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THE CONTINUED TRANSITION TO ELECTRIC VEHICLES IN U.S. CITIES

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EXECUTIVE SUMMARY

Growth in the electric vehicle market continues globally. Cumulative global electric vehicle sales surpassed 3 million units in 2017, with the United States now the third largest electric vehicle market after China and Europe. Governments at national, regional, and local levels continue to support the market to help achieve energy, climate change, local air quality, and industrial development goals. The United States is a particularly compelling laboratory for analysis because of its large variation in local electric vehicle sales and support policies.

This white paper assesses the U.S. electric vehicle market and the actions driving it. The paper catalogues actions in place, identifies exemplary practices, and discerns links between various electric vehicle promotion actions and electric vehicle uptake. The analysis is primarily focused on the 50 most populous metropolitan areas, which represented about 79% of the 2017 U.S. electric vehicle market. The work statistically analyzes the links among various state and local policies, public and workplace charging infrastructure, consumer incentives, model availability, and the share of new vehicles that are plug-in electric.

Figure ES-1 illustrates the share of new vehicle registrations that are plug-in electric across U.S. metropolitan areas in 2017. The 50 most populous metropolitan areas that are the primary focus of this analysis are labeled. Electric vehicle shares were generally highest in the major west coast markets. The San Jose area had the highest share at 13%, followed by other California areas at 5 to 8%. Top markets in Colorado, Oregon, New Hampshire, New York, and Washington had shares of 3 to 5%. Overall, the share of new vehicles that are plug-in electric in these 50 areas is 1.6%, exceeding that of the rest of the United States by a factor of about 2.5.

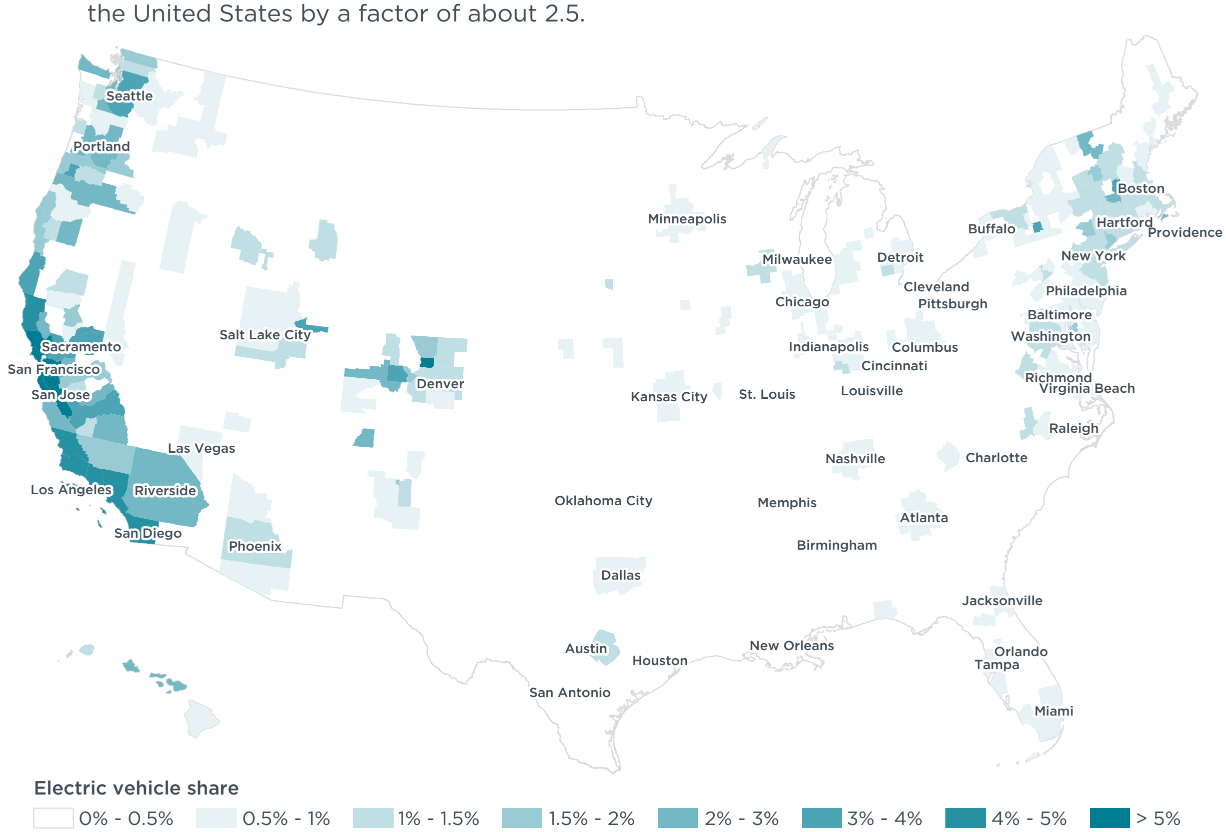

Figure ES-1. Electric vehicle share of new 2017 vehicle registrations by metropolitan area. *(New vehicle registration data from IHS Automotive)*

On the basis of our collection of local-level data, we conducted a statistical analysis to assess the link between key electric vehicle support activities and market uptake at the metropolitan area level. In particular, we analyzed the connection between electric vehicle shares and the availability of more electric vehicle models, charging infrastructure, incentives, high-occupancy vehicle lane access, and other promotion actions. Our analysis leads us to the following four conclusions:

***Electric vehicle market growth requires many actions by many different players*.** Actions by various stakeholders are linked with electric vehicle uptake. Many local, state, and utility stakeholders across the United States are reducing consumer barriers with policy, incentives, and awareness campaigns. States that adopt California's Zero Emission Vehicle regulation catalyze the market, spurring automaker marketing and expanded model availability. This provides assurance of a growing market and is typically complemented by policy incentives, sustained charging infrastructure investment, and consumer awareness measures.

***Growth in electric vehicle uptake starts with expanded model availability*.** This research affirms a statistical link between electric vehicle model availability and uptake. The top five electric vehicle markets by volume, representing nearly half of all U.S. electric vehicle sales, each had at least 28 available electric vehicle models in 2017. However, across major U.S. markets, about half of the population has access to 10 or fewer electric models, indicating how limited electric vehicle exposure generally is. Availability of more models in more vehicle segments, especially lower-cost and higher-range electric vehicles, is a key to continued electric vehicle market development.

***Even as electric vehicle costs continue to decline, consumer incentives remain important*.** Electric vehicle prices have greatly decreased even as their electric ranges have increased, reflecting great progress in battery technology and its increased production scale. Yet electric vehicle uptake continues to be linked to incentives that reduce the effective electric vehicle cost. Substantial consumer incentives, typically worth $2,000 to $5,000, were available in nine of the top 10 major metropolitan areas with the highest uptake. Consumers in California markets, Denver, and Seattle have benefited from substantial purchase incentives. Additional perks from carpool lane access and/or preferential parking policies benefit electric vehicle drivers in several markets, including Nashville, Phoenix, Raleigh, Salt Lake City, and many areas in California.

***Electric vehicles and various types of charging infrastructure grow in unison*.** Public regular, public fast, and workplace charging are each linked with electric vehicle uptake. Markets with high electric vehicle uptake have at least 300 public charge points per million people; by contrast, half of the U.S. population lives in a market with charging infrastructure at least 70% below this benchmark. In the top electric vehicle markets, about 10 to 20% of the available public charging is fast charging. In addition, new to this report, we find that the top electric vehicle markets typically have at least 100 workplace charge points per million people.

I. INTRODUCTION

The transition to electric drive is critical to limiting transportation carbon emissions, energy consumption, and local air pollution, and governments of the world are implementing policies to accelerate the transition. Government efforts to support the electric vehicle market are beginning to take hold, as the early market steadily grows each year. The global light-duty electric vehicle market exceeded 1.2 million annual sales in 2017, up more than 50% from 2016, indicating a clear increase toward economies of scale (International Zero-Emission Vehicle Alliance, 2018a). The United States is a large part of this global growth, along with the leading world electric markets of China and Europe. The United States provides an especially rich laboratory for deeper analysis because of the variation of electric vehicle sales and policy implementation across the nation.

Figure 1 shows annual electric vehicle sales in the United States from 2010 through 2017. The figure shows the eight companies with the most electric vehicle sales in 2017, as well as annual sales from all others (HybridCars, 2018). The eight companies account for 92% of the 2017 electric vehicle market in the United States. There is a general automaker trend toward more electric vehicle models and greater production volumes. The four highest-selling models were the Chevrolet Bolt, Chevrolet Volt, Toyota Prius Prime, and Tesla Model S, each with more than 20,000 U.S. sales. Most companies had increased electric vehicle sales from 2016 to 2017. As shown, electric vehicle sales in the United States increased from approximately 150,000 in 2016 to more than 190,000 in 2017, growing by about 29%.

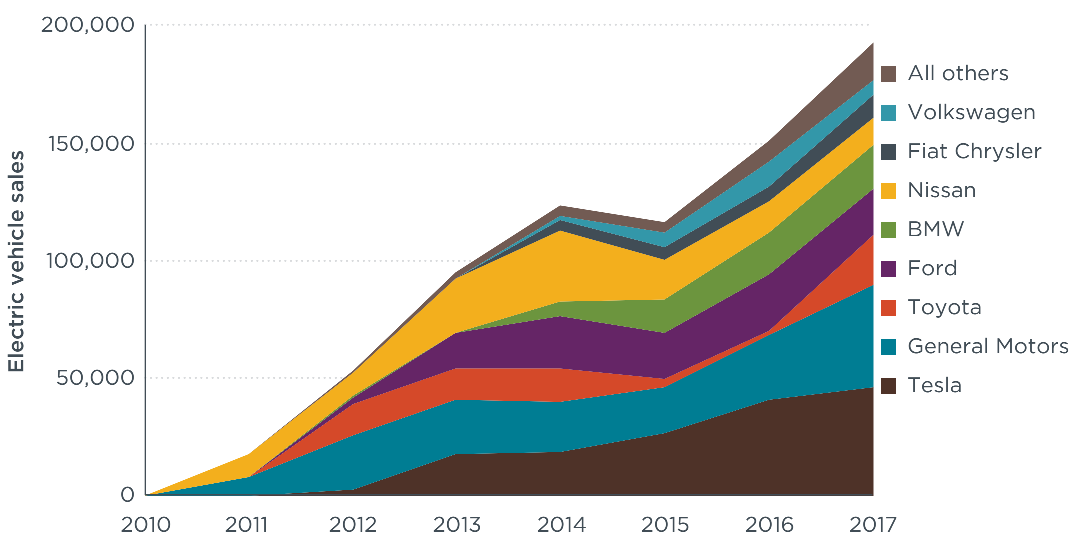

Figure 1. Automaker annual electric vehicle sales in the United States through 2017.

Automakers continue to bring more electric models across more vehicle segments to the market at greater scale. New plug-in offerings such as the Mitsubishi Outlander, Tesla Model 3, and next-generation Nissan Leaf launched in the United States in late 2017 and will likely continue to be made more widely available across more local U.S. markets. Furthermore, automakers have announced their moves toward an order of magnitude greater volume of electric vehicle production, with dozens of new model offerings in the years ahead. Battery cost reductions will ensure that these new models have lower cost and longer range than the previous models. Because of these trends toward more models at lower prices, this is an important time for governments to consider their support policies and investments in charging infrastructure.

U.S. electric vehicle sales vary substantially at the state, regional, and local levels, as do government actions and support policies. California and the other nine Zero Emission Vehicle states account for approximately two-thirds of the U.S. EV market (Lutsey, 2018). These markets and others continue to implement a wide array of actions including consumer incentives, infrastructure deployment, and information campaigns help to overcome consumer barriers to electric vehicle adoption. Financial and nonfinancial incentives, public charging infrastructure, fleet programs, informational materials and tools, and public events help to overcome consumer barriers related to higher upfront costs, functional electric range and range anxiety, and an overall lack of awareness and understanding. Many governments are now working to bolster policy effectiveness and capture a broader set of prospective consumers.

This paper updates and builds upon our annual U.S. electric vehicle market analysis of how state, regional, and local actions are helping to overcome the prevailing electric vehicle barriers. We analyze the U.S. electric vehicle market in 2017, updating for new market data, policy, and infrastructure developments. Our previous analyses (e.g., Slowik & Lutsey, 2017) identified several factors—including financial incentives, public and workplace charging infrastructure, model availability, access to high-occupancy vehicle (HOV) lanes, and city actions—that are linked with higher electric vehicle uptake.

We describe and catalogue electric vehicle promotion actions and their implementation, identify best-practice policies, discern statistical links between promotion actions and electric vehicle uptake, and evaluate major market trends between 2016 and 2017. In Section II, we highlight several additional studies that provide background on the factors that have driven electric vehicle market growth in previous years. In Section III, we summarize and analyze all the data at the metropolitan area level. Continued updates to these types of studies are important to understand how the market evolves as new electric vehicles enter the market, new consumers are attracted to them, and new policy actions are implemented. As compared to our previous work (Slowik & Lutsey, 2017), this analysis of the 2017 U.S. market includes more market activity, more charging infrastructure, more electric vehicle models on the market, and greater local policy action.

Our cataloguing of local-level electric vehicle actions and statistical analysis are based on the promotion actions and policies that were in place throughout the majority of calendar year 2017. A primary unit of analysis is "electric vehicle uptake"—the proportion of new vehicles registered that are plug-in electric vehicles, both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). The analysis is primarily focused on the 50 most populous U.S. metropolitan areas (U.S. Census Bureau, 2018a), which together accounted for 79% of the 2017 electric vehicle market and approximately 55% of the nation's population. To summarize the work, we present figures on electric vehicle market data and several underlying policy factors and statistically assess the relationships with a stepwise multiple linear regression analysis.

II. DATA COLLECTION ON ELECTRIC VEHICLE PROMOTION ACTIVITIES

This section catalogues and summarizes data on major state, city, and utility policies and activities that are supporting the purchase and use of electric vehicles across major U.S. metropolitan areas, organized into three broad categories: consumer incentives; charging infrastructure; and planning, policy, and other promotion activities. We collected information on dozens of promotion actions that were in place in 2017. When possible, we quantified the applicable data—for example, estimating the average value of consumer financial incentives and counts of charging infrastructure. Recurring consumer benefits such as HOV access and parking incentives were analyzed over a six-year ownership period, based on how long vehicles are typically owned or their financing terms. For discrete qualitative actions, such as electric vehicle outreach events, we more simply catalogued the metropolitan areas in which the given actions or policies were implemented in 2017. The approach follows that of our four previous papers (most recently Slowik & Lutsey, 2017) while accounting for the promotion actions that were under way in 2017. The Annex includes a summary list of the 40 actions and tangible examples of metropolitan areas with those actions in place. The actions, and their implementation across the 50 most populous metropolitan areas, are summarized below.

CONSUMER INCENTIVES

Consumer incentives—including purchase, operation, parking, and HOV lane access incentives—are in place in many states and metropolitan areas. Incentives help to overcome key cost and convenience barriers and give impetus to the early electric vehicle market while technology costs fall and consumers become familiar with the technology. Numerous studies have found that purchase and other consumer incentives are linked with electric vehicle uptake (e.g., Jin, Searle, & Lutsey, 2014; Lutsey et al., 2015; Lutsey, Slowik, & Jin, 2016; Tal & Nicholas, 2016; Vergis & Chen, 2014; Yang et al., 2016; Zhou et al., 2016, 2017).

Purchase incentives. State and federal incentives have been major components of electric vehicle public policies in the United States. The federal government provides up to $7,500 in income tax credits for the purchase or lease of electric vehicles. This incentive applies uniformly across the metropolitan areas and is not included in our evaluation. State incentives such as rebates, tax credits, or substantial tax exemptions were available in 19 of the 50 metropolitan areas in this study. The value of incentives ranges from $1,750 (Pennsylvania) to as much as $5,000 (Colorado). New York began its state rebate program for up to $2,000 in March 2017. Oregon established a rebate program in 2017 that launched in 2018 and is therefore excluded from our 2017 market analysis. Utah's rebate program expired in 2016 and is not included here. To expand the market to lower-income buyers, California and Oregon provide increased rebates for low- to moderate-income residents, increasing the standard value by $2,000 and $2,500, respectively. We do not include the increased rebate values in our quantification of incentives but note for context that these rebates in California amount to about 9% of all rebates—and about 16% of all rebate funding—applied for in 2017 (CSE, 2018).

Purchase incentives from local governments are less common and typically are of lesser value than state incentives. Riverside provides a $500 rebate, and exemptions from local taxes are available in Seattle. Averaging across the 19 areas that offered incentives, the average value was approximately $2,300 for BEVs and $1,800 for PHEVs. Our estimates include a population-based weighting of state incentives for the metropolitan areas that span multiple states.

Vehicle operation incentives. Additional incentives are sometimes available after the initial purchase or lease of an electric vehicle, such as exemptions from or reductions in state license and registration fees (5 areas) and emissions inspections (23 areas). Vehicle operation incentives tend to be worth approximately $100 over a six-year ownership period. Arizona has a unique registration exemption program for BEVs that amounts to approximately $1,100.

Some states have implemented annual fees for electric vehicles, resulting in a disincentive in 12 metropolitan areas: Colorado (Denver), Georgia (Atlanta), Michigan (Detroit), Missouri (Kansas City, St. Louis), North Carolina (Charlotte, Raleigh), Tennessee (Memphis, Nashville), Virginia (Richmond, Virginia Beach), and Washington (Seattle). Annual fees typically apply to BEV and PHEV owners, but some states such as North Carolina and Virginia limit the fees to BEV drivers only (U.S. DOE, 2015). Other states are considering similar legislation, in part as a means of offsetting depleting gas tax revenues. Table 1 shows the relative effect of electric vehicle license fees as compared to state annual motor fuel sales tax revenues, based on U.S. Census Bureau (2018b) data. As shown, electric vehicle fees on average account for far less than 0.1% of annual motor fuel sales tax revenues; such fees have a very small effect on state fuel tax revenue. Research has concluded that improved vehicle efficiency has had a much greater effect on depleting transportation budgets than electric vehicles (Vermont Agency of Transportation, 2016). This dynamic is likely to continue for several years to come (NRC, 2015).

Table 1. Annual fees for electric vehicles relative to state motor fuel sales tax.

State	Motor fuel sales tax revenue in 2016 (million)	2017 electric vehicle fee (per vehicle)	Approximate annual revenue from electric vehicle fee (million)	Electric fee revenue as percent of annual motor fuel sales tax revenue
Colorado	$667	$50	$0.21	0.031%
Georgia	$1,655	$200	$0.51	0.031%
Michigan	$1,029	$135	$0.55	0.053%
Missouri	$717	$75	$0.08	0.012%
North Carolina	$1,936	$100	$0.21	0.011%
Tennessee	$898	$100	$0.10	0.011%
Utah	$420	$44	$0.05	0.012%
Virginia	$896	$64	$0.19	0.021%
Washington	$1,458	$150	$1.07	0.073%

Parking incentives. Various state and local electric vehicle parking policies that provide benefits to electric vehicle drivers exist in 14 of the metropolitan areas in this study. Nevada and Hawaii offer free parking for electric vehicles at eligible metered parking locations. Cincinnati, Salt Lake City, and San Jose provide free parking at city parking meters and participating garage lots. Eligibility varies across programs; for example, Cincinnati's program only includes BEVs, whereas in Salt Lake City, free parking is available for vehicles with a city-rated fuel economy above 41 miles per gallon. Vehicles with the Clean Air Permit in San Jose are eligible for free parking at all city parking meters and a few parking garages that typically cost $100 per month. Applying our previous methodology (Jin et al., 2014), we estimate that the six-year value of parking incentives ranges from about $300 in Cincinnati to about $600 in Las Vegas. Nashville, Orlando, and Sacramento also provide local parking incentives; however, these programs are relatively limited in number and availability and are therefore not quantified here.

Other local parking actions include policies that require new designated parking spaces for electric vehicles and increase their number over time. New York City requires 25% of new spaces to be electric vehicle–ready, meaning that parking facilities must be equipped with wiring and panel capacity to supply charging. Such actions help to provide additional perks to drivers, raise overall public awareness, and avoid costly future building retrofits. Several governments impose penalties to discourage gasoline car drivers from parking in designated spaces.

High-occupancy vehicle (HOV) lane access. Eighteen of the 50 metropolitan areas allow single-occupant electric vehicles to use HOV lanes. We apply our previous methodology for the value of HOV lane access, based on our approximations of HOV lane-miles and relative level of congestion in each metropolitan area that allows single-occupant electric vehicles to use the lanes (see Slowik & Lutsey, 2017). We estimate that areas where HOV lanes have the highest six-year ownership value are San Jose, Los Angeles, San Francisco, Nashville, and Raleigh (ranging from $3,350 in San Jose to $1,950 in Raleigh).

CHARGING INFRASTRUCTURE

An expanded charging infrastructure network, including home, workplace, and public locations, can increase driver confidence in the vehicle's range, extend operating functionality, and increase visibility and public awareness of the technology. Several studies find that workplace and public charging infrastructure are statistically linked with electric vehicle uptake (Hall, Cui, & Lutsey, 2017; Hall & Lutsey, 2017a; Slowik & Lutsey, 2017; Zhou et al., 2017). In California, nearly half of electric vehicle drivers report having access to charging at work (CARB, 2017a).

Government, utility, and industry stakeholders are increasing the charging infrastructure network in multiple ways. Government support includes direct deployment, financial incentives, expediting permitting and installation processes, and adopting electric vehicle–ready building codes. Utility actions include direct installation and financial incentives. Multiple automakers including BMW, Nissan, Tesla, and Volkswagen, as well as partner equipment providers such as Electrify America, EVgo, and ChargePoint, are also investing in charging infrastructure to support greater adoption of electric vehicles.

We update our analysis to use data from PlugShare on public and workplace charging infrastructure in 2017. The PlugShare data are based on user-updated charge point information and include detailed categorization of the charging facilities by type and location. Our previous infrastructure estimates were based on data from the U.S. DOE Alternative Fuels Data Center (AFDC) and U.S. DOE Workplace Charging Challenge. The PlugShare data include about 10% more public charge points than the AFDC data. We analyzed the PlugShare data and organized the many charger categories into "public" and "workplace" groups. When there was ambiguity in the data nomenclature, such as chargers with "restricted access," we categorized those that are likely primarily workplace chargers as "workplace" (e.g., corporations and office buildings), and categorized others as "public" (e.g., hotels and hospitals). Note that we included "school/university" chargers in the "workplace" group, as these locations are often large employers where many people commute and vehicles have long dwell times similar to those parked at office buildings.

Figure 2, based on data from PlugShare, shows the numbers of public DC fast charge points (including CHAdeMO, SAE Combo, and Tesla), public Level 2 charge points, and workplace charge points per million population in the 50 most populous metropolitan areas. This provides a simple illustration of how much infrastructure has been built and allows for relative comparisons across the metropolitan areas. Areas are ordered from top to bottom according to the sum across the three columns.

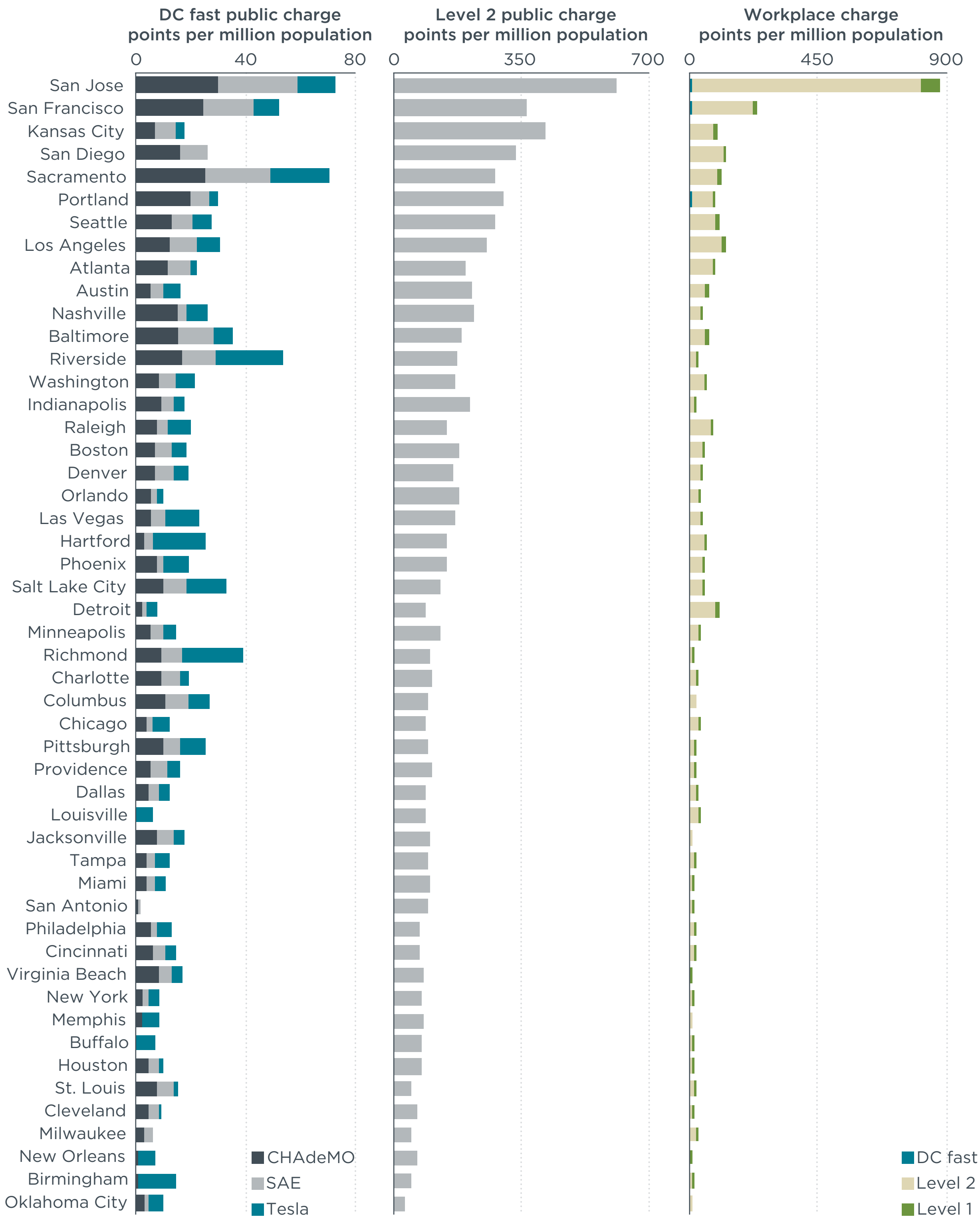

Figure 2. Public (DC fast and Level 2) and workplace charge points per million population in the 50 most populous U.S. metropolitan areas. *(Charging infrastructure data from PlugShare)*

We make several observations based on the data in Figure 2. Areas with the most extensive charging infrastructure in 2017 had roughly 50 to 75 DC fast charge points and 300 to 600 Level 2 charge points per million population. However, many areas had just a fraction of that amount of public charging. More than half of the 50 major metropolitan areas had fewer than 18 DC fast charge points and fewer than 110 Level 2 charge points per million population. Overall, the U.S. public charging infrastructure is 86% Level 2 and 14% DC fast. Areas outside of California with a relatively high number of DC fast charge points per million population include Baltimore, Columbus, Portland, Richmond, Salt Lake City, and Seattle. Overall, the U.S. workplace charging infrastructure is 88% Level 2, and the rest is a mix of DC fast and Level 1. Although we do not include Level 1 chargers in our quantification of *public* charge points, there is reason to include Level 1 workplace charge points because of the much longer typical dwell time at workplaces. The PlugShare data revealed an additional insight: On average across the major metropolitan areas, new charging installations in 2017 tended to have more chargers per location than previously, increasing by about 50% since 2015.

The top five areas on average had about 8 times the public charging infrastructure per capita relative to the bottom five areas. San Jose had about 17 times as much public charging infrastructure per capita as Oklahoma City. San Jose, with more than 800 workplace charge points per million population, also stands out as having far greater workplace charging per capita than others. The markets with the next highest workplace charging availability, at about 100 workplace charge points per million population, are San Diego, Los Angeles, Sacramento, Detroit, and Kansas City. San Jose and Detroit stand out as the only markets with more workplace charge points than public charge points. In the analysis below, we investigate the relationships between electric vehicle uptake and public and workplace charging infrastructure.

State-level charging infrastructure actions. State governments promote charging infrastructure in several specific ways. For example, low-carbon fuel standards (present in seven metropolitan areas) assist charging providers by incentivizing low-carbon transportation fuels and also provide a funding mechanism. States can also provide private charger incentives or support for residences and/or commercial businesses (21 areas) as well as promote public charging stations by means of financial incentives or direct deployment of publicly available infrastructure (31 areas). Many states have begun to open up various planning processes, driven by public utility commissions and power utility proposals, to deploy charging infrastructure, as described below.

City-level charging infrastructure actions. Numerous additional actions at the local level also grow the infrastructure network. These include streamlined electric vehicle service equipment (EVSE) permitting processes (14 areas), electric vehicle–ready building codes (10 areas), EVSE financial incentives or support (two areas), and city-owned chargers (38 areas). Select workplaces in all 50 areas have made electric vehicle charging available to employees while at work; however, the number of workplace charge points vary greatly across the 50 areas. California requires cities to adopt ordinances for expedited EVSE permit processes and EV-ready building codes (California Building Standards Commission, 2016), although these are typically local-level actions. These policies generally mean faster approval and installation processes for charging stations and ensure that future construction will include the necessary conduit and panel capacity to support increased electric vehicle charging. San Francisco's 2017 EV-ready building code ordinance, for example, requires all new residential, commercial, and municipal construction to have service capacity to simultaneously charge electric vehicles at 20% of parking spaces but also have the supporting infrastructure in place to install outlets at 100% of spaces (San Francisco Department of the Environment, 2017).

As the early market develops, governments increasingly seek to identify priority areas for charging infrastructure deployment. Portland and Denver in particular have been active in identifying priority locations for future installations, including areas with a larger proportion of multifamily and garage-free homes, large businesses with long commuting distances, locations that lack public transit and have high average vehicle miles traveled, key destination and recreation areas, and others (see City of Portland, 2017; Denver Department of Public Health and Environment, 2017). Portland determines key charger locations by plotting the various criteria on a composite heat map, prioritizing areas where several factors overlap (Portland Bureau of Planning and Sustainability, 2018).

PLANNING, POLICY, AND OTHER PROMOTION ACTIVITIES

States and cities implement a variety of additional planning, policy, and other promotion activities. These generally fall into areas that include state regulation, state and city policy planning, electric vehicle fleet initiatives, electric power utility policy, and other outreach and education awareness activities.

Zero Emission Vehicle regulation. California's Zero Emission Vehicle (ZEV) regulation requires incrementally greater electric vehicle sales over time. Ten states (California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont) have adopted the ZEV regulation; 13 of the 50 metropolitan areas in this analysis are in these states. The program requires at least 8% of new vehicle sales to be electric in California by 2025 (CARB, 2017b). The ZEV regulation, in turn, pushes for greater electric vehicle model availability and greater marketing effort by automakers (NESCAUM, 2016, 2017).

The ZEV regulation differed functionally across ZEV states in 2017. For example, automakers could focus early electric vehicle deployment in California and delay efforts in other ZEV states to foster technology development and manage associated costs. This flexibility expired as of 2018, and manufacturers are now required to offer increasing numbers of electric vehicles in ZEV states outside of California. (Our analysis of the 2017 market does not capture the market effects of the flexibility's expiration.) Many of the ZEV states implement a statewide or multistate roadmap or action plan to help support ZEV deployment and supplement the ZEV regulation (see, e.g., California Office of the Governor, 2016; NESCAUM, 2013, 2014).

ZEV Alliance participation. Multiple states have joined networks to increase collaboration and best-practice learning through information exchange with proactive governments around the world. The International Zero-Emission Vehicle Alliance is a 14-member consortium of eight U.S. states (California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, Vermont), two Canadian provinces, and four European nations (International Zero-Emission Vehicle Alliance, 2018b). Alliance members share a vision to make all new passenger vehicles in their jurisdictions zero-emission no later than 2050. Thirteen of the 50 metropolitan areas in this analysis are in ZEV Alliance states.

Direct sales. The ability for companies to sell new vehicles directly to customers, as opposed to through the traditional automobile dealership franchising model, is another factor that affects electric vehicle sales. Some states have rules that prohibit direct sales, hindering the electric vehicle market by blocking Tesla and potentially other companies from selling electric vehicles. In 2014, Michigan adopted legislation making it impermissible for vehicle manufacturers to sell vehicles directly to retail customers without going through franchised dealers (Michigan Legislature, 2014). In contrast, Maryland in 2015 passed a law that, among other things, authorizes “a manufacturer or distributor to be licensed as a vehicle dealer if the manufacturer or distributor deals only in electric or nonfossil-fuel burning vehicles” (Maryland General Assembly, 2015). We find that 11 states have blocked or have substantially limited direct vehicle sales in their jurisdictions. Of the 50 metropolitan areas in this analysis, 36 are in states that allow direct sales.

City electric vehicle strategies. Many metropolitan areas have some form of local or regional electric vehicle strategy, commonly called “action” or “readiness” plans. Such strategies play an important role by creating a forum and network of local, state, utility, charging provider, auto dealership, and other stakeholders to discuss common issues surrounding the growth of the electric vehicle market. City electric vehicle strategies help to identify and shape local actions to overcome key electric vehicle barriers (e.g., cost, convenience, infrastructure, awareness) and to prepare local infrastructure and utilities to support an increased number of electric vehicles on local roads. The city of Portland adopted a particularly comprehensive electric vehicle strategy that sets key goals and identifies 49 unique actions across several categories (charging infrastructure, fleet, private vehicle, shared mobility, information and awareness, and economic development) that the city will take to accelerate the transition to electromobility (City of Portland, 2017). We identify 26 areas with electric vehicle strategies in place.

Public awareness and outreach activities. Consumer awareness and understanding is a critical precursor to electric vehicle market growth. Despite actions to date, the public lacks basic knowledge related to electric vehicles (Jin & Slowik, 2017; Kurani & Hardman, 2018). Awareness activities, including online informational materials (30 areas) and outreach events (48 areas), help to increase familiarity and general understanding of electric vehicles and their features. The city of Boston hosts a particularly informative website, providing information and additional links about electric vehicles, their economic and environmental benefits, a fuel cost savings calculator, a buying guide, upcoming ride-and-drive events, a map of available public charging stations, the city’s EV policy, and available incentives (City of Boston, 2017). Online resources vary drastically in the type and amount of detail they provide, as well as the accessibility of the information. Although we did not evaluate the differences quantitatively, there is evidence that comprehensive, locally focused information that is easily accessible within three or fewer clicks is best suited to support prospective electric vehicle buyers (Santini et al., 2016).

Outreach events are an effective way to raise awareness and increase familiarity. National Drive Electric Week is one of the largest initiatives, with more than 240 such events across the United States in 2017. Many local governments participate in or support the events, which include announcements by local officials, ribbon-cuttings for new public charging stations, charging station giveaways, ride-and-drives, and technology demonstrations. Some local outreach programs have especially been taking strides to expand the electric vehicle market beyond early adopters; we found that 14 of the 50 areas held some sort of outreach event in low-income communities. It is difficult to quantify the exact value of outreach events with respect to spurring electric vehicle adoption, although there is increasing evidence that indicates success. Research by the California Plug-in Electric Vehicle Collaborative found that 9% of survey respondents purchased or leased an electric vehicle within three months of a test drive (PEVC, 2017). Research by the Center for Sustainable Energy found that the probability of future electric vehicle purchases increased for consumers across all income levels after a test drive (CSE, 2016).

Fleets. Integrating electric vehicles in fleets directly increases their use and can help overcome barriers to their wider adoption by increasing overall visibility and exposure (Jin & Slowik, 2017; NRC, 2015). There are many government fleet-based electric vehicle actions, including state fleet purchasing incentives (20 areas), local electric vehicle carsharing programs (18 areas), municipal electric vehicle fleet targets (21 areas), and use of electric buses in public transportation fleets (16 areas). Several examples of leading fleet actions are discussed below.

Massachusetts has offered incentives for fleet electric vehicles since 2014, in part as a strategy to increase the technology's visibility to the public (Commonwealth of Massachusetts, 2017). Public entities such as municipal governments, public universities, and state agencies are eligible for incentives up to $5,000 per PHEV, $7,500 per BEV, and $10,000 for dual-head charging stations. Colorado and other states extend fleet incentives to both public and private entities (Colorado Clean Air Fleets, 2017).

Local carsharing program BlueIndy in Indianapolis is expanding toward 500 all-electric Bolloré Bluecar vehicles and 200 charge points (BlueIndy, 2017). Although typically in smaller volumes, carsharing programs such as Maven by General Motors, ReachNow by BMW, Enterprise, and other services have integrated electric vehicles into their fleets in some cities. Maven, for example, launched an all-electric Chevy Bolt carsharing fleet in Austin in 2018. In an effort to broaden access to electric mobility, a few cities are working to launch dedicated electric carsharing programs in low-income communities that are often subject to greater socioeconomic challenges and environmental pollution. The largest is Los Angeles, where 100 electric Bolloré Bluecar vehicles and 200 stations are anticipated to be used by 7,000 unique users within three years (City of Los Angeles, 2016). Similar initiatives are underway in Sacramento and Portland. There also appear to be emerging efforts to integrate electric vehicles within ride-hailing fleets (e.g., Uber, Lyft). Maven, for example, leases electric Chevy Bolt vehicles to ride-hail drivers in 11 U.S. cities (Maven Gig, 2018). Leading governments have begun exploring policy measures to encourage electric ride-hailing, as they recognize its potential for high electric vehicle-miles traveled, reduced emissions, and increasing consumer exposure and awareness (see, e.g., CPUC, 2018).

Some local governments are integrating electric vehicles into their municipal or public transit fleets. Columbus plans to integrate 200 electric vehicles and the supporting charging infrastructure into its municipal fleet (Clean Fuels Ohio, 2016). The local transit authority in Louisville is expanding its electric bus fleet to 15 all-electric buses. Major transit operators in Los Angeles and Seattle have committed to electrifying their entire bus fleets, which together include about 3,600 buses (Hymon, 2017; King County Metro, 2017). Such procurement initiatives offer multiple benefits, including reduced air pollution and vehicle emissions, lower fuel and maintenance costs, increased overall visibility and exposure, and a demonstrated public commitment to the advanced technology.

***Utility*.** Electric power utilities play a critical role in supporting the transition to electric drive, and utility actions to promote electric vehicles are becoming increasingly common in many areas. Utilities (and ratepayers) stand to benefit from greater adoption of electric vehicles, such as from their potential to increase revenue, reduce rates, and manage grid loads (Hall & Lutsey, 2017b; Lowell, Jones, & Seamonds, 2017; Ryan & McKenzie, 2016). Early utility involvement in this area generally includes actions to educate and steer consumers toward electric vehicles and optimal charging practices, such as utility charging pilots or research (32 areas), offering time-of-use (TOU) rates (39 areas), distributing informational materials or hosting outreach events (48 areas), providing a cost comparison tool (24 areas), and procuring electric vehicles in the utility fleet (34 areas).

Several especially forward-thinking utilities are exploring additional actions to promote electric vehicles, such as offering preferential rates for electric vehicle charging (19 areas), electric vehicle or EVSE financial incentives (10 areas), and direct deployment of or investment in public charging infrastructure (15 areas). Some utilities are working to expand the market by providing EVSE informational materials specific to multifamily properties (seven areas), deploying public charging infrastructure in low-income communities (four areas), and offering increased financial incentives for semi-public EVSE at multifamily properties (two areas).

Utility rate structures can help steer customers toward electric vehicles and optimal charging practices. TOU rate options are a relatively common and simple strategy to manage electricity demand through pricing signals and also provide financial benefits to electric vehicle drivers. By charging when electricity prices are very low (typically overnight), TOU rates minimize the refueling costs for electric vehicles. We identified a smaller number of utilities that also provide preferential rates for electric vehicles. These types of rate structures help to ensure that driving on electricity is cheaper than driving on gasoline—a critical element to electric vehicles' widespread adoption (Nicholas, 2018).

A select few utilities offer financial incentives for electric vehicles or their infrastructure. Austin Energy provides incentives for residential and commercial EVSE, valued at up to $1,500 for privately owned Level 2 residential stations, $4,000 for Level 2 multifamily-property residential stations that are available to all residents, and up to $10,000 for hosting a DC fast station (Austin Energy, 2017). Several utilities in California offer rebates for electric vehicles valued at approximately $600, funded by the statewide Low Carbon Fuels Standard (Mulkern, 2017).

Utilities are increasingly investing in or directly deploying public charging infrastructure. Kansas City Power & Light's "Clean Charge Network" currently has more than 1,000 Level 2 charging stations (KCP&L, 2018). In California, the state Public Utilities Commission approved rate-based EVSE rollout plans by the three major utilities that will deploy 1,500, 3,500, and 7,500 charging stations in their service territories with at least 10% located in disadvantaged communities (see, respectively, Edison International, 2016; SDG&E, 2016; CPUC, 2016). Utilities in Oregon appear headed in a similar direction now that Oregon has enacted laws allowing major utilities to submit plans to help accelerate transportation electrification, and several pilot projects were approved in 2018 (Pacific Power, 2018). Similar utility programs have recently been approved or are pending approval in Boston, Columbus, and Seattle. We also identified other programs in which utilities are funding, co-funding, or supporting state efforts, such as those by Duke

Energy, Jacksonville Electric Authority, and NV Energy (see Duke Energy, 2016; JEA, 2017; NV Energy, 2015).

Utilities appear increasingly interested in realizing the benefits of adding electric vehicles to their fleets, such as improving safety, reducing emissions, and enhancing consumer awareness, brand image, and public relations through community visibility and employee expertise (Edison Electric Institute, 2014). One major utility fleet program is that of Pacific Gas & Electric in Northern California, which plans to invest around $100 million over 5 years to integrate electric vehicles within its fleet in order to lower fuel and maintenance costs, extend vehicle operating life, reduce emissions, and deliver electricity during emergencies (PG&E, 2015).

SUMMARY OF ACTIONS

Table 2 summarizes the implementation of the actions described above, categorizing across columns into state, local, and utility areas of action. The cataloguing of actions shown includes only those that were in place throughout the majority of 2017. The 50 metropolitan areas are ordered from top to bottom by total number of electric vehicle promotion actions. The extent of policy action varies greatly across the 50 areas. Six areas in California have adopted the most actions, implementing about 30 to 35 of the 40 actions that we discuss in this paper. Other areas with 23 to 26 actions include Boston, Denver, New York City, Portland, and Seattle.

Table 2. Electric vehicle promotion actions across major U.S. metropolitan areas.

Metropolitan area	State action														Local action															Utility action											Total actions (out of 40)
	State ZEV program	State International ZEV Alliance participation	State low carbon fuel policy	State BEV purchase incentive	State PHEV purchase incentive	State increased incentive for low-income	State fee reduction or testing exemption	No state annual electric vehicle fee	State private charger incentive, support	State public charger promotion	State parking benefit	State fleet purchasing incentive	State manufacturing incentive	State allows direct sales to consumers	City electric vehicle strategy	Streamlined EVSE permitting process	EV-ready building code	City vehicle purchase subsidy	City parking benefit	City EVSE incentive, support	City carpool lane (HOV) access	City-owned EV chargers	Workplace charging	City electric carsharing program	City informational materials	City outreach events	City outreach events in low-income communities	City electric vehicle fleet target	City electric buses in public transportation	Utility charging pilot or other research	Utility public charging infrastructure	Utility public charging infrastructure in low-income communities	Utility time of use rates offered	Utility preferential EV rates	Utility EV or EVSE incentive, support	Utility increased incentives for EVSE at multifamily properties	Utility info materials or outreach events	Utility EVSE informational materials for multifamily properties	Utility cost comparison tool	Utility electric vehicle fleet	
Los Angeles	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X	X	34
Sacramento	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X		X		X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	X	34
San Francisco	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	34
San Jose	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X		X	X	X		X	X		X		X	X	X	X	X	X		X		X	X	32
Riverside	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X			X	X	X		X	X				X	X	X	X	X			X	X	X	X	31
San Diego	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X				X	X	X		X	X		X		X	X	X	X	X			X			X	29
New York	X	X		X	X		X	X	X	X		X		X	X	X	X		X		X	X	X	X	X	X		X		X			X	X			X		X		26
Portland	X	X	X	X	X		X		X	X		X		X	X	X						X	X	X	X	X	X	X	X	X	X		X				X		X	X	26
Boston	X	X		X	X		X	X	X	X		X		X			X		X			X	X	X	X	X			X	X			X				X		X	X	23
Denver				X	X		X		X	X		X		X	X		X		X			X	X	X	X	X	X	X	X	X			X				X		X	X	23
Seattle				X	X		X		X	X		X	X	X	X	X		X				X	X	X	X	X		X	X	X							X	X	X	X	23
Baltimore	X	X		X	X		X	X	X	X		X		X								X	X		X	X	X	X	X	X			X	X			X			X	22
Atlanta							X			X			X	X	X	X					X	X	X		X	X		X		X	X		X	X	X		X	X	X	X	21
Philadelphia				X	X			X		X		X		X	X				X			X	X	X	X	X		X	X	X			X		X		X			X	20
Austin							X	X							X				X			X	X			X	X	X		X	X		X	X	X	X	X	X	X	X	19
Raleigh							X		X	X		X		X	X	X			X		X	X	X		X	X	X			X			X				X			X	18
Washington				X	X		X	X	X	X		X		X	X					X	X		X	X		X							X				X			X	17
Charlotte							X		X	X		X	X		X	X					X	X	X		X	X				X			X				X			X	16
Chicago							X	X					X	X		X				X			X	X	X	X			X				X				X	X	X	X	16
Hartford	X	X		X	X		X	X		X		X										X	X			X				X			X				X		X	X	16
Buffalo	X	X		X	X		X	X	X	X		X		X	X								X	X									X				X				15
Houston							X	X							X	X						X	X	X	X	X		X					X	X			X		X	X	15
Indianapolis								X					X	X	X							X	X	X		X		X	X	X	X		X	X			X				15
Minneapolis								X		X				X								X	X	X	X	X		X		X			X	X			X		X	X	15
Phoenix							X	X	X		X										X	X	X			X	X			X			X	X			X		X	X	15
Las Vegas							X	X		X	X			X					X			X	X			X					X		X	X			X			X	14
New Orleans				X	X		X	X	X	X			X										X	X		X	X	X		X							X				14
Providence	X	X		X	X		X	X		X		X		X									X			X	X										X			X	14
Salt Lake City										X							X		X		X	X	X		X	X				X			X		X		X		X	X	14
Kansas City									X	X				X	X				X			X	X	X	X	X					X		X				X				13
Orlando								X						X	X				X			X	X		X	X		X			X				X		X			X	13
Cincinnati								X		X				X					X			X	X		X	X				X			X				X			X	12
Cleveland							X	X		X				X	X								X			X				X			X				X		X	X	12
Jacksonville								X						X								X	X		X	X	X			X	X				X		X		X		12
Miami								X						X	X						X		X			X			X	X			X				X		X	X	12
Pittsburgh				X	X			X		X		X		X								X	X			X	X	X					X								12
Richmond													X	X	X						X	X	X		X	X				X				X			X			X	12
Oklahoma City								X	X	X													X			X	X			X			X				X		X	X	11
St. Louis							X		X	X			X	X									X	X		X							X				X		X		11
Columbus								X		X				X	X							X	X		X	X		X			X											10
San Antonio								X							X							X	X		X	X	X		X								X			X	10
Tampa								X						X	X							X	X		X	X											X		X	X	10
Dallas							X	X														X	X			X			X				X				X		X		9
Memphis														X						X	X	X			X						X		X				X			X	9
Virginia Beach													X	X						X		X			X					X				X			X			X	9
Birmingham								X															X			X				X			X	X			X	X			8
Milwaukee							X	X														X	X		X	X							X				X				8
Nashville														X					X		X	X	X					X	X								X				8
Detroit							X															X	X			X							X	X			X				7
Louisville								X															X		X	X			X				X				X				7

"X" indicates that a given electric deployment action was in place in 2017.
ZEV = Zero Emission Vehicle; BEV = Battery electric vehicle; PHEV = Plug-in hybrid electric vehicle; HOV = high-occupancy vehicle lane;
EVSE = Electric vehicle service equipment

III. ANALYSIS OF ELECTRIC VEHICLE MARKET

This section evaluates the electric vehicle market and the underlying factors that are supporting growth. We analyze electric vehicle *uptake*, measured as the percentage of new light-duty vehicle registrations that were plug-in electric vehicles in 2017. Vehicle registration data are from IHS Automotive. We compare the data on electric vehicle uptake and public charging infrastructure, model availability, policy incentives, and promotion actions across the major cities. The relationship between electric vehicle uptake and these factors, taking into account the new 2017 data, is analyzed and discussed in the statistical analysis below.

ELECTRIC VEHICLE UPTAKE

The U.S. electric vehicle market in 2017 was up about 29% over 2016. As a percentage of all U.S. light-duty vehicle registrations, electric vehicles accounted for around 1.2% of the market. The 50 metropolitan areas in our study account for about 79% of 2017 U.S. electric vehicle registrations; these areas constitute about 60% of the total light-duty vehicle market and 55% of the U.S. population. These 50 areas have approximately 2.5 times the electric vehicle uptake of the rest of the country (i.e., 1.6% versus 0.6%). In 2017, the U.S. electric vehicle market was about evenly split between BEVs (51%) and PHEVs (49%).

Figure 3 shows the share of new vehicles that are plug-in electric across the more than 900 metropolitan statistical areas. The 50 most populous areas are labeled. Electric vehicle uptake tends to be highest in major metropolitan areas on the West Coast, followed by other hot spots in Colorado and the Northeast. California alone accounted for about half of the total U.S. electric vehicle market in 2017. San Jose had the highest share at 13%, followed by a handful of other California cities at 3% to 7%.

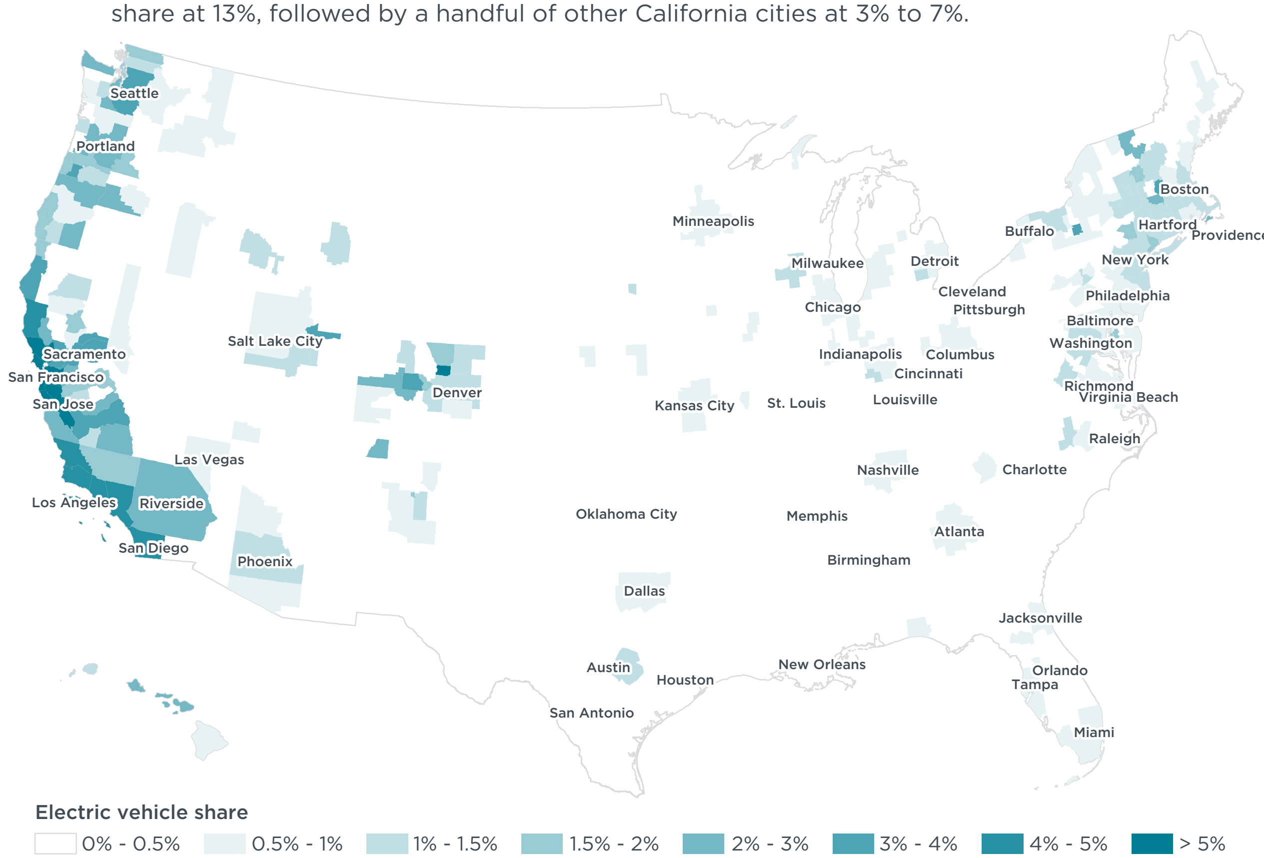

Figure 3. Electric vehicle share of new 2017 vehicle registrations by metropolitan area. *(New vehicle registration data from IHS Automotive)*

We point out several major changes from 2016 to 2017. Overall, the national electric vehicle market increased approximately 29%. In terms of number of electric vehicle registrations, the three areas with the largest annual increases were Los Angeles, San Francisco, and New York City. In addition, new electric vehicle registrations jumped by more than 1,000 units in Boston, Chicago, Riverside, Sacramento, San Diego, San Jose, and Seattle as compared to 2016. In terms of percent growth, Buffalo stands out with 91% growth in new electric vehicle registrations from 2016 to 2017. Boston, Denver, Virginia Beach, and Hartford saw between 60% and 77% year-over-year growth, and Baltimore and Sacramento grew by more than 50%. Year-over-year growth was 40% or greater in 12 of the 50 most populous metropolitan areas. The eastern ZEV markets of Baltimore, Boston, Buffalo, Hartford, New York, and Providence each saw 35% to 91% growth. There were also many smaller cities with high percentage increases between 2016 and 2017. Many high-growth areas were associated with new models, incentives, local actions, and additional charging, which are analyzed below.

In the opposite direction, several areas experienced decreases in electric vehicle registrations in 2017. Of the 50 most populous areas, Detroit experienced the greatest decrease; other declining markets were Atlanta, Miami, Indianapolis, Nashville, Memphis, and Salt Lake City. As shown in Table 3, each of the areas with a decrease in electric vehicle registrations had no consumer purchase incentives in place in 2017. Three of the markets had consumer incentives in 2016 that were no longer available in 2017. Five of the seven areas had annual electric vehicle fees in place (up from two areas in 2016), making it less affordable to drive electric in these areas. Indianapolis was the only case among these declining markets where there was neither an annual fee nor the removal of a substantial consumer incentive, but there is an annual fee of $150 that goes into effect in Indiana in 2018. Legislators in Utah are considering increasing the annual electric vehicle fee from $44 to more than $200.

Table 3. Change in electric vehicle registrations, consumer purchase incentive, and annual electric vehicle fee for major metropolitan areas with decreased electric vehicle registrations from 2016 to 2017.

Metropolitan area	Change in electric vehicle registrations	Consumer purchase incentive		Annual electric vehicle fee	
		2016	2017	2016	2017
Detroit	−35%	$0 →	$0	$0 →	$135
Nashville	−16%	$2,500 →	$0	$0 →	$100
Indianapolis	−13%	$0 →	$0	$0 →	$0
Memphis	−12%	$2,500 →	$0	$0 →	$100
Miami	−5%	$0 →	$0	$0 →	$0
Atlanta	−5%	$0 →	$0	$200 →	$200
Salt Lake City	−3%	$1,000 →	$0	$44 →	$44

Red arrow indicates that the electric vehicle value proposition became less attractive from 2016 to 2017; orange arrow indicates no change from 2016 to 2017.

Although this paper is focused on the most populous metropolitan areas, the Figure 3 map above also reveals other relatively high electric vehicle share areas across the smaller metropolitan areas, as defined by the U.S. Office of Management and Budget (see U.S. Census Bureau, 2018a). Several of the smaller markets with the highest regional electric vehicle shares were in Colorado, Connecticut, Hawaii, Massachusetts, Michigan, New Hampshire, New York, North Carolina, Oregon, Vermont, and Washington. Figure 4 summarizes the leading areas within each region as well as the regional differences in electric vehicle uptake. We identify the four relative leaders in each region, including only areas with populations of more than 50,000 to exclude smaller areas that generally had fewer than 30 electric vehicle registrations in 2017. The figure shows the percentage above regional average electric vehicle uptake (vertical bars, left axis) as well as the regional electric vehicle share (dashed line, right axis).

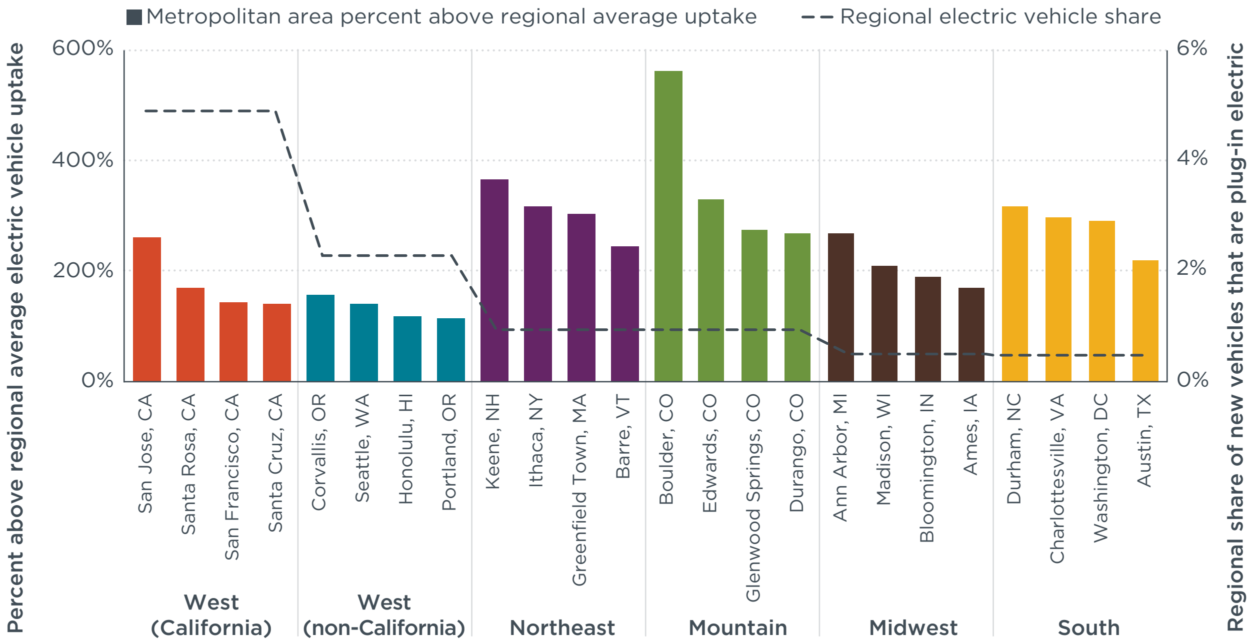

Figure 4. Regional electric vehicle shares and regionally leading metropolitan areas. *(New vehicle registration data from IHS Automotive)*

The figure shows how electric vehicle shares in California and the non-California West were much higher than elsewhere, and also how several areas stand out as having substantially higher electric vehicle uptake relative to their region's average. In particular, Edwards (3% electric share) and Boulder (5%) in Colorado were 3.3 and 5.6 times, respectively, the Mountain region's average. In the Northeast, Keene (New Hampshire) and Ithaca (New York) led the region with 3.5% and 3.1% electric vehicle shares, amounting to 3.7 and 3.2 times the regional average. Ann Arbor (Michigan) and Madison (Wisconsin) in the Midwest had approximately 1.4% and 1.1% electric vehicle shares, more than 2.7 and 2.1 times the regional average. In the South, Durham (North Carolina) and Charlottesville (Virginia) were more than 3 times the South average, with approximately 1.4% shares. In the non-California West, smaller metropolitan areas with high electric vehicle uptake include Corvallis (Oregon) and Honolulu (Hawaii), with approximately 3.6% and 2.6% electric vehicle shares. Smaller metropolitan areas in California with high shares include Santa Rosa (8.4%) and Santa Cruz (6.9%).

CHARGING INFRASTRUCTURE

Charging infrastructure is critical to support electric vehicle market growth. We analyze public charging infrastructure across the 200 most populous metropolitan areas, based on data from PlugShare (2018), in terms of public charging infrastructure per million population in each area. Figure 5 shows how the public Level 2 and DC fast charging infrastructure (horizontal axis) corresponds to electric vehicle uptake (vertical axis) in 2017. The size of each data circle is proportional to the electric vehicle registrations in each area, the largest market being Los Angeles. The U.S. average is shown as approximately 1.2% electric vehicle uptake and 150 public Level 2 and DC fast chargers per million population.

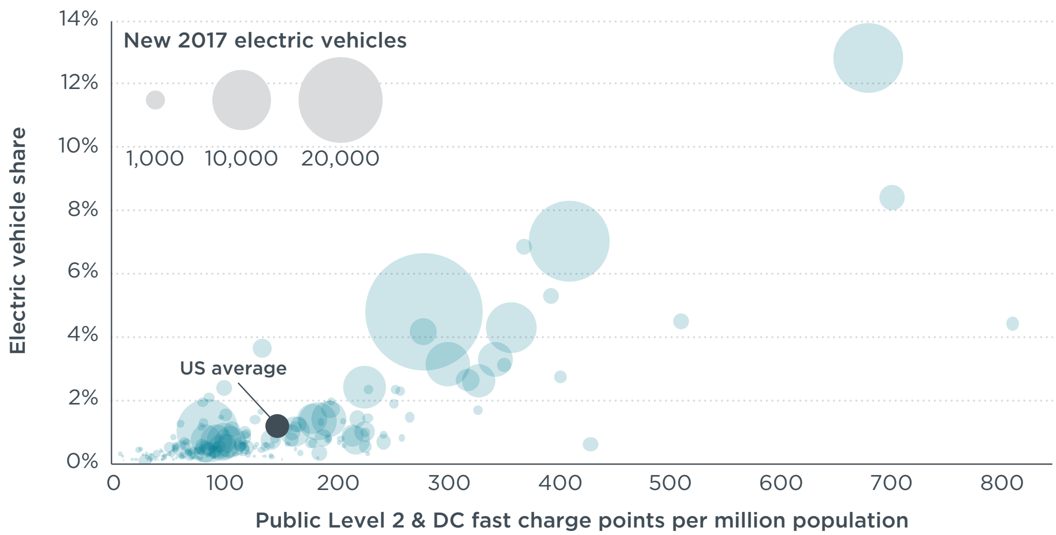

Figure 5. Electric vehicle share of new vehicles and public charge points per million population for the 200 most populous metropolitan areas. *(New vehicle registration data from IHS Automotive; charging infrastructure data from PlugShare)*

The figure shows an approximate trend, with the areas with high electric vehicle shares generally having greater public charging infrastructure availability. The 10 areas with the highest electric vehicle uptake have about 2 to 5 times the average public charging infrastructure. Of the 20 areas with the highest electric vehicle shares, 18 had a greater than average number of public charge points. San Jose, with the highest electric vehicle uptake in 2017, had more than 4 times the national average number of public charge points. Averaging across the 200 areas, DC fast accounts for approximately 12% of the total public charging infrastructure; however, the deployment of DC fast and Level 2 charging stations varies greatly across the areas (Figure 2). The connection between charging infrastructure and electric vehicle uptake is further explored in the statistical analysis below.

We make several additional observations from the data in Figure 5. The data suggest that nominal benchmarks of at least 300 public charge points per million population (25 DC fast and 275 Level 2) underpin higher electric vehicle uptake at this point in the market in 2017. Areas with high electric vehicle uptake also appear to deploy roughly 10 public Level 2 chargers for each DC fast charger. There are several areas clustered around 300 to 400 public charge points per million population and about 2.5 to 7% electric vehicle uptake, including Honolulu, Portland, Seattle, and several California cities (Los Angeles, Sacramento, San Diego, Santa Barbara). This approximate extent of charging is also seen in Austin, a relative leader in the South region and where electric vehicle uptake is about the national average. Other markets including Atlanta, Baltimore, Boston, and Nashville are developing the infrastructure to support market growth, with about 200 to 250 public charge points per million population.

Developing markets continue to grow the public charging network. From 2016 to 2017, the number of the 200 most populous metropolitan areas with more than 200 public charge points per million population went from 29 to 34. Many cities, however, have much lower charging availability than this benchmark. We find that half of the U.S. population lives in an area that has fewer than 90 public charge points per million population (i.e., at least 70% below the leading-city benchmark of 300 public charge points per million).

Figure 6 illustrates electric vehicle share (vertical axis) as compared with workplace charge points per million population (horizontal axis) for the 200 most populous metropolitan areas, with the proportional 2017 electric vehicle registrations shown by the circle size. The U.S. average is shown as approximately 1.2% electric vehicle uptake and 42 workplace chargers per million population. As indicated above, among the most populous 50 metropolitan areas, San Jose led with more than 800 workplace charge points per million population, followed by San Diego, Los Angeles, Sacramento, Detroit, and Kansas City, each with more than 100 workplace charge points per million population. Similar to the plot of public charge points versus electric vehicle sales share (Figure 5), there is an approximate visual trend where areas with the most charging infrastructure typically had higher electric vehicle shares. Of the 20 areas with the highest electric vehicle shares among the 200 shown, 15 had greater than average workplace charge point availability.

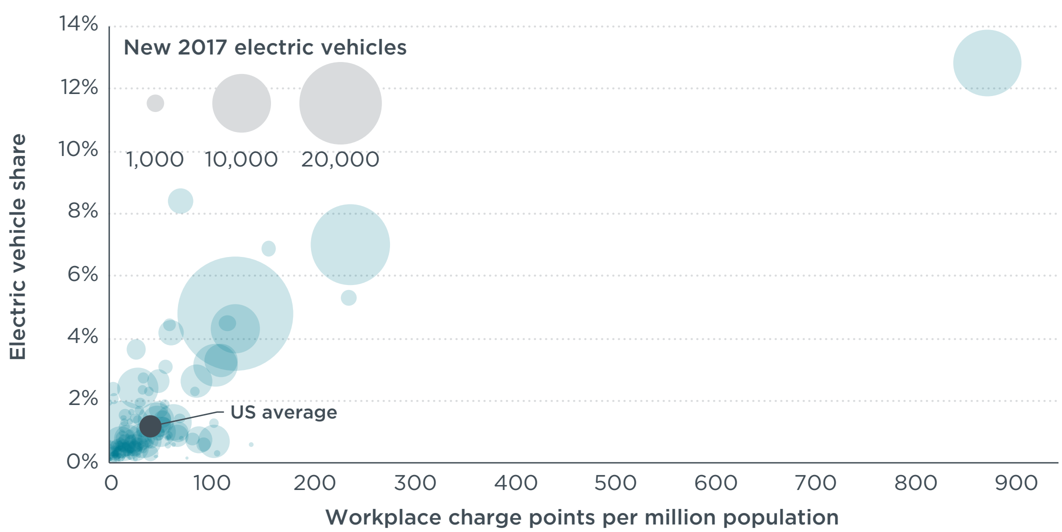

Figure 6. Electric vehicle share of new vehicles and workplace charge points per million population for the 200 most populous metropolitan areas. *(New vehicle registration data from IHS Automotive; charging infrastructure data from PlugShare)*

We also investigated several other potential relationships in the charging infrastructure data, including the relationship between public charging infrastructure and *cumulative* new electric vehicles that were deployed in each area from 2011 through 2017. The data indicate that as of 2017, markets with high electric vehicle uptake (e.g., Los Angeles, San Francisco, San Jose) tend to have 35 to 40 electric vehicles for each public charge point. Several factors may influence the ratio of electric vehicles to public charge points, including access to home and workplace charging, housing and population density characteristics, and the various policies and promotion actions that are the focus of this analysis. Although research shows that there is currently no universal benchmark for the number of electric vehicles per public charge point (Hall & Lutsey, 2017a), lagging electric vehicle markets can strive toward the current leading benchmarks of similar cities. There is reason to suspect that such electric vehicle per charge point ratios might increase over time in more maturing markets as infrastructure reaches higher capacity with increased utilization (NREL, 2017).

MODEL AVAILABILITY

The availability of a range of electric vehicle models across multiple vehicle segments is a key factor for the broader adoption of electric vehicles, as consumer vehicle make and model preferences vary widely. Although the number of non-electric models is in the hundreds, the proliferation of electric models is greatly expanding the market to more prospective customers, up from a small handful in 2012 to more than 40 in 2017. However, electric vehicle model availability tends to be much higher in California than in the rest of the U.S. (NESCAUM, 2017; Reichmuth & Anair, 2016). In 2017, there were a variety of available models in different vehicle segments including compact and hatchback (e.g., Nissan Leaf, Chevrolet Bolt), smaller luxury cars (e.g., BMW i3, Audi A3), midsize cars (e.g., Ford Fusion Energi, Tesla Model S), sport utility vehicles (e.g., Mitsubishi Outlander, BMW x40e), and a minivan (Chrysler Pacifica).

Figure 7 shows the number of available models (horizontal axis), electric vehicle share (vertical axis), and total 2017 sales (circle size) across the 50 most populous metropolitan areas with several areas labeled. We define model availability as the number of electric models that had at least 20 new registrations in 2017, to better distinguish models that were available beyond a few select showrooms or may have been purchased in other regions. The figure shows a general upward trend, where areas with more models available tend to have relatively higher electric vehicle sales and sales shares. The five leading markets by volume, representing nearly half of all 2017 U.S. electric vehicle sales, were also the five top markets in terms of model availability, with 28 to 37 available models.

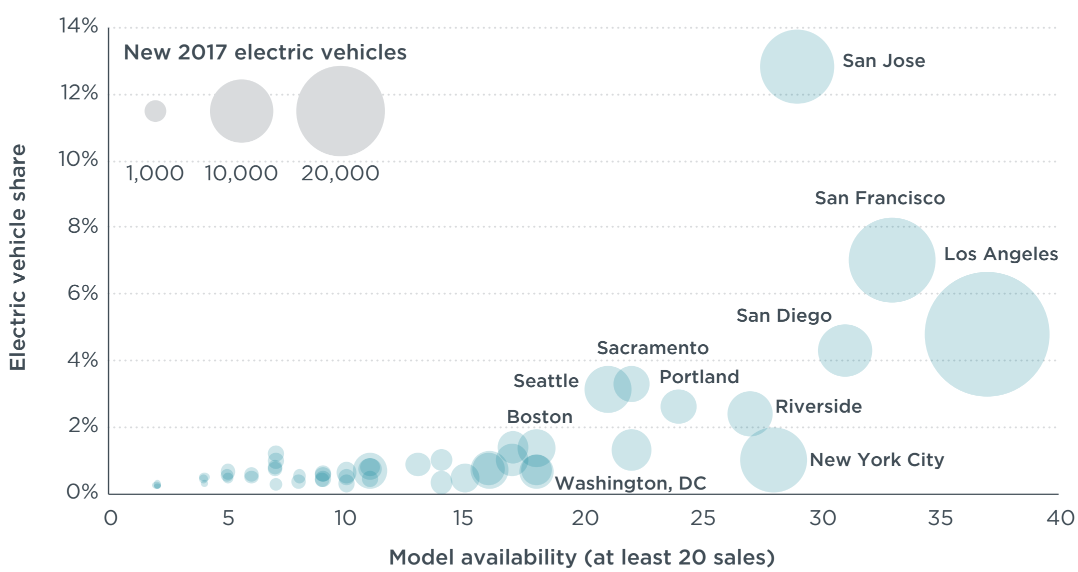

Figure 7. Electric vehicle share of new vehicles and model availability in the 50 most populous metropolitan areas. *(New vehicle registration data from IHS Automotive)*

In terms of sales share, each of the seven areas with more than 2.5% uptake (more than twice the national average of 1.2%) had 21 or more models available in 2017. The four areas with the highest electric vehicle share (above 4%) had 29 to 37 models, namely San Diego, Los Angeles, San Francisco, and San Jose. Uptake in these areas was between 3.6 times (San Diego) and 10.8 times (San Jose) the average among the 50 major markets. There were 28 models that were made substantially available in New York City and 22 in Washington, D.C., both of which are relatively strong electric vehicle markets. New York City had the fourth highest electric vehicle sales volume in 2017, and Washington, D.C. (1.3% share) is a regional leader among surrounding areas in the South and Northeast. As compared to 2016, 40 of the 50 most populous metropolitan areas saw an increase in model availability. The average increase across the 50 cities was about two electric vehicle models.

We also analyzed model availability among the 200 most populous areas. Based on the threshold of at least 20 sales of a given model, we find that 86% of the 200 most populous metropolitan areas had no more than 10 electric vehicle models available to consumers. In terms of population in these areas, we find that about half (46%) of the population was in an area that had 10 or fewer models available in 2017. Prospective consumers in markets with high electric vehicle uptake had about 2.5 to 3.5 times this availability. Many cities, such as Birmingham, Jacksonville, Louisville, Memphis, Milwaukee, Nashville, New Orleans, Oklahoma City, and Richmond, had five or fewer models available, and electric vehicle uptake in each of these cities was less than half of the national average (with the exception of Nashville, with just over half the national average). The link between model availability and electric vehicle uptake is further explored in the statistical analysis below.

POLICY INCENTIVES

Financial and nonfinancial incentives help overcome key cost and convenience barriers and give impetus to the early electric vehicle market while technology costs fall and awareness improves. Figure 8 shows the estimated value of consumer incentives (vertical bars, right axis) and 2017 electric vehicle uptake (black line, left axis) across the 50 cities, ordered from left to right based on highest uptake. Our quantification includes estimates of state, city, and utility purchase incentives; HOV lane access; and "other" incentives, namely parking perks and exemptions from state and local fees and emissions inspections. The utility incentive is based on the implementation of the Low Carbon Fuel Standard in California. Also shown are "fees," which are typically at the state level. The incentive values shown are the average of BEV and PHEV incentives in each area. Incentives and fees that occur for future years after the initial purchase or lease are evaluated over a six-year ownership period with a 5% annual discount rate.

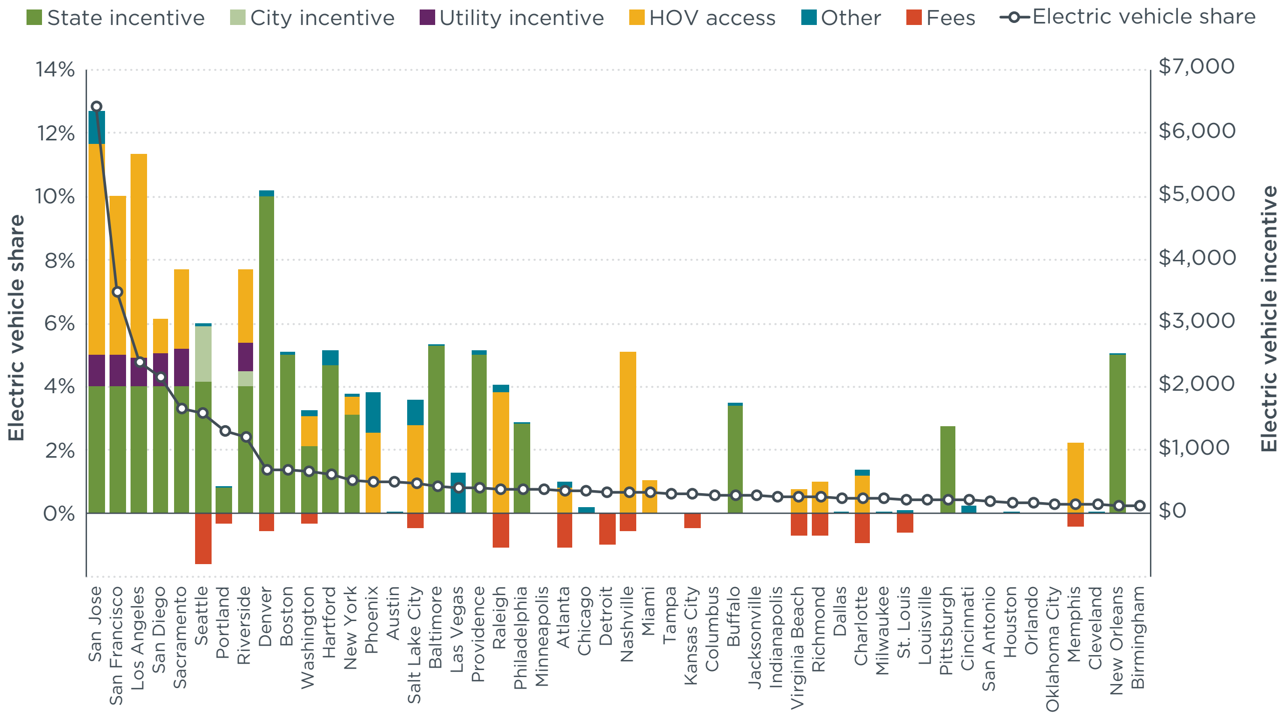

Figure 8. Electric vehicle share of new vehicles and available consumer incentives. *(New vehicle registration data from IHS Automotive)*

The figure shows how most of the areas with high electric vehicle shares tend to have substantial incentives. Many high-uptake areas offer multiple incentives. For example, electric vehicle drivers in California cities can benefit from state and utility purchase incentives and HOV access. Drivers in Denver receive substantial state purchase incentives, and those in Seattle receive both state and city financial tax credits. New York State began offering incentives in March 2017, and Buffalo had the highest year-over-year growth rate among the 50 cities. The Atlanta case also demonstrates the importance of incentives. Georgia offered an incentive worth approximately $5,000 through mid-2015. In 2014, the electric vehicle share in Atlanta was 3.5%, more than 4 times the national average. Since the expiration of the state incentive (and the introduction of a $200 annual fee for electric vehicles), electric vehicle registrations have fallen to well below the national average. However, there are also counterexamples with relatively high incentives but low uptake, such as Buffalo, Pittsburgh, and New Orleans. In New Orleans, Louisiana's state income tax policies include "alternative fuel vehicle" language, and although the legislation includes electric vehicles, there may be additional barriers related to consumer awareness and understanding of the incentive, its applicability, and its exact value.

The Denver case demonstrates the importance of incentive *design* (see Yang et al., 2016). Beginning in 2017, Colorado modified its electric vehicle tax credit to provide incentives upfront at the point of sale in order to be more enticing to prospective consumers and make the process easier and simpler (Drive Electric Northern Colorado, 2016). Although there are other factors, electric vehicle sales in Colorado increased by about 50% from 2016 to 2017, with the Denver area experiencing about 65% year-over-year growth, more than twice the national average.

Each of the 50 most populous metropolitan areas exceeding the average U.S. uptake (1.2%) offered purchase incentives in 2017, with one exception. Portland is one counterexample with low incentives and high uptake. However, electric vehicle drivers in the Portland area benefit from a broad array of local and utility actions, a highly active outreach and awareness association (Forth Mobility), and extensive charging infrastructure; some drivers also benefit from Washington's state vehicle purchase tax credit. Oregon's adoption of the ZEV mandate also helps to ensure relatively high model availability in the Portland area. Although Oregon did not offer purchase incentives in 2017, rebates worth approximately $2,500 per electric vehicle are available in 2018. The link between incentives and electric vehicle uptake is further explored in the statistical analysis.

ELECTRIC VEHICLE PROMOTION ACTIONS

Figure 9 displays the number of state, city, and utility promotion actions (from Table 2) in the 50 markets (vertical bars, right axis) as well as the electric vehicle share (black line, left axis), ordered from left to right by highest share. The eight areas to the left in the chart with the highest uptake (>2%) have adopted 23 to 34 actions. These areas tend to have a strong mix of state, city, and utility actions. New York and Baltimore also have a strong mix of promotion actions but remain in the middle of the pack in terms of electric vehicle share. Markets with the lowest uptake tend to have fewer than 15 actions. The link between promotion actions and electric vehicle uptake is further explored in the statistical analysis below.

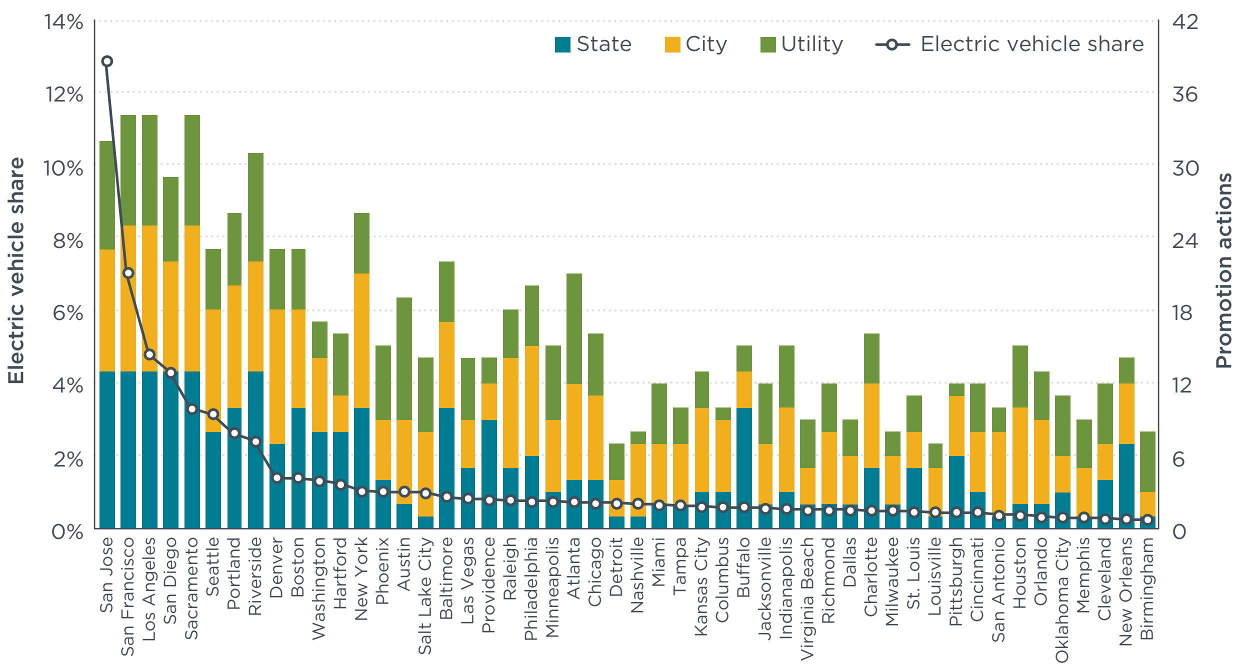

Figure 9. Electric vehicle share of new vehicles and promotion actions. *(New vehicle registration data from IHS Automotive)*

Figure 9 also shows the relative breakdown of state, city, and utility actions in each of the markets. Areas with the greatest number of city actions include the California cities, Denver, New York City, Philadelphia, Portland, Raleigh, and Seattle. Austin has an especially active utility, but promotion actions at the state level are lacking. Other areas with a high number of utility promotion actions include Atlanta and the California cities. State electric vehicle promotion actions are very limited in Alabama, Florida, Kentucky, Michigan, Tennessee, Texas, Utah, Virginia, and Wisconsin. Areas where several local actions are in place, such as Austin and Salt Lake City, could benefit from greater support at the state level. In contrast, Rhode Island and New York have implemented several state actions, and the Providence and Buffalo areas could benefit from greater city and utility support. Utility action in Nashville and Pittsburgh appears quite limited.

COMPARISON OF 50 MAJOR METROPOLITAN AREAS

This section compares the underlying factors identified above across the 50 metropolitan areas to further investigate their potential relationship with electric vehicle uptake. Figure 10 shows how charging infrastructure, promotion actions, and model availability relate to electric vehicle uptake. The horizontal axis displays promotion actions, the vertical axis shows public charging infrastructure per million population, the color of the circles indicates the number of available electric vehicle models, and the circle size represents electric vehicle uptake. Selected areas are labeled, as is the 50-city average. As shown, areas with the highest uptake tend to have the most extensive infrastructure deployment, many promotion actions, and high model availability.

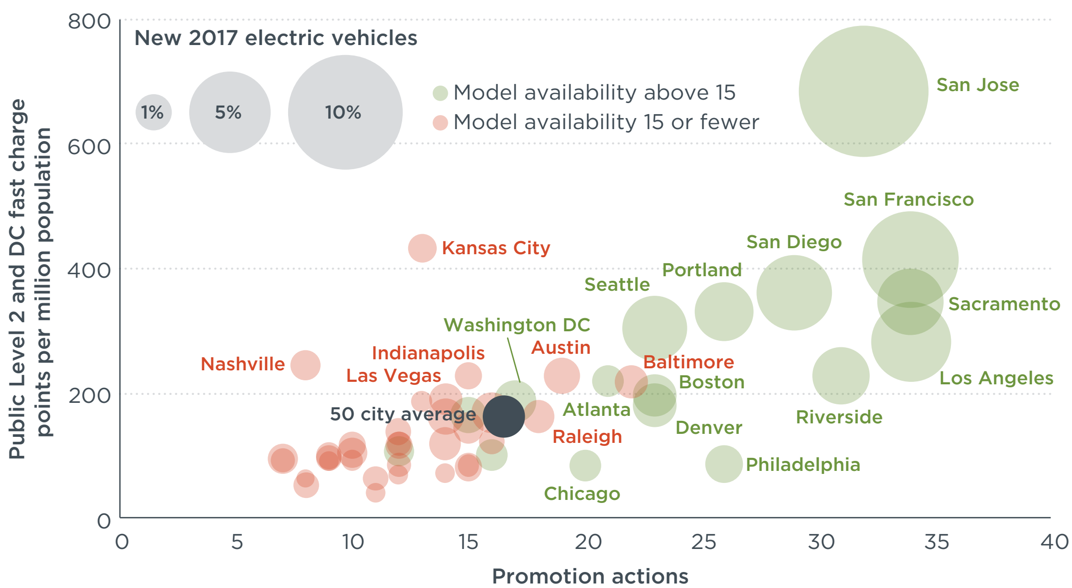

Figure 10. Public charge points, promotion actions, model availability, and electric vehicle uptake. *(New vehicle registration data from IHS Automotive; charging infrastructure data from PlugShare)*

Several observations emerge from Figure 10. Viewing the figure as four quadrants around the 50-city average data point reflects relative gaps. Areas in the lower left quadrant have relatively limited sufficient charging infrastructure, fewer promotion actions, and relatively low model availability, and these areas tend to have less electric vehicle uptake than the U.S average. In contrast, the largest circles (highest uptake) are generally green and clustered in the upper right quadrant, reflecting high model availability, strong public charging infrastructure, and many promotion actions. Austin and Baltimore in the upper right quadrant have an above-average number of promotion actions and public charging infrastructure and could benefit from greater model availability. Areas in the upper left quadrant (e.g., Kansas City, Nashville, Indianapolis) are relatively behind in promotion actions, and model availability tends to be relatively limited in these markets. Areas in the lower right quadrant (e.g., Philadelphia, New York City) could benefit from greater public charging infrastructure. The relationship between these variables and electric vehicle uptake is further investigated in the statistical analysis below.

Figure 11 summarizes electric vehicle uptake and each of the variables discussed above across the 50 metropolitan areas: public charging infrastructure per million population, model availability, consumer incentives, and number of promotion actions. The data for the 50 metropolitan areas are ordered from top to bottom based on 2017 electric vehicle uptake. The figure shows a general visible positive trend between electric vehicle share and each of the variables. Overall, the areas with the highest uptake also tended to have more extensive public charging infrastructure, a wider selection of electric vehicle models, greater consumer incentives, and many state, city, and utility actions. The top 10 areas in terms of electric vehicle shares tend to overlap with the top 10 areas for public charging infrastructure (7 of top 10), workplace charging infrastructure (7 of top 10), model availability (8 of top 10), incentives (8 of top 10), and promotion actions (9 of top 10).

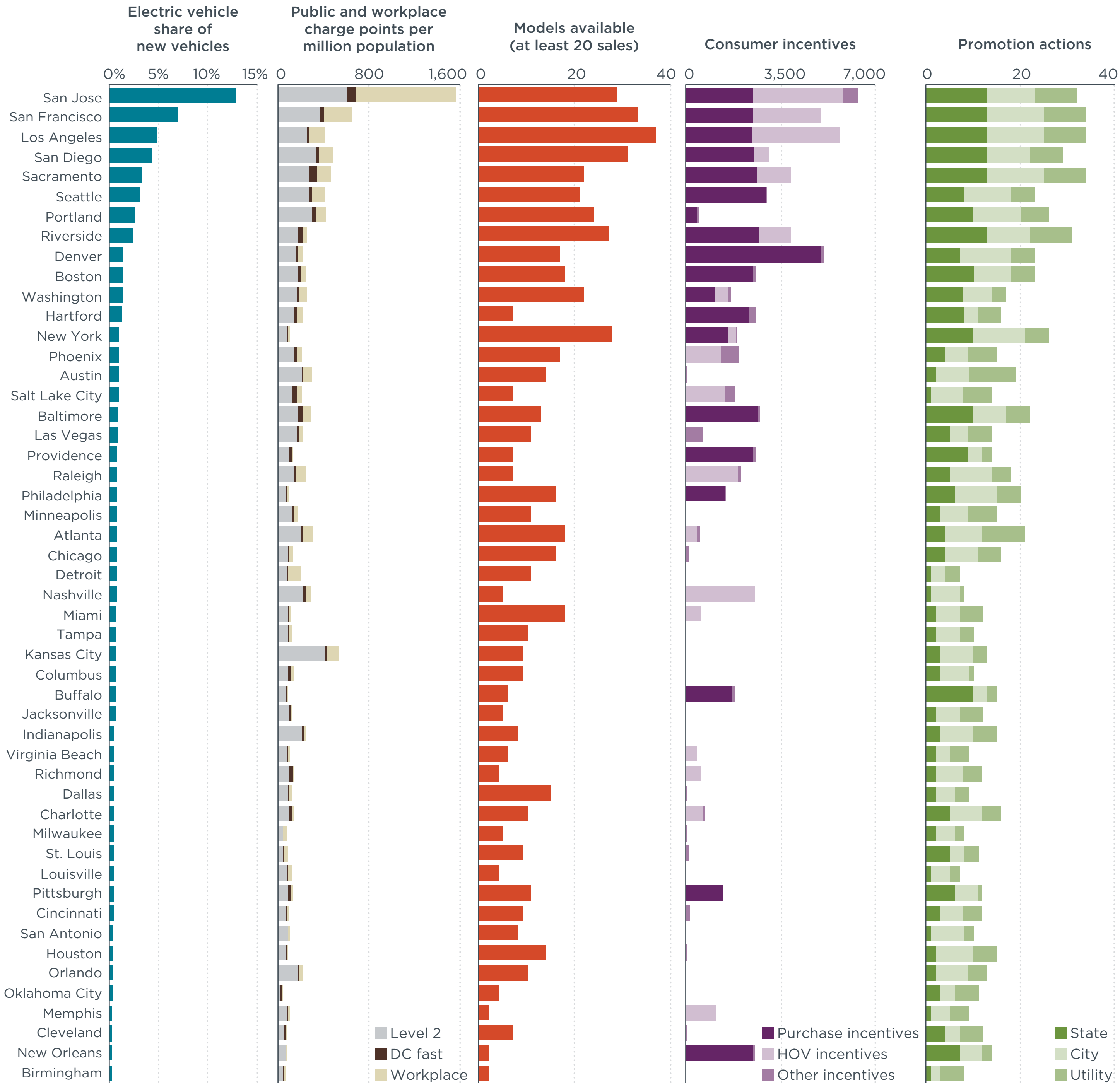

Figure 11. 2017 electric vehicle uptake, public charging infrastructure, model availability, incentives, and promotion actions in the 50 most populous U.S. metropolitan areas. *(New vehicle registration data from IHS Automotive; charging infrastructure data from PlugShare)*

There are also some anomalies in Figure 11 where variables do not visibly follow the generally positive trend with higher electric vehicle uptake. Kansas City stands out as an area with substantial public charging infrastructure per capita, yet low uptake. Model availability, consumer incentives, and promotion actions are each limited in Kansas City. Those cities with relatively high consumer incentives for their electric vehicle uptake position either were implemented more recently (e.g., Buffalo), saw a more recent change in the incentive design (e.g., Denver), or are more limited in availability and promotion (e.g., New Orleans). As mentioned above, although the relatively high-uptake Portland market lacked Oregon purchase incentives in 2017, drivers benefit from several other programs, and incentives are now in place in 2018.

Figure 11 also helps to visualize the relative gaps in electric vehicle promotion activities. For example, New York City has high model availability and promotion actions yet relatively low public charging infrastructure availability. The Austin and Atlanta markets have relatively high numbers of promotion actions, above-average public charging infrastructure, and above-average model availability, but they lack the consumer incentives of other markets. Baltimore, Boston, Buffalo, Hartford, and Providence stand out as having substantial consumer incentives, strong year-over-year growth, but still relatively low uptake. We note that the introduction and growing availability of the Chevrolet Bolt, a relatively affordable long-range electric vehicle, led to that model accounting for 31 to 59% of new BEV sales in these markets. These examples of anomalies and gaps within Figure 11 collectively indicate that no single factor or two is likely to drive market growth. Rather, a comprehensive package of extensive charging infrastructure, high model availability, consumer incentives, and numerous promotion actions is key to increase electric vehicle uptake.

STATISTICAL ANALYSIS

This section summarizes the results of our statistical analysis, in which we discern links between the potential electric vehicle market drivers analyzed above and electric vehicle uptake. We analyze the 200 most populous metropolitan areas where data are available, as well as the 50 most populous metropolitan areas for which we have more detailed data. The 200-area analysis includes data on model availability, incentives, and charging infrastructure. The 50-area analysis includes the additional variables of HOV lane access and total electric vehicle promotion actions. Although there are various consumer preference and demographic factors that influence individual electric vehicle purchases, this study is focused on the narrower question of the metropolitan area–level market response to targeted electric vehicle policies and supporting actions. For the analysis below, we conducted a stepwise multivariate linear regression using StatPlus software to identify the best statistical fits among the factors researched above with electric vehicle uptake (AnalystSoft, 2018a, 2018b).

The results from the statistical analysis are summarized in Table 4, showing relationships between the variables with the strongest fits at both the 200– and 50–metropolitan area levels. We conducted the analysis for BEVs, PHEVs, and both types combined as electric vehicles (EVs) because this revealed additional statistically significant regressions with additional nuanced differences that might be useful for comparison with other data analyses for which separate BEV and PHEV data were unavailable. We report the strongest statistical fits for each of the six regressions. Each column represents a unique statistically significant regression with three to five independent variables (marked with “X”) regressed against electric vehicle share.

Table 4. Summary of significant independent variables for six statistical regressions on electric vehicle shares in U.S. metropolitan areas.

Variable	200 U.S. metropolitan areas			50 U.S. metropolitan areas		
	BEV	PHEV	EV	BEV	PHEV	EV
Model availability, BEV	X			X		
Model availability, PHEV		X				
Model availability, EV			X			X
BEV incentive	X			X		
PHEV incentive		X				
EV incentive			X			
Public charging per capita (Level 2)	X	X	X			
Public charging per capita (DC fast)	X	X	X			
Workplace charging per capita	X	X	X	X	X	X
High occupancy vehicle lane incentive					X	X
Total promotion actions					X	X
Regression adjusted R^2	0.82	0.78	0.83	0.94	0.91	0.94

BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle; EV = electric vehicle (including BEV and PHEV); X = significant variable (p-value < 0.05).

For the regressions of the data for the 200 most populous metropolitan areas, we find statistical fits for BEVs, PHEVs, and EVs, each with five independent variables. Each includes model availability, consumer incentives, Level 2 public charging, DC fast public charging, and workplace charging, and each had adjusted R^2 values of 0.78 to 0.83. For each of the 50-metropolitan area regressions, workplace charging remains significant, whereas model availability remains significant in the BEV and EV cases, and incentives remain significant in the BEV case. The 50-metropolitan area regressions also show significant links with HOV lane access value and total number of promotion actions. All of the variables' p-values were less than 0.05. The statistical fits help to explain more of the variability in the 50-metropolitan area regressions (adjusted R^2 = 0.91 to 0.94). See the Annex for additional details of the regressions.

As shown in Table 4, the three separate 200-metropolitan area regressions suggest that incentives, public charging infrastructure (Level 2 and DC fast), workplace charging infrastructure, and model availability are key factors for bolstering the electric vehicle market. The three 50-metropolitan area regressions are more granular, as we collected more data on more dimensions, especially on promotion actions, in the 50 metropolitan areas. The 50-metropolitan area regressions indicate that model availability, incentives, workplace charging, HOV lane access, and total number of promotion actions are significantly linked with electric vehicle uptake. Two of the variables (model availability and promotion actions) appear to nearly be approaching multicollinearity guidelines, but there were no other collinearity questions. We also tested median household income as an additional variable and found that income is not a significant independent variable in the strongest statistical fits for any of the six regressions. Overall, the relationships shown in Table 4 suggest that greater model availability, consumer incentives, public and workplace charging, carpool lane access, and total promotion actions have been important factors in the growth of the electric vehicle market.

IV. CONCLUSIONS

As summarized and analyzed in this assessment, many factors are helping to spur electric vehicle growth in markets across the United States. The activities and policies help to explain why the electric vehicle market is growing more quickly in some areas than others. On the basis of our cataloguing of dozens of unique electric vehicle actions, we ultimately find statistically significant relationships between the electric vehicle share of new light-duty vehicle sales and model availability, consumer incentives, public charging infrastructure, workplace charging infrastructure, high occupancy vehicle lane access, and total electric vehicle promotion actions. The markets across the United States with more of the underlying support activities are experiencing greater electric vehicle market growth.

Our primary conclusion from this work is that electric vehicle market growth requires many actions by many different players. Actions by various stakeholders are linked with electric vehicle uptake. Local, state, and utility stakeholders are reducing consumer barriers with policy, fiscal and nonfiscal incentives, infrastructure, and awareness campaigns. The 10 states that have adopted the California ZEV regulation especially catalyze the market, spurring expanded model availability and marketing. This provides assurance of a growing market and is typically complemented with many local, utility, and state actions. Beyond the leaders in California, we saw high 2017 market growth of 35 to 91% in the ZEV markets of Baltimore, Boston, Buffalo, Hartford, New York, and Providence. High electric vehicle uptake in non-ZEV markets such as Austin, Denver, and Seattle also exemplify the importance of comprehensive action.

Several markets especially make it clear that no one or two actions are sufficient to grow the electric vehicle market. Kansas City, for example, has among the most extensive public charging infrastructure per capita but lacks incentives, model availability, and promotion actions, and remains below the national average electric vehicle uptake. Several markets such as Nashville, New Orleans, Pittsburgh, and Raleigh have substantial consumer purchase incentives or offer HOV lane access as a perk but have limitations in model availability and in various local electric vehicle promotion areas. Houston and Philadelphia have adopted numerous local promotion actions, but incentives and public charging infrastructure are especially lacking in these areas. Atlanta and Austin have deployed charging infrastructure and utility actions but are largely without consumer incentives and many of the city and state policies seen elsewhere. The above text and Annex Table A1 provide tangible examples where such actions are being implemented.

Growth in electric vehicle uptake starts with having a variety of electric models available with increased range and utility. This research finds a clear statistical link between electric vehicle model availability and uptake. The top five electric vehicle markets by volume, representing nearly half of all U.S. electric vehicle sales, each had at least 28 available electric vehicle models in 2017. In contrast, across major U.S. markets, about half of the population has access to 10 or fewer models, indicating how limited electric vehicle exposure generally is. In addition, outside of the markets with high electric vehicle uptake, many dealerships tend to have low inventories of electric models. The expanded availability of the Chevrolet Bolt, a relatively affordable long-range electric vehicle, serves as an important example. The Bolt in 2017 quickly accounted for approximately 30 to 60% of all BEV sales in several high-growth markets, including Baltimore, Boston, Buffalo, Hartford, and Providence. Newer entrants across more markets, such as the all-wheel-drive Mitsubishi Outlander PHEV and Chrysler Pacifica minivan PHEV, are expanding the use cases for electric vehicles. The ZEV regulation, as a result of changes in the 2018 model year, is expected to increasingly support the northeastern and Oregon markets that have lagged California markets in available models and uptake.

Even as electric vehicle costs continue to decline, consumer incentives remain important. Since 2013, when electric cars with a range of less than 90 miles were priced around $35,000, battery costs have greatly declined. This simultaneously opens up lower-cost and increased-range options. Today, electric cars with a range of 150 miles cost several thousand dollars less, and the 238-mile Chevrolet Bolt is priced at about $37,000 before incentives. Even with this great progress, electric vehicle uptake continues to be linked with incentives that reduce the effective electric vehicle cost. Nine of the top 10 major metropolitan areas with the highest electric vehicle uptake offered consumer incentives typically worth $2,000 to $5,000. Consumers in California markets, Denver, and Seattle have benefited from substantial purchase incentives. Counterexamples with the removal of such incentives and/or imposition of electric vehicle fees (e.g., Atlanta, Detroit, Indianapolis, Memphis, Nashville, Salt Lake City) stand out as rare markets with declining 2017 electric vehicle uptake.

Electric vehicle adoption and various types of charging infrastructure grow in unison. Public regular, public fast, and workplace charging are each linked with electric vehicle market uptake. These relationships remain complex and multidirectional: Infrastructure increases electric vehicle awareness and driver confidence, and more electric vehicle users increase demand for infrastructure. In our continued effort to identify evolving benchmarks to inform local markets, we find that markets with high electric vehicle uptake have at least 300 public charge points per million people in 2017. As evidence of how many markets lack sufficient electric vehicle charging infrastructure, half of the U.S. population lives in a market where available charging is at least 70% lower than this benchmark. About 10 to 20% of the available public charging is fast charging in the top electric markets. In addition, new to this report, we find that top electric markets tend to have at least 100 workplace charge points per million people and that public and workplace charging each play key roles in opening up the electric vehicle market. Further research into how best to deploy charging infrastructure as the electric vehicle market and its infrastructure coevolve is warranted.

The implications of this work are broader than simply the direct local and state U.S. actions analyzed above. Given the increasingly uncertain federal U.S. policy on vehicle efficiency, city, state, and utility actions will take on additional importance in maintaining growth in the market. Governments globally continue to learn from each other's policy and market experiences. The larger electric vehicle sales markets of Europe and China provide similarly rich natural experiments in how the various market, policy, incentive, and infrastructure actions are driving growth. For example, the cities in this report with the highest electric vehicle uptake are in the middle of the pack among the world's top markets that are developing their own electric vehicle playbooks to accelerate the market (Hall et al., 2017). The collective adoption of similar actions to help overcome barriers will help all regions around the world to meet their air pollution, climate, and fuel-saving goals sooner.

REFERENCES

AnalystSoft (2018a). StatPlus:mac; http://www.analystsoft.com/en/products/statplusmac/.

AnalystSoft (2018b). Forward Stepwise Regression; www.analystsoft.com/en/products/statplus/content/help/analysis_regression_forward_stepwise_regression_model.html.

Austin Energy (2017). "Plug-In Austin: Multifamily Properties: Rebates Available to Install Charging Stations for Your Residents"; https://austinenergy.com/ae/green-power/plug-in-austin/multifamily-properties/.

BlueIndy (2017). www.blue-indy.com/benefits.

California Air Resources Board (CARB) (2017a, January). *California's Advanced Clean Cars Midterm Review: Appendix B: Consumer Acceptance of Zero Emission Vehicles and Plug-in Hybrid Electric Vehicles*; www.arb.ca.gov/msprog/acc/mtr/appendix_b.pdf.

California Air Resources Board (CARB) (2017b, January). *California's Advanced Clean Cars Midterm Review: Summary Report for the Technical Analysis of the Light Duty Vehicle Standards*; www.arb.ca.gov/msprog/acc/mtr/acc_mtr_summaryreport.pdf.

California Building Standards Commission (2016). 2016 California Green Building Standards Code; www.ladbs.org/docs/default-source/publications/code-amendments/2016-calgreen_complete.pdf?sfvrsn=6.

California Office of the Governor (2016). *2016 ZEV Action Plan: An Updated Roadmap Toward 1.5 Million Zero-Emission Vehicles on California Roadways by 2025*; www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf.

California Plug-in Electric Vehicle Collaborative (PEVC) (2017). *California Plug-In Electric Vehicle Statewide Ride-and-Drive Series Best. Ride. EVer! 2016 Final Report*; www.pevcollaborative.org/sites/all/themes/pev/files/2016%20BRE%20Final%20Report.pdf.

California Public Utilities Commission (CPUC) (2016, December). *Decision Directing Pacific Gas and Electric Company to Establish an Electric Vehicle Infrastructure and Education Program*; http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M171/K539/171539218.pdf.

California Public Utilities Commission (CPUC) (2018). "Electrifying the Ride-Sourcing Sector in California"; www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/About_Us/Organization/Divisions/Policy_and_Planning/PPD_Work/PPD_Work_Products_(2014_forward)/Electrifying%20the%20Ride%20Sourcing%20Sector.pdf.

Center for Sustainable Energy (CSE) (2016). Experience Electric #Thebetterride; https://mtc.ca.gov/sites/default/files/MTC_EXEL_Final_Report.pdf.

Center for Sustainable Energy (CSE) (2018). California Air Resources Board Clean Vehicle Rebate Project, Rebate Statistics; https://cleanvehiclerebate.org/eng/rebate-statistics.

City of Boston (2017). EV-Boston: Electric Vehicle Resources; www.boston.gov/departments/environment/ev-boston-electric-vehicle-resources

City of Los Angeles (2016). *Recommendation for Contract Award to BlueCalifornia, LLC, for Electric Vehicle Carshare Operations Using Grant Funds from the California Air Resources Board (CARB) Fiscal Year 2014-15 Targeted Car Sharing and Mobility Options in Disadvantaged Communities*; http://clkrep.lacity.org/onlinedocs/2015/15-1227_rpt_DOT_11-23-2016.pdf.

City of Portland (2017). 2017 City of Portland Electric Vehicle Strategy; www.portlandoregon.gov/bps/article/619275.

Clean Fuels Ohio (2016). "Obama Administration Announces New Actions to Accelerate the Deployment of Electric Vehicles and Charging Infrastructure"; www.cleanfuelsohio.org/single-post/2016/11/08/Obama-Administration-Announces-New-Actions-to-Accelerate-the-Deployment-of-Electric-Vehicles-and-Charging-Infrastructure

Colorado Clean Air Fleets (2017). Charge Ahead Colorado; http://cleanairfleets.org/programs/charge-ahead-colorado.

Commonwealth of Massachusetts (2017). *Massachusetts Electric Vehicle Incentive Program (MassEVIP): Fleets*; www.mass.gov/eea/agencies/massdep/air/grants/massevip-municipal.html.

Denver Department of Public Health and Environment (2017, August). "New Electric Vehicle Study Shows Expanded Charging Stations Key to Improving Air Quality, Boosting Vehicle Sales"; www.denvergov.org/content/denvergov/en/environmental-health/about-us/news-room/2017/EVstudy.html.

Drive Electric Northern Colorado (2016). "New Colorado Tax Credit Provides $5,000 Toward EV Purchase"; http://driveelectricnoco.org/2016/06/colorado-tax-credit-change-takes-flat-5000-off-price-of-evs/.

Duke Energy (2016). "Duke Energy Project to Increase Public EV Charging Stations in N.C. by 30 Percent"; https://news.duke-energy.com/releases/duke-energy-project-to-increase-public-ev-charging-stations-in-n-c-by-30-percent.

Edison Electric Institute (2014). *Transportation Electrification: Utilities Leading the Charge*; www.eei.org/issuesandpolicy/electrictransportation/fleetvehicles/documents/eei_utilityfleetsleadingthecharge.pdf.

Edison International (2016). "SCE Receives CPUC Approval for 'Charge Ready' Pilot Program; Will Install As Many As 1,500 Electric Vehicle Charging Stations in Southland"; http://newsroom.edison.com/releases/sce-receives-cpuc-approval-for-charge-ready-pilot-program;-will-install-as-many-as-1-500-electric-vehicle-charging-stations-in-southland.

Hall, D., Cui, H., & Lutsey, N. (2017). *Electric Vehicle Capitals of the World: What Markets Are Leading the Transition to Electric?* International Council on Clean Transportation; www.theicct.org/publications/EV-capitals-of-the-world-2017.

Hall, D., & Lutsey, N. (2017a). *Emerging Best Practices for Electric Vehicle Charging Infrastructure*. International Council on Clean Transportation; www.theicct.org/publications/emerging-best-practices-electric-vehicle-charging-infrastructure.

Hall, D., & Lutsey, N. (2017b). *Literature Review on Power Utility Best Practices Regarding Electric Vehicles*. International Council on Clean Transportation; http://theicct.org/literature-review-power-utility-best-practices-regarding-EVs.

HybridCars (2018). December 2017 Dashboard; www.hybridcars.com/december-2017-dashboard/

Hymon, S. (2017, July). "Metro Board Approves Purchase of 95 Electric Buses and Goal of Fully Electric Fleet by 2030"; https://thesource.metro.net/2017/07/27/as-metro-pursues-electric-bus-fleet-by-2030-three-bus-contracts-go-to-board-on-thursday/.

International Zero-Emission Vehicle Alliance (2018a). "The Transition to Electric Vehicles Is Underway"; https://twitter.com/ZEVAlliance/status/957409272459153408.

International Zero-Emission Vehicle Alliance (2018b). ZEV Alliance; www.zevalliance.org.

Jacksonville Electric Authority (JEA) (2017). Plug-in Electric Vehicles; www.jea.com/Ways_to_Save/Go_Green/Plug-in_Electric_Vehicles/.

Jin, L., Searle, S., & Lutsey, N. (2014). *Evaluation of State-Level U.S. Electric Vehicle Incentives.* International Council on Clean Transportation; http://theicct.org/evaluation-state-level-us-electric-vehicle-incentives.

Jin, L., & Slowik, P. (2017). *Literature Review of Electric Vehicle Consumer Awareness and Outreach Activities*. International Council on Clean Transportation; http://theicct.org/literature-review-EV-consumer-awareness-and-outreach.

Kansas City Power & Light (KCP&L) (2018). *KCP&L Clean Charge Network*; www.kcpl.com/about-kcpl/environmental-focus/clean-charge-network.

King County Metro (2017). *Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet*; http://kingcounty.gov/~/media/elected/executive/constantine/news/documents/Zero_Emission_Fleet.ashx?la=en.

Kurani, K., & Hardman, S. (2018). “Automakers and Policymakers May Be on a Path to Electric Vehicles; Consumers Aren’t.” Institute of Transportation Studies, University of California, Davis; https://its.ucdavis.edu/blog-post/automakers-policymakers-on-path-to-electric-vehicles-consumers-are-not/.

Lowell, D., Jones, B., & Seamonds, D. (2017). “MJB&A Analyzes State-Wide Costs and Benefits of Plug-in Vehicles in Five Northeast and Mid-Atlantic States.” M. J. Bradley & Associates; www.mjbradley.com/reports/mjba-analyzes-state-wide-costs-and-benefits-plug-vehicles-five-northeast-and-mid-atlantic.

Lutsey, N. (2018). *California’s Continued Electric Vehicle Market Development.* International Council on Clean Transportation; www.theicct.org/publications/california-electric-vehicle-2018.

Lutsey, N., Searle, S., Chambliss, S., & Bandivadekar, A. (2015). *Assessment of Leading Electric Vehicle Promotion Activities in United States Cities*. International Council on Clean Transportation; www.theicct.org/leading-us-city-electric-vehicle-activities.

Lutsey, N., Slowik, P., & Jin, L. (2016). *Sustaining Electric Vehicle Market Growth in U.S. Cities*. International Council on Clean Transportation; www.theicct.org/leading-us-city-electric-vehicle-2016.

Maryland General Assembly (2015). House Bill 0235; http://mgaleg.maryland.gov/webmga/frmMain.aspx?pid=billpage&stab=02&id=HB0235&tab=subject3&ys=2015rs.

Maven Gig (2018). “Need a Car for Your Rideshare Job?”; https://mavengig.maven.com/us/.

Michigan Legislature (2014). House Bill 5606; www.legislature.mi.gov/(S(udlbis5czbmyivc1tr3dqu3j))/mileg.aspx?page=GetObject&objectname=2014-HB-5606.

Mulkern, A. (2017, February 23). “Utilities paying EV drivers ‘climate credits’.” Environment & Energy Publishing; www.eenews.net/climatewire/stories/1060050446

National Renewable Energy Laboratory (NREL) (2017). National Plug-in Electric Vehicle Infrastructure Analysis. *U.S. Department of Energy Office of Energy Efficiency and Renwable Energy*. Retrieved from https://www.nrel.gov/docs/fy17osti/69031.pdf

National Research Council (NRC) (2015). *Overcoming Barriers to the Deployment of Plug-in Electric Vehicles*. National Academies Press; www.nap.edu/catalog.php?record_id=21725.

Nicholas, M. (2018). Ensuring driving on electricity is cheaper than driving on gasoline. International Council on Clean Transportation; www.theicct.org/publications/ensuring-driving-on-electricity-cheaper-than-gasoline.

Northeast States for Coordinated Air Use Management (NESCAUM) (2013). *State Zero-Emission Vehicle Programs: Memorandum of Understanding*; www.nescaum.org/documents/zev-mou-8-governors-signed-20131024.pdf/.

Northeast States for Coordinated Air Use Management (NESCAUM) (2014). *Multi-State ZEV action Plan. ZEV Program Implementation Task Force*; www.nescaum.org/documents/multi-state-zev-action-plan.pdf/.

Northeast States for Coordinated Air Use Management (NESCAUM) (2016). *Electric Vehicle Marketing Analysis*; www.nescaum.org/documents/nescaum-elec-vehicle-marketing-analysis-20161219.pdf/view.

Northeast States for Coordinated Air Use Management (NESCAUM) (2017). "Driving ZEV Success in the Northeast." Presented to California Air Resources Board, March 24.

NV Energy (2015). "Nevada Electric Highway to Link Northern and Southern Nevada with Electric Vehicle Charging Stations Along U.S. Route 95"; http://energy.nv.gov/uploadedFiles/energynvgov/content/Programs/Nevada%20Electric%20Highway%20Fact%20Sheet.pdf.

Pacific Gas and Electric (PG&E) (2015). "PG&E to Step Up the Addition of Electric Vehicles to its Fleet"; https://www.pge.com/en/about/newsroom/newsdetails/index.page?title=20151015_pge_to_step_up_the_addition_of_electric_vehicles_to_its_fleet_.

Pacific Power (2018). "Electric Vehicles Gain Traction with Approval of Pacific Power Pilot Projects"; www.pacificpower.net/about/nr/nr2018/oregon-electric-vehicle-pilot-programs.html.

PlugShare (2018). www.plugshare.com/.

Portland Bureau of Planning and Sustainability (2018). Electric vehicle composite analysis. Retrieved from https://www.arcgis.com/home/item.html?id=ffae460eaec94a7a8c3504a139e0c89a

Reichmuth, D., & Anair, D. (2016). *Electrifying the Vehicle Market: Evaluating Automaker Leaders and Laggards in the United States*; www.ucsusa.org/sites/default/files/attach/2016/08/Electrifying-Vehicle-Market-full-report.pdf.

Ryan, N., & McKenzie, L. (2016). Utilities' role in transport electrification: Capturing benefits for all ratepayers. *Energy and Environmental Economics (E3)*; www.fortnightly.com/fortnightly/2016/04/utilities-role-transport-electrification-capturing-benefits-all-ratepayers.

San Diego Gas & Electric (SDG&E) (2016). "SDG&E to Install Thousands of Electric Vehicle Charging Stations"; https://www.prnewswire.com/news-releases/sdge-to-install-thousands-of-electric-vehicle-charging-stations-300211765.html.

San Francisco Department of the Environment (2017). San Francisco Green Building Code; https://sfenvironment.org/green-building-ordinance-sf-building-code.

Santini, D. J., Zhou, Y., Rood, M., & Vazquez, K. (2016). *Effects of Utility Outreach on Plug-in Electric Vehicle Market Success*. Argonne National Laboratory.

Slowik, P., & Lutsey, N. (2017). *Expanding the Electric Vehicle Market in U.S. Cities*. International Council on Clean Transportation; www.theicct.org/publications/expanding-electric-vehicle-market-us-cities.

Tal, G., & Nicholas, M. (2016). *Exploring the Impact of the Federal Tax Credit on the Plug-In Electric Vehicle Market*. University of California, Davis; https://trid.trb.org/view.aspx?id=1392922.

U.S. Census Bureau (2018a). Metropolitan and Micropolitan; www.census.gov/programs-surveys/metro-micro.html.

U.S. Census Bureau (2018b). State Government Tax Collections: 2016; https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk.

U.S. Department of Energy (DOE) (2015). States assessing fees on electric vehicles to make up for lost fuel tax revenue; www.energy.gov/eere/vehicles/fact-901-november-30-2015-states-assessing-fees-electric-vehicles-make-lost-fuel-tax.

Vergis, S., & Chen, B. (2014). Understanding Variations in U.S. Plug-In Electric Vehicle Markets. University of California, Davis, Research Report UCD-ITS-RR-14-25.

Vermont Agency of Transportation (2016). *Sec. 15. 2016 Plug-In Hybrid and Electric Vehicle Registration Fees: Legislative Report December 2016*; http://legislature.vermont.gov/assets/Legislative-Reports/2016-Legislative-EV-Study-FINAL-formatted.pdf.

Yang, Z., Slowik, P., Lutsey, N., & Searle, S. (2016). *Principles for Effective Electric Vehicle Incentive Design*. International Council on Clean Transportation; www.theicct.org/principles-for-effective-EV-incentive-design.

Zhou, Y., Santini, D., Rood, M., Bluestein, L., Mitchell, G., Stephens, T., & Ward, J. (2016). *An Assessment of Causes of PEV Success Across U.S. Metro Areas.* Argonne National Laboratory; https://anl.app.box.com/s/u3jnk1mwsbt3c406ielw0h1zbwy42wh1.

Zhou, Y., Santini, D., Vazquez, K., & Rood, M. (2017). *Contributing Factors in Plug-in Electric Vehicle Adoption in the United States: A Metro/County Level Investigation.* Argonne National Laboratory; https://trid.trb.org/view.aspx?id=1439160.

ANNEX

Table A1. Representative electric vehicle promotion actions.

Action	Level	Example and link
State ZEV program	State	California – Zero Emission Vehicle Program
State International ZEV Alliance participation	State	Multiple – Zero Emission Vehicle Alliance
State low carbon fuel policy	State	California – Low Carbon Fuel Standard
State BEV purchase incentive	State	Colorado – Innovative Motor Vehicle Tax Credit
State PHEV purchase incentive	State	Massachusetts – MOR-EV
State increased incentive for low-income consumers	State	California – Clean Vehicle Rebate
State fee reduction or testing exemption	State	Arizona – Reduced Vehicle License Tax
No state annual electric vehicle fee	State	California – Zero-emission vehicle fee beginning 2020
State private charger incentive, support	State	Missouri – Alternative Fuel Infrastructure Tax Credit
State public charger promotion	State	Ohio – Alternative Fuels Transportation Program
State parking benefit	State	Hawaii – Free Parking for Electric Vehicles
State fleet purchasing incentive	State	Massachusetts – Electric Vehicle Incentive Program: Fleets
State manufacturing incentive	State	California – Sales and Use Tax Exclusion Program
State allows direct sales to consumers	State	Maryland – House Bill 235
City electric vehicle strategy	Local	Portland, Oregon – 2017 City of Portland Electric Vehicle Strategy
Streamlined EVSE permitting process	Local	Chicago, Illinois – Drive Electric Chicago
EV-ready building code	Local	Denver, Colorado – Municipal building code
City vehicle purchase subsidy	Local	Riverside, California – Alternative Fuel Vehicle Rebate Program
City parking benefit	Local	Cincinnati, Ohio – Free Parking for All-Electric Vehicles
City EVSE incentive, support	Local	Washington, DC – Alternative fuel infrastructure credit
City carpool lane (HOV) access	Local	Nashville, Tennessee – HOV Smart Pass
City-owned EV chargers	Local	Raleigh, North Carolina – Electric Vehicle Charging Stations
Workplace charging	Local	Multiple – Workplace Charging Challenge Progress Update 2016
City carsharing program link	Local	Indianapolis, Indiana – BlueIndy
City informational materials	Local	Chicago, Illinois – Drive Electric Chicago
City outreach events	Local	New Orleans, Louisiana – National Drive Electric Week
City outreach events in low-income communities	Local	Watts, California – National Drive Electric Week
City electric vehicle fleet target	Local	New York, New York – OneNYC
City use of electric buses in public transportation	Local	Louisville, Kentucky – Transit Authority of River City
Utility charging pilot or other research	Utility	Birmingham, Alabama – Alabama Power Electric Transportation
Utility public charging infrastructure	Utility	Kansas City, Missouri – Clean Charge Network
Utility public charging infrastructure in low-income communities	Utility	San Diego, California – SDG&E to install thousands of EV chargers
Utility time of use rates offered	Utility	Detroit, Michigan – Electric Pricing Options
Utility preferential EV rates	Utility	Atlanta, Georgia – Georgia Power Plug-in Electric Vehicle Rate
Utility EV or EVSE incentive, support	Utility	Austin, Texas – Austin Energy – Plug-in Austin
Utility increased incentives for EVSE at multifamily properties	Utility	Austin, Texas – Austin Energy – Multifamily Properties
Utility info materials or outreach events	Utility	Baltimore, Maryland – Baltimore Gas and Electric – Electric Vehicles
Utility EVSE informational materials for multifamily properties	Utility	Seattle, Washington – EV service equipment for multi-family housing
Utility cost comparison tool	Utility	Dallas, Texas – Oncor – EV Savings Calculator
Utility electric vehicle fleet	Utility	San Francisco, California – PG&E to Step Up Addition of EVs

Table A2. Summary of six multiple linear regressions for electric vehicle uptake.

	50-metropolitan area regressions					
	Independent variable	**Coefficient**	**Standard error**	***T* statistic**	***p*-value**	**β**
Battery electric vehicle share	Workplace chargers per million population	0.0000800	0.0000044	18.18	0.00000	0.770
	Model availability (BEV)	0.0007500	0.0001900	3.97	0.00025	0.189
	Incentives (BEV)	0.0000009	0.0000003	2.71	0.00943	0.133
Plug-in hybrid electric vehicle share	Workplace chargers per million population	0.0000400	0.0000036	9.73	0.00000	0.545
	Number of promotion actions	0.0004800	0.0000600	8.72	0.00000	0.448
	HOV lane access	0.0000013	0.0000005	2.51	0.01553	0.141
Electric vehicle share	Workplace chargers per million population	0.0001200	0.0000075	15.56	0.00000	0.693
	Number of promotion actions	0.0005200	0.0001900	2.69	0.00993	0.189
	Model availability (EV)	0.0003700	0.0001700	2.20	0.03339	0.150
	HOV lane access	0.0000025	0.0000011	2.31	0.02541	0.103

	200-metropolitan area regressions					
	Independent variable	**Coefficient**	**Standard error**	***T* statistic**	***p*-value**	**β**
Battery electric vehicle share	Workplace chargers per million population	0.0000700	0.0000049	13.32	0.00000	0.509
	Public Level 2 charters per million population	0.0000200	0.0000037	6.20	0.00000	0.268
	Model availability (BEV)	0.0005400	0.0001200	4.54	0.00001	0.172
	Incentive (BEV)	0.0000009	0.0000002	4.10	0.00006	0.137
	Public DC fast chargers per million population	0.0000400	0.0000200	2.40	0.02038	0.086
Plug-in hybrid electric vehicle share	Public Level 2 charters per million population	0.0000200	0.0000028	8.07	0.00000	0.382
	Workplace chargers per million population	0.0000200	0.0000038	6.50	0.00000	0.276
	Public DC fast chargers per million population	0.0000800	0.0000100	6.29	0.00000	0.252
	Model availability (PHEV)	0.0002200	0.0000600	4.01	0.00009	0.157
	Incentive (PHEV)	0.0000008	0.0000002	3.84	0.00009	0.136
Electric vehicle share	Workplace chargers per million population	0.0000900	0.0000080	11.39	0.00000	0.427
	Public Level 2 charters per million population	0.0000500	0.0000059	7.86	0.00000	0.330
	Public DC fast chargers per million population	0.0001300	0.0000300	4.45	0.00001	0.159
	Incentive (EV)	0.0000019	0.0000004	4.65	0.00001	0.149
	Model availability (EV)	0.0003100	0.0000800	4.10	0.00006	0.147