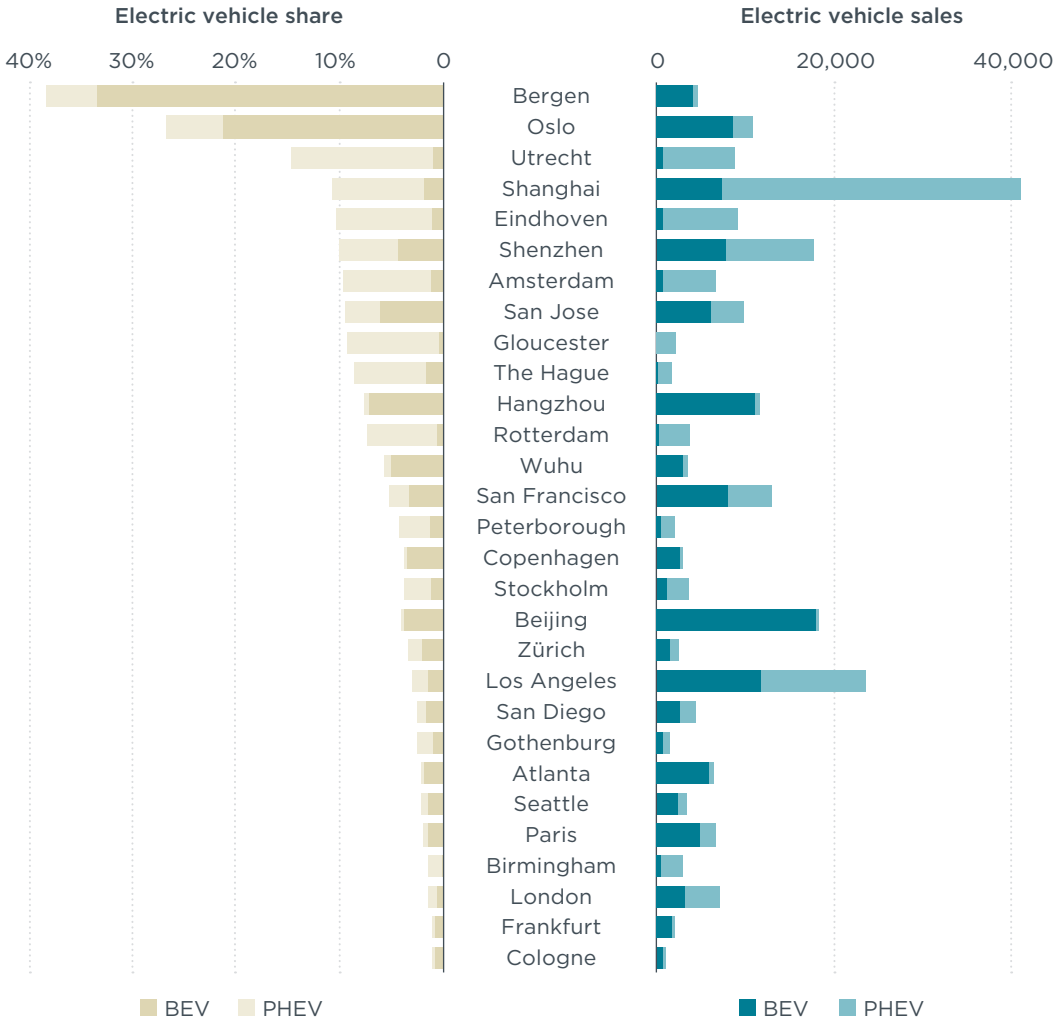

Figure A1. Electric vehicle sales share (left) and sales volumes (right) for 2015 (*new vehicle registration data from IHS Markit and IHS Automotive*).

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Criteria for evaluating electric vehicle support actions. To provide a consistent qualitative analysis, each of the electric vehicle support actions were evaluated with a blank, +, or ++ based on the extent of action taken. These rankings are shown in the right-hand column of the tables outlining electric vehicle support actions for each of the metropolitan areas in the report. The criteria for each category (financial incentives, nonfinancial incentives, charging infrastructure, research & campaigns, and transit & fleets) are defined in Table A1.

Table A1. Criteria used for evaluating the electric vehicle support actions in each city profile

Type of Program	(blank)	+	++
Financial incentives	None	National or regional level incentives with value under $5,000	National and regional level incentive value exceeding $5,000
Nonfinancial incentives	None	One or two actions from the list below	Three or more actions from the list below
Charging infrastructure	< 100 charge points per million people	> 100 charge points per million people	> 400 charge points per million people
Research & campaigns	No significant research projects or consumer awareness campaigns	Notable research project(s) or consumer awareness campaign(s)	Notable research project(s) and consumer awareness campaign(s)
Transit & fleets	None	Substantial electrification in one of the categories below	Substantial electrification in two or more of the categories below

Nonfinancial incentives include local parking benefits, low-emission/environmental zones, congestion charges or exemptions from tolls, high-occupancy vehicle (HOV) or bus lane access, and exemptions from registration restrictions. Transit and fleet activities include government fleet vehicles, municipal buses, taxis, and car sharing services. Where financial incentives are based primarily on tax and fee exemptions rather than subsidies, such as in the Netherlands, we used the values determined in Slowik and Lutsey (2016).

Definitions of metropolitan regions. As noted in the introduction, this paper discusses statistics such as population, vehicle sales, and charging infrastructure at the metropolitan area level rather than at the city level. This helps promote consistency among countries and recognizes that programs instituted at a local level affect people in a wider area through commute and travel patterns. In the United States, our analysis uses the United States Census Bureau Metropolitan Statistical Area (MSA) definition, and in the Europe, our analysis uses the Functional Urban Area (FUA) definition, in most cases. In China, this analysis includes only city definitions, which include large areas that resemble metropolitan areas in other regions. Table A2 below lists the definitions used for each metropolitan area examined in this analysis.

Table A2. Definitions of metropolitan areas used in this analysis

City	Type of urban area	Constituent jurisdictions
Shanghai	Municipality	Shanghai
Shenzhen	Sub-provincial city	Shenzhen
Beijing	Municipality	Beijing
Copenhagen	FUA	Byen København, Københavns omegn, Nordsjælland
Paris	FUA	Paris, Seine-et-Marne, Yvelines, Essonne, Hauts-de-Seine, Seine-Saint-Denis, Val-de-Marne, Val-d'Oise
Amsterdam	Poly-FUA	Alkmaar en omgeving, IJmond, Agglomeratie Haarlem, Zaanstreek, Groot-Amsterdam, Het Gooi en Vechtstreek
Utrecht	FUA	Utrecht (province)
Oslo	FUA	Oslo, Akershus
Stockholm	FUA	Stockholms län
Zürich	FUA	Zürich (Canton), Zug
London	FUA	Greater London, Kent, Essex, Luton, Hertfordshire County, Buckinghamshire County, Berkshire, Surrey
San Jose	MSA	Santa Clara County
San Francisco	MSA	San Francisco County, Alameda County, Contra Costa County, Marin County, San Mateo County
Los Angeles	MSA	Los Angeles County, Orange County

Carbon emissions. In our vehicle life and fuel cycle assessment of electric vehicle CO_2 emissions, we sought to give comparisons that best reflect a comparison with similar internal combustion engine vehicles in each jurisdiction. For consistency, we used a 2015 Nissan Leaf for all electric vehicle calculations and average numbers for passenger cars sold in 2015 in each region. In our calculations, we used the numbers and data sources shown in Table A3.

Table A3. List of values and sources used in carbon emissions calculations

Coefficient	Value	Source
Electric vehicle efficiency	0.30 kWh/mile	Fueleconomy.gov (2016) (real-world)
Transmission & distribution efficiencies	93.5%	United States Environmental Protection Agency and Department of Transportation (US EPA and DOT, 2012)
Charging efficiency	85%	US EPA and DOT (2012)
Upstream fuel extraction emissions factor (electricity)	1.06	US EPA and DOT (2012)
Upstream fuel extraction emissions factor (fuel)	1.28	US EPA and DOT (2012)
NEDC to real-world adjustment factor	1.40	International Council on Clean Transportation (ICCT, 2015a)
EPA test cycle to real-world adjustment factor	1.25	US EPA and DOT (2012)
Carbon intensity of electricity generation, coal	1024 (g/kWh) (EU) 1029 (g/kWh) (China)	International Energy Agency (IEA, 2015)
Carbon intensity of electricity generation, natural gas	471 (g/kWh) (EU) 587 (g/kWh) (China)	IEA (2015)
Carbon intensity of electricity generation, oil/other	820 (g/kWh) (EU) 587 (g/kWh) (China)	IEA (2015)

For simplicity, nuclear power and all forms of renewable energy were assumed to contribute 0 g/kWh of CO_2. As discussed in the text, the power mix reflects electricity generated in each region and does not reflect power imports or exports. Data for power generation mix comes from the Shift Project (2016), which uses data from the World Bank, except for the following: Switzerland, from Bundesamt für Energie (BFE, 2015); United Kingdom, from Department of Energy & Climate Change (2016); and California, from California Energy Commission (2016). Data on conventional internal combustion engine passenger car fleets comes from ICCT (2015a) for Europe; U.S. Environmental Protection Agency (2015) for the United States; and ICCT (2015b) for China.

Public charge point data. In analyzing the density of public charging infrastructure, we use the same regional definitions as used for electric vehicle sales and population, with the boundaries described above. The numbers include "semi-public" charging infrastructure, such as Tesla Superchargers or chargers accessible only at certain times of day. We did not include "level 1" chargers with less than 3 kW of power, and where applicable, fast charging is defined as greater than 35 kW of power. Our charge point data comes from the following sources:

- China: Electric Vehicle Charging Infrastructure Promotion Alliance (EVCIPA, 2016); Dated August 20, 2016
- Denmark: E.ON (2016); Clever (2016); Accessed October 31, 2016
- France: Etalab (2016); Accessed October 14, 2016
- Netherlands: Open Charge Map (2016); Accessed September 9, 2016
- Norway: Nobil (2016); Accessed October 31, 2016
- Sweden: Open Charge Map (2016); Accessed September 9, 2016
- Switzerland: Open Charge Map (2016); Accessed September 9, 2016
- United Kingdom: Office for Low Emission Vehicles (2016c); Accessed October 18, 2016
- United States: AFDC (2016); Accessed October 19, 2016

Table A4 and the subsequent list of references is used in the Annex for the above methodology data as well as the additional research into the city policies in place to promote electric vehicles.

Table A4. References for electric vehicle promotional actions discussed in each city profile

City	Financial incentives	Nonfinancial incentives	Charging infrastructure	Research and campaigns	Transit and fleets
Shanghai	Yang et al. (2016); Shanghai Municipal People's Government (2016)	People's Government of Jiading District (2014)	Mitchell (2016); Shanghai Municipal People's Government (2013); Ministry of Transport of the People's Republic of China (2016)		Lu (2015); Wang & Liu (2015)
Shenzhen	Yang et al (2016); Liu (2015)	Liu (2015); Shenzhen Municipal People's Government (2015)	Shenzhen Municipal People's Government (2015); Liu (2015)		Shenzhen Transportation Commission (2016); Shenzhen Municipal People's Government (2015); Wang & Liu (2015); China Electricity Council (2016)
Beijing	Yang et al. (2016); Beijing Municipal People's Government Office (2015)	Yang et al. (2016); Bloomberg News (2016)	D1EV (2015); Beijing Times (2015); Beijing Municipal Development and Reform Commission (2015)	Beijing New Energy Vehicle Experience Center (BNEV, 2016a); Ministry of Science and Technology (2014)	Wang & Liu (2015)
Copenhagen	Danish Government (2011); Dansk Elbil Alliance (2016)	City of Copenhagen (2009); City of Copenhagen (2016); Tsang, et al., 2012	Dansk Elbil Alliance (2016); City of Copenhagen (2009); International Energy Agency (IEA, 2016)	Capital Region of Denmark (2016)	Hansen (2015); DriveNow (2016); Arriva (2016); EnergiWatch (2016); City of Copenhagen (2009)
Paris	European Automobile Manufacturers Association (ACEA, 2016); City of Paris (2016a); Métropole du Grand Paris (2016); Ministère de l'Environnement, de l'Énegie et de la Mer (2017); AVERE-France (2016)	City of Paris (2016a); Reuters (2016); Chazan (2016)	Etalab (2016); City of Paris (2016a)	Green Car Congress (2016)	EDF (2015); City of Paris (2012); IEA (2016)
Amsterdam	Netherlands Enterprise Agency (2015); Munnix (2015); City of Amsterdam (2016a, 2016b); IEA (2016)	City of Amsterdam (2016a); City of Amsterdam (2016d); City of Amsterdam (2015)	Netherlands Enterprise Agency (2015); City of Amsterdam (2016a, 2016c); Tietge et al. (2016); Living Lab Smart Charging (2016)	City of Amsterdam (2016a); IEA (2016)	Netherlands Enterprise Agency (2015); City of Amsterdam (2015, 2016a); IEA (2016)
Utrecht	Netherlands Enterprise Agency (2015); Munnix (2015); IEA (2016)	Netherlands Enterprise Agency (2015)	City of Utrecht (2015 a, 2015b, 2015c); Living Lab Smart Charging (2016)	Kane (2016); Eneco (2016); Netherlands Enterprise Agency (2016); IEA (2016)	Netherlands Enterprise Agency (2016)
Oslo	Norsk elbilforening (2016)	Norsk elbilforening (2016); Pütz & Nørbech (2012)	Holtsmark & Skonhoft (2014); Nobil (2012); C40Cities (2014); Norsk elbilforening (2016)	FREVUE (2016)	City of Oslo (2016)
Stockholm	van der Steen et al. (2015); Mock & Yang (2014)	City of Stockholm (2012)	Environmental and Health Administration (2016)	Vattenfall (2015); Environmental and Health Administration (2016)	Sunnerstedt (2013)
Zürich	Swiss Federal Office of Energy (2014, 2016)		EKZ (2016b)	IBM (2011); EKZ (2016a, 2016b)	Interface (2015); Schmitz (2015)
London	Gov.uk (2016); Transport for London (TfL) (2016a)	TfL (2016b, 2016c)	OLEV (2016c); TfL (2016c)	Auendi et al. (2014); OLEV (2016a)	Mayor of London (2016); TfL (2016a); LoCITY (2016)
San Jose	California Air Resources Board (CARB) (2016a); Searle et al. (2016)	Searle et al. (2016); Lutsey et al. (2016)	Searle et al. (2016); Lutsey et al. (2016)	Lutsey et al. (2016); National Drive Electric Week (2016);	Lutsey et al. (2016); CARB (2016b); City of San José (2016)
San Francisco	CARB (2016a); Lutsey et al. (2016)	Pacific Gas and Electric Company (2016); CARB (2016a)	U.S. Department of Energy (2016)	Pacific Gas and Electric Company (2016); National Drive Electric Week (2016)	Dawid (2013); CARB (2016b)
Los Angeles	Lutsey et al. (2016)	Lutsey et al. (2016)	Lutsey et al. (2016)	Lutsey et al. (2016)	CARB (2016b)

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