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LEADING EDGE OF ELECTRIC VEHICLE MARKET DEVELOPMENT IN THE UNITED STATES: AN ANALYSIS OF CALIFORNIA CITIES

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EXECUTIVE SUMMARY

Electric vehicles passed one million cumulative sales globally in 2015 and are entering a new phase of more rapid deployment as automakers and consumers grow increasingly accustomed to the new technology. Growth to date in the electric vehicle market has been supported by governments, industry, and advocacy groups. Few places have done as much as California to help grow the electric vehicle market.

This study analyzes the California electric vehicle market in 2015 to discern best-practice policy and promotion activities that might be emulated elsewhere. The work provides a first such analysis of electric vehicle markets at the city level in California. Along with an analysis of city-level electric vehicle uptake, we assess the public charging infrastructure, model availability, and other factors to identify leading-edge electric vehicle markets in California. Within this work, we conduct a detailed analysis of the 30 California cities with the highest rates of electric vehicle penetration, examining how local organizations like regional and city governments, utilities, businesses, and nonprofits are promoting electric vehicles through a wide array of activities.

Figure ES-1 highlights the California markets with the highest electric vehicle uptake, as compared with the California and U.S. averages. As shown, there are 30 California cities with from 6% to 18% electric vehicle share of new vehicle sales. This amounts to 8 to 25 times that of the U.S. average in 2015. These vehicle markets range greatly in size, from hundreds of electric vehicle sales up to approximately 4,000 in the case of San Jose. These cities tended to have about 20 electric vehicle models locally available over 2015, far more than generally is the case across other U.S. cities, as well as other California cities.

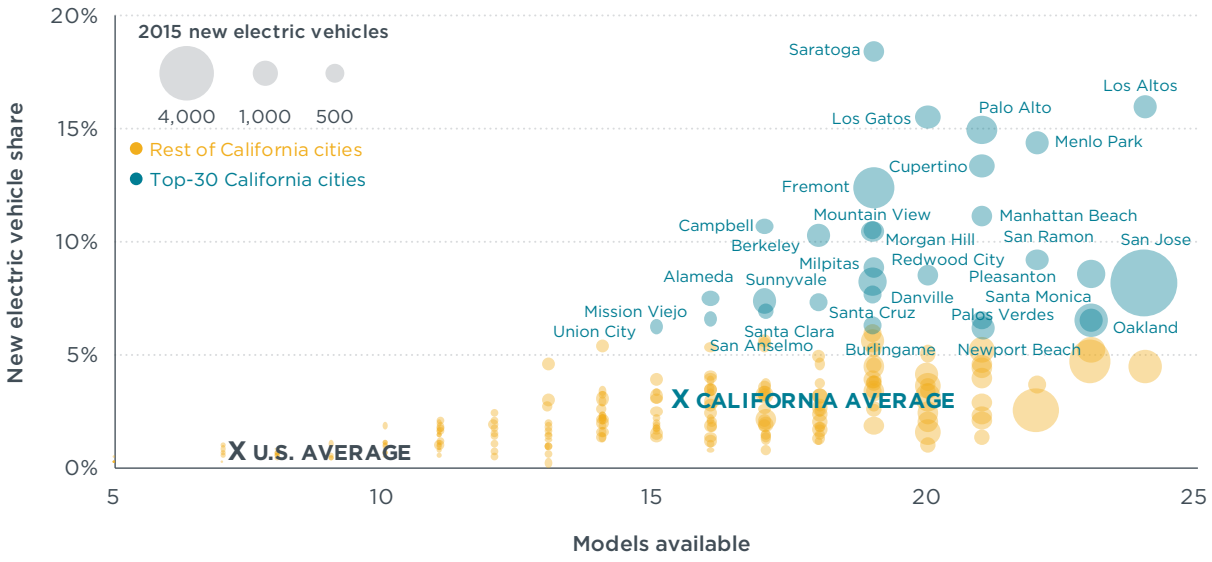

Figure ES-1. New electric vehicle shares and model availability in California cities in 2015

This analysis finds a link between electric vehicle uptake and many underlying factors in a multivariate regression analysis. Electric vehicle model availability, public electric vehicle charging network, local promotion activities for electric vehicles (e.g., outreach events, informational websites, electric car sharing services, and government and fleet

programs) and median income in each city were found to be significantly correlated with new electric vehicle sales share, although causality could not be determined within our analysis. Some factors we examined (California Clean Vehicle Rebate claim rate and the prevalence of single-family homes) were not linked with electric vehicle uptake. Furthermore, other factors for which data was not available (such as the income of electric vehicle purchasers specifically, rather than city-level median income) or that cannot be quantified (such as cultural differences between cities) could be influencing electric vehicle uptake in these cities.

Based on this analysis, we make three conclusions about the development of the electric vehicle market in California –

Comprehensive policy support is helping support the electric vehicle market. Consumers in California benefit from federal and state electric vehicle incentives, as well as from persistent local action and extensive charging infrastructure. The Zero-Emission Vehicle program has increased model availability and provided relative certainty about vehicle deployment that local stakeholders can bank on. The major metropolitan areas in California had 3 to 13 times the average U.S. electric vehicle uptake in 2015.

Local promotion activities are encouraging the electric vehicle market. The 30 cities in California with the highest electric vehicle uptake —with 8 to 25 times the U.S. electric vehicle uptake—have seen the implementation of abundant, wide-ranging electric vehicle promotion programs involving parking, permitting, fleets, utilities, education, and workplace charging. These cities tend to be smaller, but Oakland and San Jose are also within the high electric vehicle uptake cities. There were twelve cities with electric vehicle market shares of new vehicles from 10% to 18% in 2015 including Berkeley, Manhattan Beach, and many throughout Silicon Valley.

The electric vehicle market grows with its charging infrastructure. The 30 California cities with the highest electric vehicle uptake have, on average, 5 times the public charging infrastructure per capita than the U.S. average. In addition, workplace charging availability in the San Jose metropolitan area is far higher than elsewhere. Increasingly, major public electric power utilities and workplaces are expanding the public charging network to further address consumer confidence and convenience.

This analysis of the California market could have broader implications in defining best practice policies to support electric vehicles. Governments around the world are contemplating more progressive regulatory policies to promote electric vehicles. Policymakers are also investigating complementary local outreach, city policy, and charging infrastructure planning to pave the way for the emerging electric vehicle market. California provides a template for such state and local activities that reach more businesses and prospective consumers. The California experience suggests that if electric vehicle models are brought to more markets and there is supporting policy in place, market growth will continue. Our findings suggest that California's playbook could be a helpful example to other regions seeking to encourage electric vehicle uptake.

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I. INTRODUCTION

In late 2015, the transition to electric vehicles reached a major milestone, as cumulative global sales passed one million. This rapid growth in the electric vehicle market took place in a short six years, an impressive result of a number of factors such as the falling cost of electric vehicles, electric vehicle offerings by every nearly major automaker, and consistent promotion actions by governments and other groups.

National, state, and local governments have been playing an active role in promoting electric vehicles by providing subsidies, tax reductions, and other incentives for consumers. When all these incentives, as well as much lower fuel costs, are taken into account the effective cost of ownership for some electric vehicle models is lower than that for a comparable conventional gasoline car in several U.S. cities (Slowik, 2015). Governments and other groups, including utilities, advocacy groups, and businesses, can also play an important role in promoting electric vehicles through non-monetary incentives like preferential lane access and parking perks that are difficult to quantify. In addition, organizing electric vehicle rallies, purchasing electric vehicles for public and private fleets, and hosting informational websites can raise the profile of electric vehicles.

California has played a pivotal role in developing the policy promotion playbook to accelerate the electric vehicle market. The state has adopted, implemented, and adjusted its landmark Zero Emission Vehicle regulation that would require approximately 15% of new passenger vehicle sales to be electric-drive by 2025 (CARB, 2011). In addition the state has a comprehensive portfolio of financial incentives, preferential consumer benefits, charging infrastructure, and public-private partnerships that exemplify global best practices for electric vehicles (Lutsey, 2015c). In addition to the many state-level actions in California, its major cities have local parking, non-financial incentives, public charging, and various consumer outreach programs to increase awareness about the technology and its benefits (Jin et al., 2014; Lutsey et al., 2015; Lutsey, 2016). The state now has active charging infrastructure deployment programs from its major electric power utilities to further promote the new technology (SDGE, 2016; Edison International, 2016).

This study builds from previous work on electric vehicle promotion actions with a deeper analysis of the leading-edge electric vehicle markets in the United States, in particular in California. Previous work has linked incentives, charging infrastructure, and other activities to growing the electric vehicle market across the U.S. (e.g., Jin et al, 2014; Lutsey et al 2015; Clark-Sutton et al, 2016; Li et al, 2015; Vergis and Chen, 2014; Greene et al, 2014). These studies tend to show aspects of how California and other areas are accomplishing increased electric vehicle uptake. Analysis at a more detailed local level has been limited. When mid-sized and smaller cities have been considered, California cities such as San Jose and Santa Cruz further stand out with higher electric vehicle uptake (Lutsey, 2015b). This leads to the question: What sets the cities with the highest electric vehicle uptake apart from the rest?

The present study attempts to answer this question with a city-level analysis and specifically by digging deeper into the activities of the top 30 California cities by new electric vehicle share. The work assesses a broader range of electric vehicle promotion actions by regional and local governments and utilities, and also businesses, advocacy groups, and the media. We incorporate information on public charger availability to assess how range confidence may be linked electric vehicle ownership. We utilize data from California's Clean Vehicle Rebate Program (CVRP) to better understand how the state rebate is contributing to electric vehicle uptake. We include an examination of model availability by city to assess the potential relationship between auto company deployment decisions and electric vehicle sales.

II. SCOPE OF ASSESSMENT AND DATA SOURCES

This study investigates the potential driving factors behind high electric vehicle sales in California cities. Within the analysis, California markets are initially compared nationally at the metropolitan area level. Then, on a city-level, California markets are compared based on available data on electric vehicle uptake, electric vehicle charging infrastructure, model availability, relative use of California rebates, and several demographic factors to better understand the leading edge of electric vehicle markets in California. Finally the top 30 California cities are analyzed in greater details based on their various government, utility, business, and advocacy electric vehicle promotion actions.

CALIFORNIA MARKET GROWTH

California plays a key role in the development of the U.S. electric vehicle market. California, although only about 12% of the U.S. auto market, represented about 54% of electric vehicle sales in 2015. As shown in Figure 1, including California and the additional states that adopt Zero Emission Vehicle (ZEV) regulatory requirements, the ZEV markets represented about 65% of the U.S. electric vehicle market in 2015. This progress in the development of the market is also seen on a local level. Examining the market growth locally, six of the nine major U.S. metropolitan areas with the highest share of new vehicles that are plug-in electric are in California (Lutsey, 2016). As compared to the projected ZEV program deployment in the last major regulatory provision (CARB, 2011), electric vehicle sales in 2015 are several years ahead of the overall schedule for fleet-wide compliance.

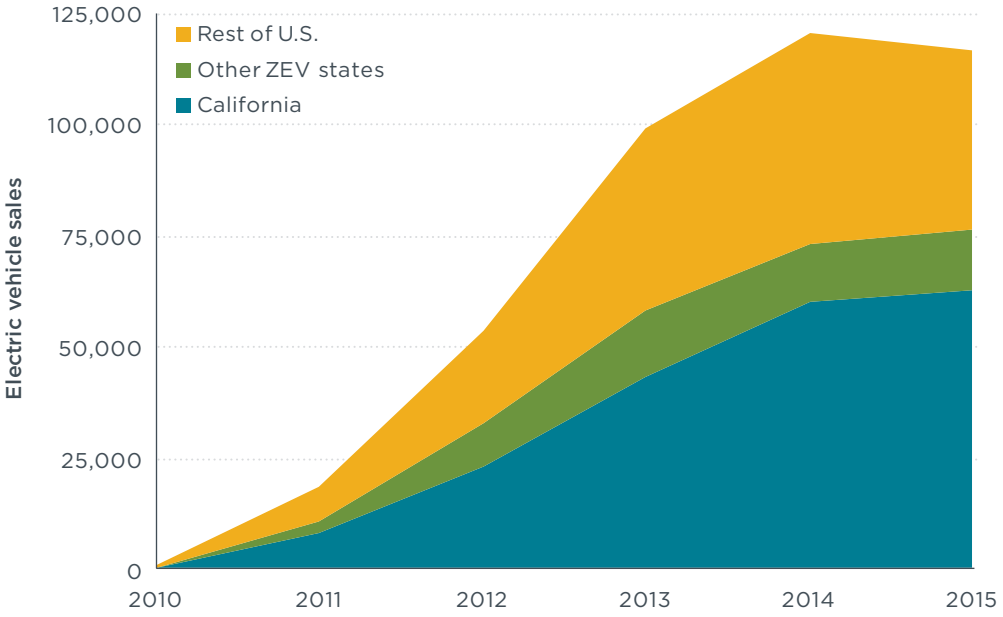

Figure 1. Electric vehicle sales in the U.S. from 2010 through 2015

Electric vehicle sales and model availability, as assessed below, are greater in California than the other states, including those that adopt California's ZEV regulation. To foster technology development and help control associated costs, the ZEV regulation allows manufacturers to focus early electric vehicle deployment in California, effectively

delaying major market introductions in the other ZEV states through 2017. Thus, many electric vehicle models are available for sale only in California, and manufacturers have invested comparatively less to date in marketing electric vehicles in the other ZEV states. Beginning in model year 2018, manufacturers will be required to place increasing numbers of electric vehicles in the ZEV-adopting states outside of California.

Our data source for electric vehicle uptake is IHS Automotive, which reports new light duty electric vehicle registrations by make and model and total new light duty vehicle registrations by city in California for the year 2015. We use this data to identify the top 30 California cities by the share of all new light-duty vehicle registrations that are battery electric or plug-in hybrid electric vehicles. For our statistical analysis of city-level electric vehicle uptake, we set a minimum of 2,000 total light duty vehicle registrations per city to avoid skewed results from cities with small sample sizes.

PUBLIC ELECTRIC VEHICLE CHARGING INFRASTRUCTURE

Public charger data is from the Department of Energy's (DOE) Alternative Fuel Data Center (AFDC, 2016). We downloaded this data in January 2016 to reflect the total number of charger outlets that were available in 2015. This dataset provides the city and address of each publicly available charger location with the number of Level 1, Level 2, and direct current (DC) fast charger outlets per location. We analyze public Level 2 and DC fast chargers for each city in this assessment and generally report on a per capita basis. Most electric vehicle users primarily rely on their home charging, followed by workplace and public charging (INL, 2015). This analysis is focused on public charging for its potential to increase the visibility, viability, and confidence to expand the use of electric vehicles. Data on workplace charging were not available for city-level analysis. Instead we analyze available information on workplace charging by metropolitan area from the U.S. DOE's Workplace Charging Challenge program.

ELECTRIC VEHICLE MODEL AVAILABILITY

Automakers make strategic decisions about where to deploy vehicles for sale, and lower-volume models are generally less likely to be substantially available at all dealerships. We used data on which electric vehicle models were newly registered in each city (from IHS Automotive) as an indicator of model availability. For example, if ten electric vehicle models were registered in a given city in 2015, we assume only those ten electric vehicle models were made available to prospective consumers in that city. Although vehicle consumers could purchase and register vehicles outside their city of residence, the total number of new electric vehicles models registered in each city within 2015 is a reasonable measure of the relative availability of electric vehicles. A spot check confirmed that in most cases, when no registrations were made for particular electric vehicle models in a particular city, the local dealerships did not offer that model. We also conducted informal phone interviews of staff at select dealerships about their electric vehicle promotion strategies. Other methods, for example, detailed counts of electric vehicles on dealership lots across cities throughout the year would provide a more thorough analysis of the availability, deployment, and marketing efforts to make more vehicles with preferred options available. (e.g., see Reichmuth and Anair, 2016)

DEMOGRAPHIC INFORMATION

There is a lack of clarity about how important income and other demographic factors might be in electric vehicle uptake to date (see, e.g., Sierchzula et al., 2015; Egbue and

Long, 2012; Hidrue et al, 2011; Lutsey et al, 2015). As a result, we collected and included several such variables in the analysis. We included the median household incomes of the California cities in the analysis, based on data from the California Department of Finance (2015a). In addition we sought to analyze the possibility of whether cities with particular household characteristics might be more or less likely to have higher electric vehicle uptake. A potential challenge, especially in more population-dense urban areas is the availability of off-street parking and charging in private or apartment garages. As a result, we sought to analyze whether areas with more detached homes—that is more likely to have garages, off-street parking, with chance for home charging—with data from California Department of Finance (2015b).

ELECTRIC VEHICLE PROMOTION ACTIONS

We considered a wide range of electric vehicle promotion actions that we found city governments and other groups were using to encourage electric vehicle uptake. The categories of promotion actions considered are listed in Table 1. We collected information on these actions from a review of websites for local governments and utilities as well as private electric vehicle interest groups for each city or region. The total number of these actions for each city is tallied in this assessment for the California cities with the highest electric vehicle uptake. Direct local fiscal incentives such as rebates were considered as one action for each category. We do not assess the total monetized policy benefit in this city-level study, as the state rebates impact all California consumers and many other factors like carpool lane access are more regional in nature.

In our cataloguing of local promotion actions, we consider all promotion actions that had occurred prior to January 1, 2016, including actions that occurred in 2014 or earlier. Promotion actions in earlier years could very plausibly affect electric vehicle uptake in 2015. Data sources for each city's actions are given in the Annex. We note that data for workplace charging availability is taken from participation in the DOE Workplace Challenge and from Google searches, but it is likely that other workplaces have installed chargers outside of the DOE program and have not issued press releases. We also recognize the limitations in analyzing these local promotion activities. As a practical limitation the promotion actions are only catalogued for the identified leading-edge cities, as described further below. All the activities are treated equally in our analysis. While some promotion actions likely have a larger effect on electric vehicle uptake than others, the relative effectiveness of each of these actions individually is not quantified here.

Table 1. Categories of electric vehicle promotion actions included in this study

City government	Regional government	Utilities	Nonprofits and media	Businesses
• City-owned public chargers • City-owned electric vehicles • Building codes require chargers • Streamlined charger permitting • Reserved parking at public chargers • Waived parking fees at meters • City electric vehicle strategy • Informational website • Outreach events	• Public Fleet Project • County-level fiscal incentives for electric vehicles • County-level building codes require chargers • Air quality management district (AQMD) electric vehicle rebate • AQMD charger rebate • AQMD outreach events	• Fiscal incentives for electric vehicles • Electricity rate discount for electric vehicles • Time-of-use electricity rates available for electric vehicles • Informational website	• Participation in Electric Drive Week • Other outreach events • Media coverage promoting electric vehicles	• Electric vehicle only dealerships • Electric vehicle company headquarters or manufacturing in city • Electric vehicle component manufacturing • Charger company headquarters • Electric vehicle only car sharing • Electric vehicle fleet purchases • Workplace charging

CALIFORNIA STATE REBATE

In this analysis we sought to investigate any differences in usage of the state electric vehicle rebate to assess patterns that might impact electric vehicle awareness and uptake. California's rebate program (CVRP) provides $1,500 for most plug-in hybrid electric models and $2,500 for most battery electric models. Data on California's CVRP is available through the Center for Sustainable Energy (2015). The available dataset lists rebate applications throughout the program from 2010 to present, including the application date, applicant type (individual, business or government), applicant zip code, and vehicle make. To assess the rebate claim rate, we compared the data for all CVRP applications filed in 2015 with all electric vehicle registrations reported by IHS, matching applicant zip codes in the CVRP data to cities. We note that eligible applicants have 18 months after the date of vehicle purchase to submit a CVRP application; it is thus likely that a time lag exists for some electric vehicle purchases. We do not attempt to account for the average delay period in this assessment of relative rebate uptake differences. Several modifications, including restrictions for high-income buyers and increased incentives for low-income buyers, have been made to the CVRP program in 2016 (CARB, 2016)

III. ANALYSIS

In this section, we first report on analysis of electric vehicle market of major California metropolitan areas as compared to those throughout the U.S. Using that as context, the following sections report specifically on analysis of California cities. The California city-level analysis includes identification of the cities with the highest electric vehicle uptake, a statistical regression of underlying factors contributing to electric vehicle uptake, and a deeper analysis of the underlying electric vehicle promotion activities in the top-30 California cities.

CALIFORNIA METRO AREAS IN OVERALL U.S. CONTEXT

To provide context for the deeper analysis, first several descriptive comparisons are noted that put the California city activities within a broader context. Figure 2 provides a summary of how major California metropolitan areas compare with the rest of U.S. areas in terms of their electric vehicle share of new vehicles and electric vehicle charging infrastructure network. As indicated in the figure, California metropolitan areas tend to stand apart from the rest of the U.S. regions in terms of electric vehicle uptake and public charging infrastructure per capita. Overall California electric vehicle uptake amounts to about half of U.S. electric vehicle sales. Electric vehicle sales in the metropolitan areas of Los Angeles, San Francisco, San Jose, and San Diego amount to about 20%, 11%, 8%, and 4%, respectively, of all U.S. electric vehicle sales. As shown, these four areas have 3 to 13 times the U.S. average electric vehicle uptake and 2 to 4.5 times the average U.S. public charging per capita.

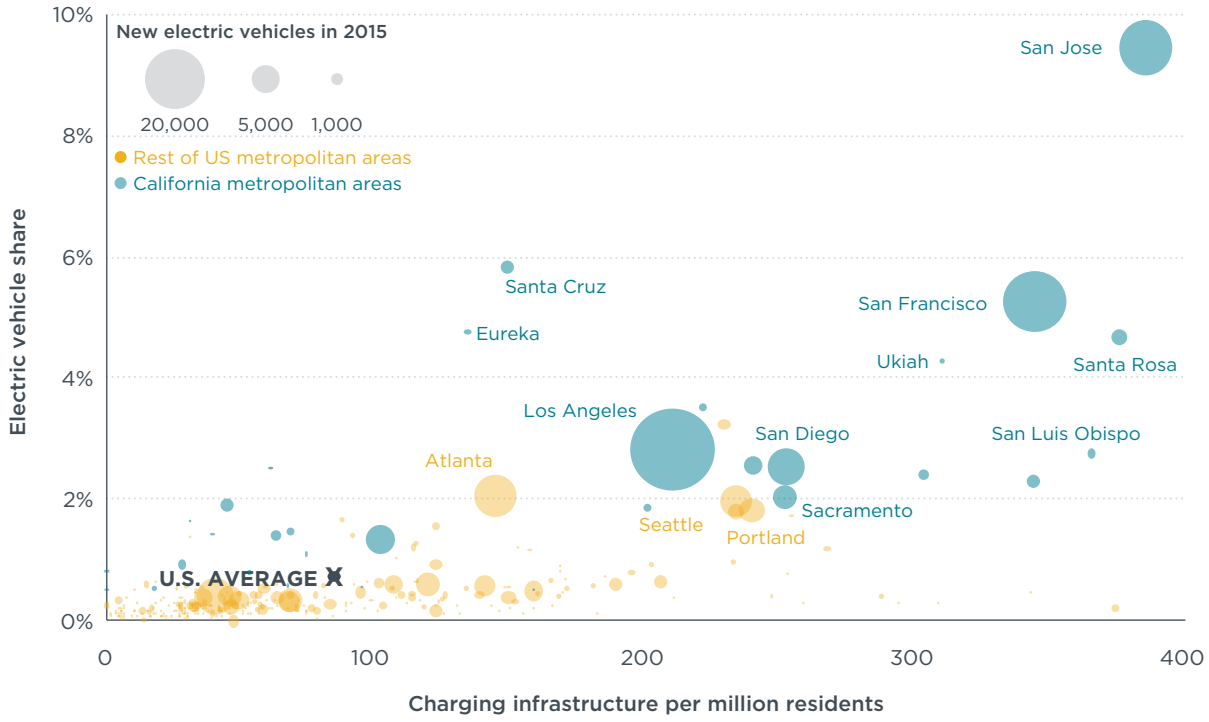

Figure 2. Electric vehicle share of new vehicle registrations and public charging infrastructure per capita in 2015, with selected U.S. metropolitan areas labeled (2015 electric vehicle registration data provided by IHS Automotive)

Public charging infrastructure has been recognized as a key factor for the growing electric vehicle market. Workplace charging is growing and can also provide a substantial amount of electric vehicle users' electricity needs when available (U.S. DOE, 2015; INL, 2015). As a result, we compared available public and workplace charging data. Figure 3 illustrates the relative deployment of public and workplace charging equipment in the 50 most populous U.S. cities (based on data from AFDC, 2016; Olexsak, 2016). These data reflect efforts to date by federal, state and local authorities to increase electric vehicle charging infrastructure deployment through a variety of different programs. As shown, California metropolitan areas are consistently among the leaders in public and workplace charging deployment. In particular the Los Angeles and San Francisco areas, with over 2,700 and 1,500 public charge points, respectively, have seen the installation of much more public charging than other cities. The San Jose area showed much greater workplace charger deployment than the rest, with over 1,400 charge points, based on data from the U.S. Department of Energy Workplace Charging Challenge program.

Figure 3. Public and workplace charging infrastructure deployment in 50 most populous U.S. metropolitan areas

The following sections report on the examination of the underlying reasons for the regional results shown above with a more granular city-level analysis of California cities. Most of the cities identified below are located within the major California metropolitan areas shown above in Figure 2 and Figure 3.

IDENTIFYING CALIFORNIA CITIES WITH THE HIGHEST ELECTRIC VEHICLE UPTAKE

To understand California cities' differing electric vehicle market growth, we compare the cities in terms of their electric vehicle uptake, as well as several underlying factors that may be contributing factors, including public charging infrastructure, model availability, use of the California rebate, income, and housing data. For this analysis of the markets with the highest uptake, California's leading-edge cities are defined as the 30 cities with the highest share of new vehicles that were battery electric and plug-in hybrid electric vehicles in 2015.

Figure 4 summarizes the data on California-city level electric vehicle uptake compared to electric vehicle model availability, identifying the 30 cities with the highest uptake. As shown, there are 30 California cities from 6% to 18% electric vehicle shares, which are 8 to 25 times that of the U.S. average in 2015. These vehicle markets range greatly in size, from hundreds of electric vehicle sales up to approximately 4,000 in the case of San Jose. Among these cities, 12 of them have electric vehicle shares above 10%.

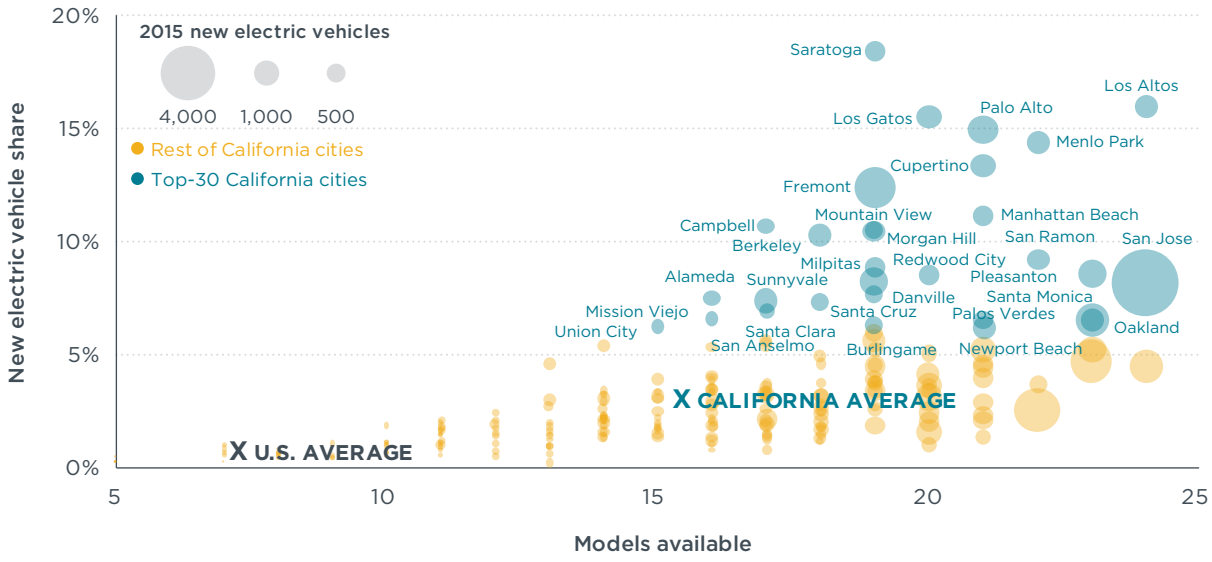

Figure 4. Electric vehicle share of new vehicle registrations and models available in California in 2015, with 30 California cities with the highest electric vehicle uptake labeled (2015 electric vehicle registration data provided by IHS Automotive)

This assessment of the number of electric vehicle models available shows a clear difference across markets regarding how many models consumers likely have access to. The California cities in general had about 15 electric vehicle models locally available on average, about double the average in U.S. metropolitan areas using the same size threshold of areas with at least 2,000 annual new light-duty vehicle registrations. The electric vehicle model availability in the top-30 California cities, as shown, tends to be greater than the California city average. Among these markets are many cities throughout Silicon Valley as well as many cities in the greater San Francisco and the greater Los Angeles areas. This shows how these smaller- and medium-sized cities have substantially higher electric vehicle uptake than California's largest cities of San Francisco (5%), San Diego (3%), and Los Angeles (2%).

Figure 5 illustrates California cities electric vehicle uptake as compared with public charging infrastructure per capita, again highlighting the 30 cities with the highest electric vehicle sales share. The U.S. and California averages are also shown in the figure for additional context. As shown, 27 of the 30 cities have higher-than-U.S.-average public charging, and 24 of those 30 have higher-than-California-average public charging infrastructure. The 30 high-uptake California cities have, on average, 5 times the charging infrastructure per capita than the U.S. average, yet how extensive the cities' public charging infrastructure is varies greatly. A few smaller cities in the top 30 have little to no charging infrastructure, while seven cities have over 1,000 charge points per million residents. Of note, Menlo Park has over 4,000 charge points per million residents and 14% electric vehicle share and is not shown on the figure. The disparity in these 30 cities' infrastructure availability largely dissipates when analyzed at the regional metropolitan area level. For example, 12 of the cities are in the San Jose area, 12 are in the San Francisco area, 5 are in the Los Angeles area, and 1 is in the Santa Cruz area—all of which have high charging infrastructure per capita (see Figure 2 above).

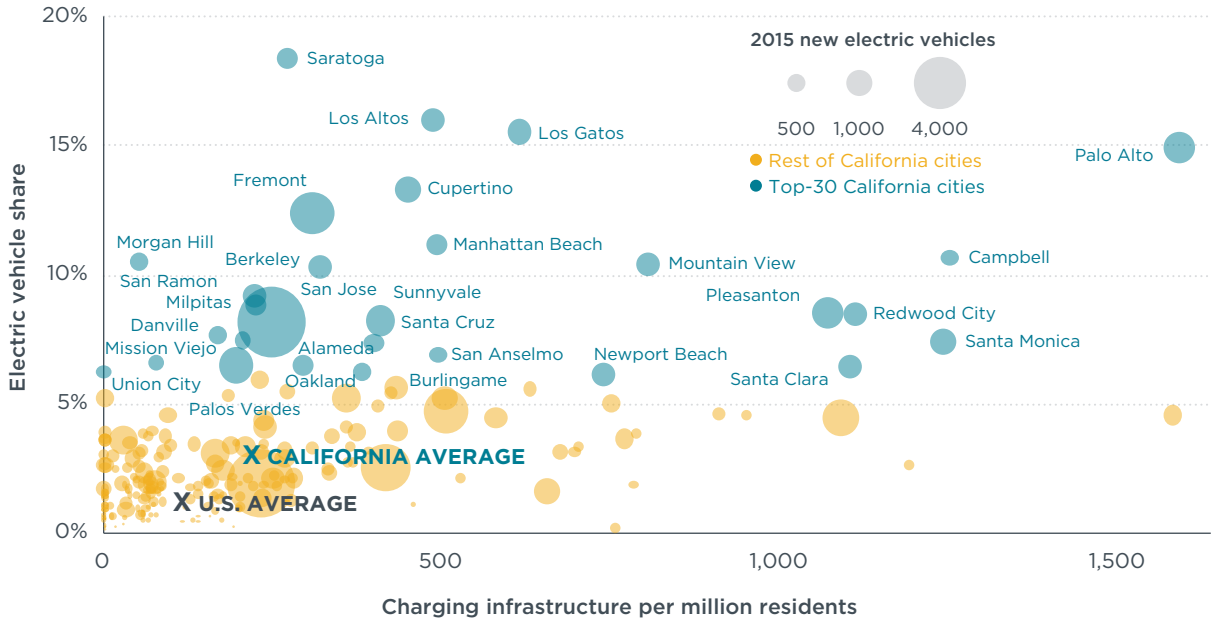

Figure 5. Electric vehicle share of new vehicles and public charging availability, with the 30 California cities with the highest electric vehicle uptake labeled

STATISTICAL LINK BETWEEN CHARGING, MODEL AVAILABILITY, AND UPTAKE

To better understand the potential contributing factors to California cities' uptake we conducted several statistical regressions among the variables mentioned above for the California cities that had greater than 2,000 new vehicles registered in 2015 (219 cities total). We analyzed the cities' electric vehicle share as the dependent variable, and considered independent variables of public charge points per capita, model availability, rebate claim rate, income, and housing (i.e., percent of housing that is detached, single-family units). For each multivariate regression, we began by including all of these independent variables. Rebate claim rate and housing were not significant

in the regressions ($p>0.05$[1] for these variables), and thus cannot be statistically linked to electric vehicle sales share. These variables were removed, and the results presented below are for regressions that included only statistically significant variables.

Three similar separate regressions yielded similar conclusions linking the variables. In the first multivariate regression, total electric vehicle sales share was positively correlated with electric vehicle model availability, public charging availability per capita, and median household income (p-values < 0.01, adjusted R-squared of 0.70). We found similar correlations for battery electric vehicles (p-values < 0.01, adjusted R-squared of 0.65) and for plug-in hybrid electric vehicles (p-values < 0.01, adjusted R-squared of 0.64) when assessed separately. From this, we find that the correlation between the public charging per capita, model availability, and median income and electric vehicle uptake is statistically significant among California cities.

The statistical results, as ever, are open to interpretation. One important aspect is that this study analyzes the above correlated variables more deeply than our previous work. By focusing only on California, this analysis removes the state rebate and the ZEV program as explanatory variables as these programs apply to all cities in this analysis, thereby allowing a more detailed assessment of the other potential underlying factors. Electric vehicle uptake and public charging infrastructure are routinely found to be linked (e.g., see Jin et al, 2014; Lutsey et al, 2015, Li et al, 2015) despite studies indicating home charging is much more heavily utilized. As a result, the availability of public charging, although it can sometimes be infrequently used, appears to still be important in growing the early electric vehicle market. A plausible interpretation is that even infrequent convenience charging is still important, as it can increase the functional vehicle range, and, even when seldom used, increase electric vehicle driver confidence to use the full existing range. Another interpretation is that the charger network increases general awareness, understanding, or comfort about the viability of the electric vehicles among prospective new buyers.

A potential complicating factor to this assessment of electric charging infrastructure is that electric vehicle owners in one city may be doing much of their public driving and non-home charging in surrounding cities. Therefore, *regional* or metropolitan area charging infrastructure could play a larger role in encouraging users to adopt electric vehicles. Many of the cities included in our analysis are located within close proximity to one another, facilitating trips in between them. For example, Los Gatos, which has one of the highest rates of new electric vehicle uptake, but relatively low chargers per capita, is located less than 30 miles from Palo Alto, Cupertino, and Redwood City, all of which have much higher charger density. This topic is included in the 30-city statistical evaluation below.

Interpreting the role of income is complicated due to several factors. The average U.S. new vehicle in 2015 was sold for approximately $33,000 (NADA, 2016). New car buyers generally are in a much higher income demographic with average household income of about $80,000 to $90,000, versus about $50,000 for the U.S. public at large (Wernle, 2015; Thompson, 2013). Luxury car buyers tend to be from households with median incomes that are considerably higher, generally around $110,000 in California (Sullivan, 2014).

1 Regressions are typically considered to be statistically significant when $p<0.05$.

Beyond being new vehicles, electric vehicle technology is currently more expensive upfront (i.e., before considering fuel savings) than conventional non-electric vehicles and therefore more accessible to affluent households. Considering there are limited electric models available, and several of the models with the highest sales, like the Tesla Model S and BMW i3 that are typically priced above $80,000 and $50,000, respectively, the early market is inherently linked to more luxury consumers. Notably, 8 of the 30 California cities with the highest uptake had median household incomes below $85,000, the approximate median new-car-buying household. The literature is mixed on how important income might be in electric vehicle purchasing behavior (see, e.g., Sierchzula et al., 2015; Egbue and Long, 2012; Hidrue et al, 2011; Lutsey et al, 2015). This analysis indicates there is a link between higher-median-income cities and their electric vehicle uptake; however, the various factors above suggest that the broader relevance beyond the early California electric vehicle market in 2015 is unclear. One potentially complicating factor is that we are comparing electric vehicle sales share with median income on a city level, but electric vehicle purchasers may have higher incomes than the median of the city in which they live. For this study, we did not have data on household income specifically for electric vehicle purchasers, and so were not able to analyze this issue more deeply.

Model availability is more self-explanatory. Available models are a prerequisite for sales of electric vehicles, and model availability, from multiple automobile companies offering more electric vehicle models, increases the chance for new consumer exposure to electric vehicles through marketing and at dealer showrooms. Model availability is analyzed here simply as the number of vehicle models that registered at least once in each city over the course of 2015. This variable offers an approximate measure of where consumers have had greater relative access to various electric vehicle models. Deeper analysis on electric vehicles physically available at dealership lots at multiple times within the year, and analysis of the relative marketing efforts across cities, were not available but would provide an improved understanding on the question about vehicle availability.

We also examined several variables that ultimately were not found to be statistically linked with electric vehicle uptake across the California cities. In particular, we investigated the rebate claim rate, or percent of California rebates granted per registered electric vehicles, but this was not found to be correlated with electric vehicle uptake. We had hypothesized that this variable might help us understand whether awareness about the rebates was linked with uptake (e.g., see Krause et al, 2013). Another hypothesis we tested was whether single-family, detached homes (as proxy for homes with garages), might be linked to electric vehicle uptake. However, the percent of homes that were single-family, detached homes in each of California cities was not found to be a significant factor in predicting electric vehicle uptake. Workplace charging was not analyzed because of limited data and an imperfect data match between workplaces in metropolitan areas and the city-level analysis, as mentioned above.

ELECTRIC VEHICLE PROMOTION ACTIONS IN CITIES WITH THE HIGHEST UPTAKE

As indicated above, factors like charging infrastructure and model availability are linked with electric vehicle uptake. To supplement these broader California findings, we sought a deeper understanding of the underlying electric vehicle promotion activities in the California cities with the highest electric vehicle uptake. These 30 high-uptake cities are investigated for various local actions as introduced above in Table 1, for 9 city-level government actions, 6 regional-level government actions, 4 utility level actions, 3

nonprofit and media activities, and 7 business actions to support electric vehicles. Note that there is some inherent ambiguity in these categories, as some actions engage cities, counties, and regional entities, and other actions involve business and governments together. This locally focused study excludes the overall state-level actions that are applicable to all the California cities that we had previously analyzed (Lutsey et al, 2015).

Figure 6 summarizes the results regarding local electric vehicle promotion activities across the 30 California cities with the highest electric vehicle uptake. The figure shows the cities from the left to right in terms of highest (18%) to lowest (6%) electric vehicle share (right axis). The cities' number of local electric vehicle promotion actions range from as low as 3 to 5 in the cases of Saratoga, Newport Beach, and Union City—and up to 12 and 13 in the cases of Palo Alto and San Jose, respectively (left axis). The two largest cities by population, San Jose and Oakland, had among the most city actions, whereas many smaller cities like Saratoga and Burlington generally had fewer actions.

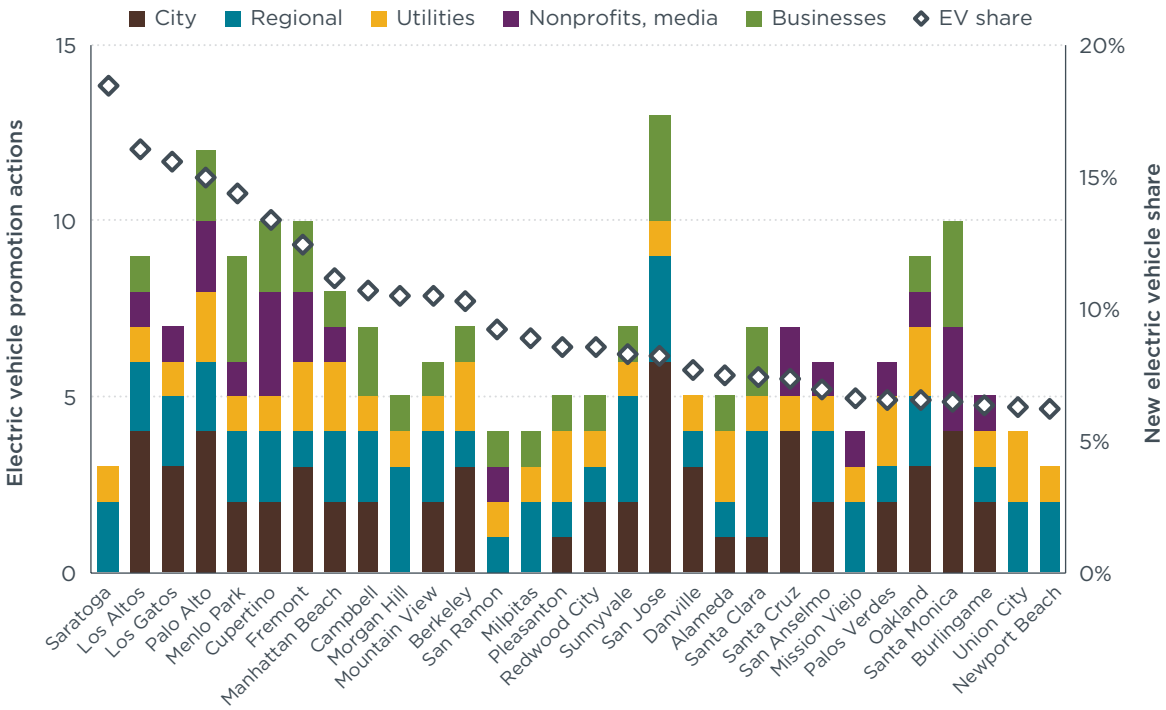

Figure 6. Electric vehicle promotion actions (left axis) and new electric vehicle share (right axis) in California cities with the highest electric vehicle uptake (2015 electric vehicle registration data provided by IHS Automotive)

We conducted a targeted statistical regression analysis on these 30 cities to analyze the effect of electric vehicle promotion actions on electric vehicle uptake in the top 30 cities. As with the regression described above on the broader set of Californian cities, we analyzed electric vehicle sales share as the dependent variable, and tested the following independent variables: public charge points per capita, model availability, rebate claim rate, income, and housing, along with electric vehicle promotion actions. As above, we removed independent variables that were not found to be statistically significant in the regression ($p>0.05$). The results presented below are for regressions that only include statistically significant variables ($p<0.05$).

Unlike above for the broader analysis, the link between public city-level charging per capita and electric vehicle uptake within this narrow 30-city dataset was not found to be statistically significant. However, acknowledging that many drivers regularly travel within their broader metropolitan areas, we analyzed charge points per capita at a metropolitan area level. For example, the 12 cities among the 30 cities that are in the San Jose metropolitan area are each analyzed as having 379 public charge points per million residents (from Figure 2), rather than their city-level values (in Figure 5). When we included metropolitan area charging per capita as an independent variable instead of city-level charging per capita, overall there was a reasonable and statistically significant correlation between electric vehicle sales share and local actions, income, and metropolitan area charging per capita (p-values < 0.05, adjusted R-squared 0.52). The regression analysis indicates that promotion actions are significantly positively correlated with new electric vehicle uptake. As above, income is positively correlated with new electric vehicle uptake. Model availability, rebate claim rate, and housing were not found to be statistically significant in this analysis of the top 30 Californian cities.

While we cannot determine causality through this analysis, it appears to be evident that the total number of local electric vehicle promotion actions by governments and other groups is linked with increased electric vehicle uptake. We repeated this analysis separately for (a) only new battery electric vehicles, and (b) only new plug-in hybrid electric vehicles, and found that the regression is significant for the former category (p-values < 0.02, adjusted R-squared 0.56) but not the latter. Thus, it appears that battery electric vehicle uptake may be more closely linked with electric vehicle promotion actions than plug in hybrid uptake.

This assessment finds that in some cities, a combination of city and regional governments, utilities, businesses, nonprofit advocacy groups, and media are contributing to a high number of electric vehicle promotion actions. Palo Alto (ranked 4th by new electric vehicle share) and San Jose (18th) registered the highest number of promotion actions at 12 and 13, respectively. Others like Los Altos (2nd), Menlo Park (5th), Cupertino (6th), Fremont (7th), Oakland (26th), and Santa Monica (27th) also were relative leaders in electric vehicle promotion. As indicated in the section above, all the top-30 cities had high electric vehicle model availability compared to the California average, and much higher electric vehicle model availability than the U.S. average.

For all these high electric vehicle uptake cities, there was a mix of public and private sector actors contributing to electric vehicle promotion activities in 2015. For example, promotions in Palo Alto included a city requirement that all new buildings be wired for easy charger installation, the Bay Area AQMD electric vehicle rebate, time-of-use electricity rates for electric vehicle owners (which allows consumers to save money by charging up with lower rates at night), a local Tesla-only car sharing service (Vukee), and hosting an Electric Drive Week event.

Within the top 30 California cities assessed here, we found that some regional government actions provide direct financial support for electric vehicle and charger purchases. Examples include AQMD rebates, the Marin county rebate, and California's Public Fleet Project, which replaces CVRP with higher rebates in high pollution cities. However, we found that no city governments on our list provide direct fiscal incentives to electric vehicle consumers. This finding aligns with our hypothesis that governments of smaller cities have more limited financial resources, and it is more difficult for them to provide direct financial support. On the other hand, this result highlights that

small- and medium-sized California cities are finding other creative ways to promote electric vehicles, and our analysis suggests that these promotion actions are effective. In addition, non-government actors are making a significant contribution to actions that encourage electric vehicle uptake.

Holding electric vehicle events, hosting information websites, and publishing news articles that highlight electric vehicles can raise general awareness and understanding, as well as produce potential network effects. The idea here is that as electric vehicles appear to become more mainstream, the majority of consumers who are initially averse to jumping into new technologies will gradually increase their understanding and become more willing to try them with more exposure (see Morton et al., 2011; Axsen & Kurani, 2011; Lin & Greene, 2010). A basic example is that if a person's neighbors own electric vehicles, that person is more likely to investigate, test drive, and purchase one. Another example is fleet purchases. For example, Santa Rosa appeared to have a substantial amount of electric vehicle purchases, and this can also greatly increase the public profile and viability in technology for prospective buyers with no exposure otherwise. Actions that exhibit and educate the public about electric vehicles can bring the technology toward the mainstream. And of course, with city electric vehicle shares above 10% in 12 California cities, such effects are increasingly likely, and perhaps underway in particular localities.

CALIFORNIA REBATE CLAIM RATE

As noted above, the rebate claim rate was not found to be a significant factor in predicting higher electric vehicle uptake across cities. Nonetheless, the rebate claim rate data were also analyzed for a potential link to automaker brands and their particular electric vehicle models. We compare the number of CVRP applications with the number of new electric vehicle registrations in 2015, and we find that approximately 75%-80% of eligible new battery electric vehicle owners and 60%-70% of new plug-in hybrid electric vehicle owners applied for the California rebate. These ranges are provided due to the uncertainty regarding when the rebates were applied for (up to 18 months after the sales) and when the rebate was granted (within 3 months). These percentage ranges are broadly consistent over multiple years, suggesting these are reliable trends. Why one quarter of new electric vehicle owners are apparently not claiming the rebate is unclear. The additional time and paperwork involved if rebates are claimed after the sale, instead of at the point of sale, could be a factor. This also indicates that there could be a lack of dealer engagement about this incentive, as any dealer would presumably want to market the rebate and highlight this to help make a new electric vehicle sale. This mixed use of rebates could indicate how those electric vehicle buyers that are more motivated by the incentives apply for them, whereas those that did not apply for the rebate clearly did not need the rebate to decide to buy the vehicle. Another factor could be that various leasing programs by particular companies might lead more customers to leases that are not eligible for the rebate because they are less than 30 months.

The estimated percentage of new electric vehicle owners who claimed California's electric vehicle rebate in 2015 varied substantially by vehicle make. Figure 7 shows the rebate claim rate for each vehicle make for which there were at least 50 new registrations in the 30 top cities. The share of each make in the total California electric vehicle market is also shown for context. Overall, battery electric vehicle consumers are apparently more likely to claim the rebate compared to plug-in hybrid electric vehicle consumers—this effect could be due at least in part to the lower value of

the plug-in hybrid rebate ($1,500) compared to the battery electric vehicle rebate ($2,500). The rebate claim rate was generally similar for the top 30 cities compared to California as a whole.

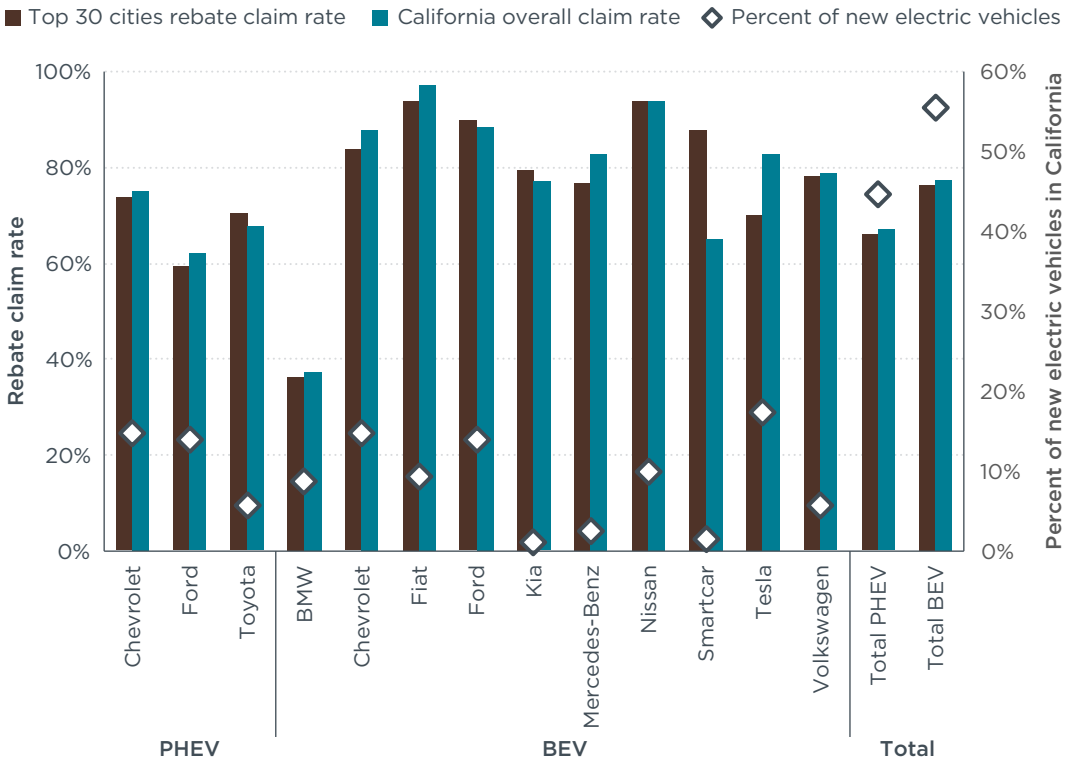

Figure 7. CVRP rebate claim rate (left axis) for major electric vehicle makes and share of each make in total new electric vehicles in California (right axis) (2015 electric vehicle registration data provided by IHS Automotive)

Automakers with larger shares of California electric vehicle sales, such as Tesla, Nissan, Ford, and Chevrolet, tended to have higher rebate claim rates, especially for battery electric vehicles. It is possible that automakers selling high volumes of electric vehicles may tend to train dealership staff to inform customers about the rebate. In interviews with two Tesla dealerships in cities on our list, we were told that Tesla Delivery Specialists are trained to educate customers about rebates for which they are eligible. As Tesla only sells electric vehicles, this type of knowledge would apply to all their sales. Interviews with Nissan, Ford, and Chevrolet dealerships in cities with high sales of these makes likewise revealed that staff at these dealerships are trained to inform customers about the rebate and assist with paperwork if necessary. Looking at particular models, there was some indication that higher priced, lower-volume luxury models (e.g., BMW i3, Cadillac ELR, and Mercedes-Benz S-class) tended to have especially low rebate claim rates. Tesla appears to break the trend, having a relatively high rebate claim rate for its price range, perhaps due to Tesla staff being well informed about the rebate. There is also a chance that two-year vehicle leases, which are ineligible for rebates, are more common for some brands. Web searches revealed, for example, that many BMW dealerships offered 24-month leases for the i3 model, which had the lowest claim rate above.

SUMMARY DISCUSSION

Figure 8 summarizes several key variables for the 30 California cities with the highest new electric vehicle shares. As shown the cities each have some clear differences in terms of their adopted electric vehicle promotion actions and charging infrastructure. Cities like Saratoga, Newport Beach, and Union City had just 3 to 5 actions, where as Palo Alto and San Jose had 12 and 13 local actions in place. Common to most of these cities, but not shown in the figure, these cities all had high electric vehicle model availability.

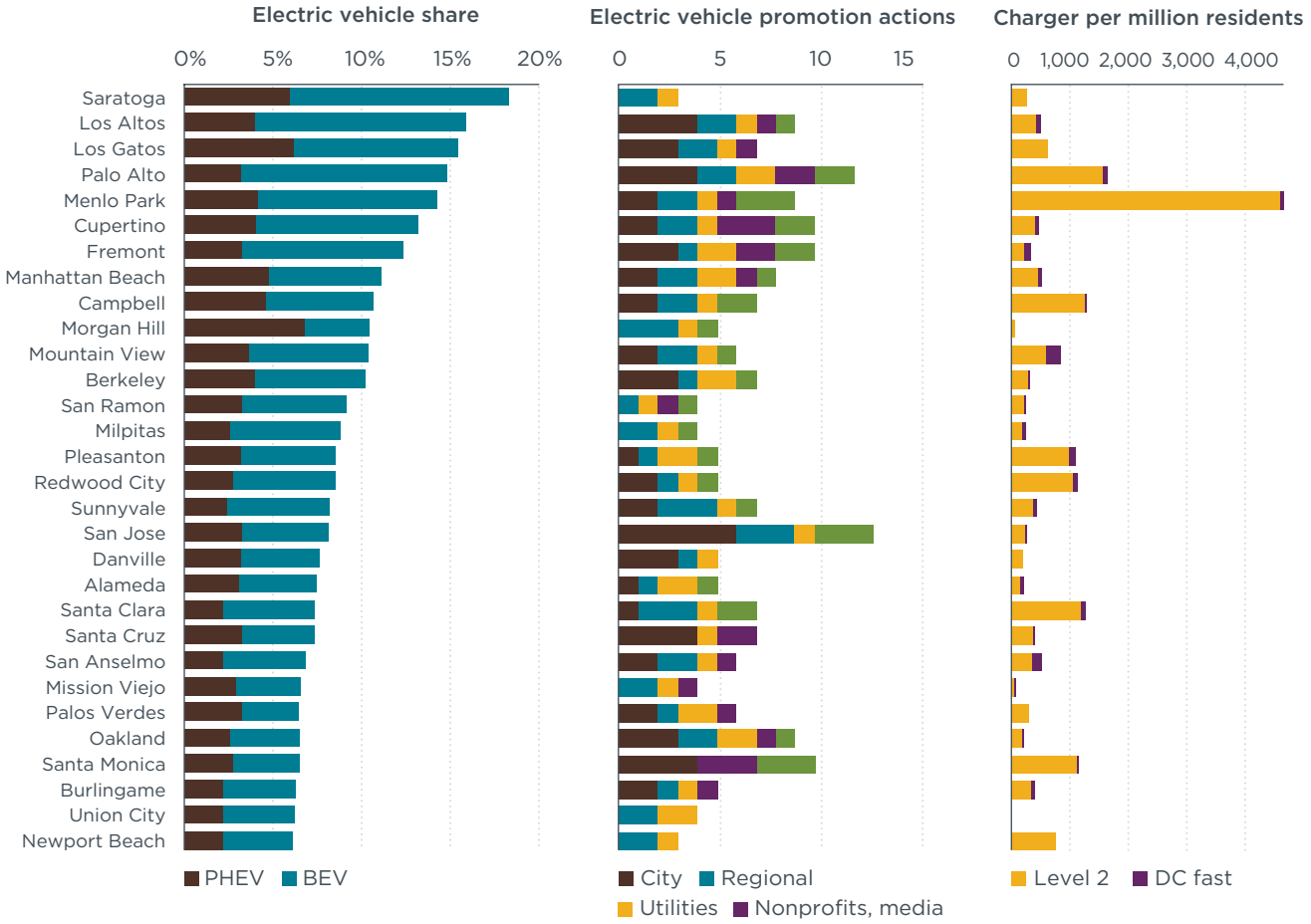

Figure 8. New electric vehicle share, number of electric vehicle promotion actions, and public chargers per million residents in the 30 California cities with the highest electric vehicle uptake (2015 electric vehicle registration data provided by IHS Automotive)

We conclude the analysis section with a series of anecdotes that might help point to future areas of research. Within this research, we analyze city-level, and metropolitan-area level public charging per capita. We find some evidence in the 30-city analysis that city-level charging per capita might be somewhat helpful in identifying relative charging density; however, regional level charging availability might be more relevant to acknowledge broader commuting and public charging patterns. The greater San Jose metropolitan area is the highest in California in terms of public chargers and workplace chargers per capita. This study focused on public charging, but deeper analysis of the growing role of workplace charging and home charging availability is warranted. This

analysis did not find evidence that a higher fraction of detached single-family housing was linked to electric vehicle uptake. Improved future analysis of housing factors (e.g., houses with private garages versus multi-unit buildings) could be useful. Detailed, time-series analysis might offer deeper insights into questions of causality between charging infrastructure and electric vehicle uptake in the future.

Typically most California cities have relatively high availability of electric vehicle models, as a clear result of the Zero Emission Vehicle program, as well as the many other statewide and local actions throughout the state. Within the California market there are far more electric vehicle models available in larger cities. Dealerships are more likely to be clustered in and around major cities so this could partially explain some of the variation within California. The associated dynamics of dealer activities including electric vehicle availability, marketing, and dealer training are relatively unexplored with just a few studies to date (see, e.g.. Cahill et al, 2014).

The findings on income point to several potential implications. Higher income is found to be among the factors that are linked to higher electric vehicle uptake. This makes sense, as electric vehicle models are relatively new and costly in 2015. But battery costs continue to drop to make the technology more affordable. Cities with median incomes below $85,000 might be more indicative of the growing mainstream electric vehicle market. Cities like Berkeley, Alameda, San Jose, Santa Cruz, and Oakland offer such examples. These cities have a broader mix of Nissan Leaf, Ford C-Max Fusion Energi, Chevrolet Volt, and Volkswagen e-Golf sales (as compared with some cities where the Tesla Model S was the highest-selling electric vehicle at over a third of electric vehicles). It would seem that policies that especially promote lower-cost electric vehicles, and incentives for less affluent customers, might be important going forward. California's latest CVRP revisions are headed in that direction (CARB, 2016).

Within the data, there are several such unexplored anomalies where particular models are much more dominant in local markets. Surely there are untold stories about a dealer engagement program, a local outreach campaign, or some other local or neighborhood activity that have been successful and could be further assessed. An open question is to what degree electric vehicle uptake above 10%, as indicated above for several cities, might suggest something more is going on in these communities. Although this analysis had no way to analyze it, speculatively, word-of-mouth communication or social network effects could be at play. Another broader question is whether there are other fundamental variables, unknown and unexplored here, that might be at the heart of consumer demand or automaker and dealer decisions about electric vehicle deployment.

IV. CONCLUSIONS

This study analyzes the California electric vehicle market in 2015 to discern best-practice policy and promotion activities to spur electric vehicle uptake. The analysis finds that there are 30 California cities with from 6% to 18% share of new vehicles that are plug in electric. These levels of electric vehicle uptake are 8 to 25 times the U.S. average in 2015. The analysis finds a link between electric vehicle uptake and many underlying factors—including electric vehicle model availability, public electric vehicle charging network, and local promotion activities for electric vehicles (e.g., outreach events, informational websites, electric car sharing services, and government and fleet programs). However, some factors analyzed here (rebate claim rate, percentage of homes that are detached single-family homes) were not found to be statistically linked with electric vehicle uptake in our analysis.

Based on this analysis, we draw several conclusions about underlying factors that are helping to drive the development of the electric vehicle market in California. Our findings indicate that comprehensive policy support—like the Zero-Emission Vehicle program, incentives, charging infrastructure, and local actions—is helping create the electric vehicle market in California. The cities with the highest electric vehicle shares have seen the implementation of abundant, wide-ranging electric vehicle promotion programs involving parking, permitting, fleets, utilities, education, and workplace charging. These cities tend to have about 20 electric vehicle models locally available, far more than generally is the case across other U.S. cities, as well as other California cities. The electric vehicle market continues to grow where public and workplace charging infrastructure is the most extensive.

With its sustained and widespread commitments to electric vehicle support, California provides a template for such state and local activities that reach more businesses and prospective consumers, and these activities may be effective at encouraging electric vehicle sales. Our findings suggest that California's playbook could be a helpful example to other regions seeking to encourage electric vehicle uptake.

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ANNEX: ADDITIONAL DATA SOURCES

Table A. Data sources for electric vehicle promotion actions in each of the cities assessed in this study

City	City government	Regional government	Utilities	Nonprofits and media	BUSINESSES
Saratoga		Brown (2013); California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)		
Los Altos	Center for Sustainable Energy (2016); Charge Across Town (2016); City of Los Altos (2013); Municode, 2016)	Brown (2013); California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)	Champion (2012); EV World (2013)	Slingshot Power (2016)
Los Gatos	Center for Sustainable Energy (2016); McDonald (2013); Peterson (2013)	Brown (2013); California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)	Silicon Valley Clean Cities (2015)	
Palo Alto	City of Palo Alto (2015; 2016); Charge Across Town (2016)	Brown (2013); California Air Resources Board (2016)	City of Palo Alto (2016); Pacific Gas and Electric Company (2016)	Charged (2012); National Drive Electric Week (2016); Nextdoor (2015)	DeMorro (2014); USDOE (2016)
Menlo Park	City of Menlo Park (2015; 2016)	California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)	Grady (2015)	Ramsey (2015); SDOE (2016); Wikipedia (2016a)
Cupertino	City of Cupertino (2016); Myllenbeck (2015)	Brown (2013); California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)	Edelstein (2014a,b); Electric Vehicle Entrepreneurs of Silicon Valley (2016); National Drive Electric Week (2016)	Center for Sustainable Energy (2016); Electric Movement (2016)
Fremont	Center for Sustainable Energy (2016); City of Fremont (2015; 2016)	California Air Resources Board (2016)	California Air Resources Board (2016); Pacific Gas and Electric Company (2016)	EVgo (2016)	USDOE (2016); Wikipedia (2016b)
Manhattan Beach	City of Manhattan Beach (2016); Daily Breeze News (2013)	California Air Resources Board (2016)	California Air Resources Board (2016)	Phoenix Cars (2015)	Perry (2014)
Campbell	Center for Sustainable Energy (2016); Van Ells (2014)	Brown (2013); California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)		Tilley (2014); USDOE (2016)
Morgan Hill		California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)		Ecosparc (2016)
Mountain View	City of Mountain View (2016)	Brown (2013); California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)		Glover (2014)
Berkeley	City of Berkeley (2016a,b)	California Air Resources Board (2016)	California Air Resources Board (2016); Pacific Gas and Electric Company (2016)		Chao (2013)
San Ramon		California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)	T&D World Magazine (2015)	USDOE (2016)
Milpitas		Brown (2013); California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)		Center for Sustainable Energy (2016)
Pleasanton	Rose (2012)	California Air Resources Board (2016)	California Air Resources Board (2016); Pacific Gas and Electric Company (2016)		USDOE (2016)

City	City government	Regional government	Utilities	Nonprofits and media	BUSINESSES
Redwood City	City of Redwood City (2015)	California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)		Center for Sustainable Energy (2016)
Sunnyvale	City of Sunnyvale (2012); Wilson (2013)	Brown (2013); California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)		USDOE (2016)
San Jose	Center for Sustainable Energy (2016); Charge Across Town (2016); City of San Jose (2016); Newsom (2011)	Brown (2013); California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)		Center for Sustainable Energy (2016); USDOE (2016); Wrightspeed Powertrains (2016)
Danville	Center for Sustainable Energy (2016); Town of Danville (2016); Walsh (2015)	California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)		
Alameda	City of Alameda (2016)	California Air Resources Board (2016)	California Air Resources Board (2016); Pacific Gas and Electric Company (2016)		USDOE (2016)
Santa Clara	Center for Sustainable Energy (2016); Haugh (2013)	Brown (2013); California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)		Center for Sustainable Energy (2016); USDOE (2016)
Santa Cruz	City of Santa Cruz (2016,n.d.); MB-PEVCC (2013)		Pacific Gas and Electric Company (2016)	National Drive Electric Week (2016); Santa Cruz Chamber of Commerce (2014)	
San Anselmo	California Air Resources Board (2016); Suwanee (2012)	California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)	Suwanee (2012)	
Mission Viejo		California Air Resources Board (2016)	California Air Resources Board (2016)	City of Mission Viejo (2011)	
Palos Verdes Peninsula *	City of Rancho Palos Verdes (2016a, 2016b)	California Air Resources Board (2016)	California Air Resources Board (2016)	Davs (2011)	
Oakland	Center for Sustainable Energy (2016); Oakland Airport (2011); Newsom (2011)	California Air Resources Board (2016)	California Air Resources Board (2016); Pacific Gas and Electric Company (2016)	Kinman (2015)	USDOE (2016)
Santa Monica	California Air Resources Board (2016); Center for Sustainable Energy (2016); City of Santa Monica (2016a,b)			National Drive Electric Week (2016); Santa Monica EV Club (2016)	Center for Sustainable Energy (2016); Santa Monica Electric Vehicles (2016); USDOE (2016)
Burlingame	City of Burlingame (2015); Swartz (2014)	California Air Resources Board (2016)	Pacific Gas and Electric Company (2016)	Metropolitan Transportation Commission (2014).	
Union City		California Air Resources Board (2016)	California Air Resources Board (2016); Pacific Gas and Electric Company (2016)		
Newport Beach		California Air Resources Board (2016)	California Air Resources Board (2016)		

** Palos Verdes Peninsula includes Palos Verdes Estates, Rancho Palos Verdes, Rolling Hills Estates*

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