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**Article**

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# Impact of Electric Vehicle Adoption on Electricity Consumption and Generation: Evidence from California

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**ABSTRACT**

The market share of electric vehicles (EV) is growing in the USA, and there are substantial numbers of federal, and state-level incentives for EV consumers. These incentives are in place primarily due to environmental concerns. This study focuses on two interrelated aspects of EV adoption. First, using monthly county-level data from 2010 to 2019, this study reveals that electric vehicles and their supportive infrastructures, such as charging stations, have a significant effect on residential and commercial electricity consumption in California. Second, analyzing electricity generation information by county, this study finds a significant negative relation between electricity usage and the share of electricity that comes from renewable sources. Although EVs emit lower pollutants than conventional vehicles, they require a significant amount of electricity for charging. If the electricity generation doesn't involve renewable or cleaner sources, public spending on EV may not contribute to a cleaner environment as much as expected.

**Keywords:** Electric Vehicle Adoption, Residential and Commercial Electricity Consumption, Renewable Electricity Generation
**JEL Classifications:** D04, Q58

## 1. INTRODUCTION

The United States is the third-largest electric vehicle (EV) market, following China and Europe. The State of California alone accounted for half of all new 2019 electric vehicle sales in the USA. Federal and state-level actions, including regulations, financial and non-financial incentives for consumers, charging infrastructure development, and consumer awareness programs, are playing an essential role in increasing EV adoption. These incentives are important because upfront purchase cost is a barrier (Bui et al., 2020). Apart from federal incentives, 40 states currently have their own EV incentive, rebate, or emission control programs (Alternative Fuel Data Center, 2020). The government is trying to promote electric vehicles, mostly due to environmental concerns (Center for Climate and Energy Solutions, 2012).

However, this study shows that EV adoption increases residential and commercial electricity consumption significantly and the excess electricity generation is negatively related to renewable energy sources. Based on our analysis, 1% increase of EV charging connectors increases monthly residential and commercial electricity consumption by 0.012% in California. Besides, a 1% increase in electricity consumption is associated with 0.34% of the decrease in the renewable electricity share. Nevertheless, discussion about the increased electricity demand due to EV and its supporting infrastructure is not addressed in an environment friendly way at California's policy level so far. If this issue is not addressed carefully, there will be unintended consequences on public spending and, most importantly, on the environment.

The U.S. Department of Energy (DOE) advocates that increasing passenger vehicle efficiency and reducing the use of petroleum-based fuels can reduce consumers' fuel costs, support the domestic industry, minimize pollution, and increase energy security (U.S. Department of Energy, 2014, p.7). The DOE supports EV as a solution for the challenge of providing affordable, clean, secure transportation. The government also supports plug-in-hybrid vehicles (PEVs) that are powered at least in part by electricity.

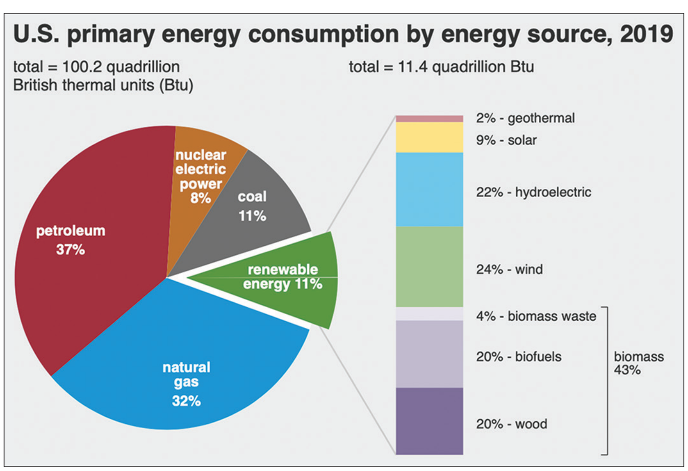
On September 8, 2011, Energy Secretary Steven Chu announced the Clean Cities Community Readiness and Planning for Plug-In Electric Vehicles and Charging Infrastructure awards. These awards helped communities forge public-private partnerships to take strategies to support the adoption of PEVs and charging infrastructure installation. These 16 awards, totaling $8.5 million, helped prepare 24 U.S. states and the District of Columbia to adopt PEV technologies to reduce U.S. petroleum dependence and build the foundation for a clean transportation system (U.S. Department of Energy, 2014).

While the changes towards electric energy sources represent a positive change, that progress is diminished by the fact that coal, natural gas, and nuclear fuels are still the most-used electricity generation sources nationwide. Natural gas and, to a certain extent, and shale oil remain relatively cheap and reliable energy sources. Despite the prevalence of non-renewable fuels, electric power can also be derived from renewable sources, including wind power, hydropower, and solar power (U.S. Energy Information and Administration [EIA], 2020). Below two figures show the energy generation share and trend by sources.

Figures 1 and 2 show that electricity generation still relies mainly on fossil fuel, primarily responsible for emitting the major air pollutants in the USA. US Department of Energy report contends, "Power plants are the largest source of sulfur dioxide ($SO_2$) emission in the United States. Power generation from fossil fuels, biomass, and waste contributes to air pollutants that adversely impact human health and the environment" (Oak Ridge National Laboratory, 2017, p vii).

This study quantifies the increase of electricity consumption due to EV adoption and reveals how the increased electricity consumption is associated with more non-renewable electricity production at the county level. This study consists of two major parts. First, using county-level monthly data from California for the year from 2010 to 2019, this study estimates the effect of EV adoption on residential and commercial electricity consumption. By employing fixed-effect panel regression, this study finds that 1% increase in electric vehicle charging connectors significantly increases the residential and commercial electricity consumption per county by 0.012%. Second, after establishing the relationship between EV adoption and electricity consumption, this study explores the electricity generation pattern by sources, especially whether there is any significant relationship between excess electricity consumption and renewable electricity generation. By analyzing 10 years of electricity generation information in California, this study finds an increased electricity consumption associated with a significant reduction of renewable energy share.

**Figure 1:** U.S primary consumption of electricity share[1] by sources in 2019.




1. Sum of the components may not equal to 100% due to independent rounding
1 Btu= 0.293071 Watt-hour
Source: U.S Energy Information Administration, Monthly Energy Review, Table 1.3 and 10.1, April 2020, Preliminary data

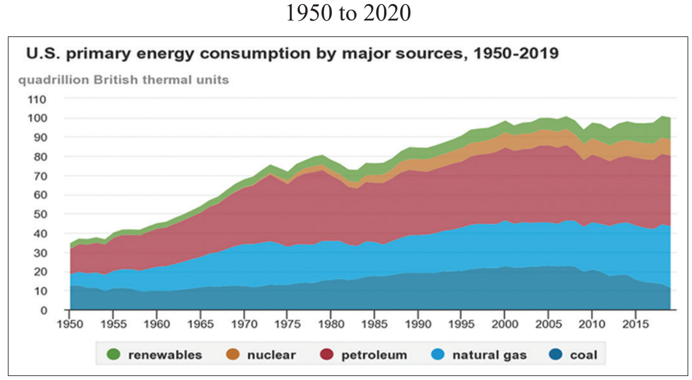
The rest of this study is organized as follows: first, I give a brief literature review in section 2. Section 3 presents an overview of the data, and section 4 discusses the model specification. I offer the result of our analysis in section 5 before concluding in Section 6, along with discussions of the limitations of this study.

## 2. LITERATURE REVIEW

There are numbers of studies about EV adoption focused on purchasing patterns due to incentives using various consumer choice models (Ferdousee, 2020; Liu and Cirillo, 2017; Østli, et al., 2017). Also, studies about electricity consumption due to the adoption of new technologies are available. Su (2019), in his research about residential electricity demand in Taiwan, found that the effects of urbanization and energy poverty have a significant positive impact on energy consumption. He used Air cooler (AC) as an exogenous variable to account for the differences between urban and rural areas. Hung and Huang (2015) also estimated the same relationship using dynamic panel data.

Nevertheless, unintended consequences due to EV incentive policies are documented. Holtsmark and Skonhoft (2014) studied Norwegian subsidy policies for EV purchasers and concluded that the sales of EVs in Norway increased rapidly as a result of these policies. Due to the subsidies, driving an EV implies very low costs to the owner on the margin, probably leading to more driving at the expense of public transport and cycling. Moreover, because most EVs' driving range is low, the policy gives Norwegian households incentives to purchase a second car, again stimulating the use of private vehicles instead of public transport and cycling. This

**Figure 2:** U.S primary energy consumption by major sources from 1950 to 2020



study also analyzed the emission level due to the production of two models of EVs and their batteries. All of these lead to more pollution. The authors concluded that the EV policy could not be justified.

Moreover, there are several studies of the environmental engineering field that are relevant to this study. For instance, Foley et al. (2012) examined the Irish government's target in 2008 that 10% of all vehicles in the transport fleet be powered by electricity by 2020. The study confirms that charging EVs will contribute 1.45% energy supply to the 10% renewable energy in transport target, which also contributes to a certain amount of $CO_2$ because of coal and gas-based electricity generation.

The findings of this study complement the studies which argue that EVs are not "zero-emission" vehicles. They may produce significant emission during manufacture, and instead of tailpipe emissions, they shift them to other locations like power plants (Hawkins et al. 2012). Nicholas et al. (2015) estimate to what extent PEVs are more environmentally friendly than conventional passenger cars in Texas, controlling for the emissions and energy impacts of battery provision and other manufacturing processes. Their study indicates that outcomes depend heavily on the electricity generation process, power plant locations, and vehicle use decisions. Results indicate that PEVs on today's grid can reduce some types of pollutants in urban areas but generate significantly higher emissions of $SO_2$ than existing light-duty vehicles. A primary concern for PEV growth is the use of coal for electricity production. Anair and Mahmassani (2012) note that PEVs can pollute more than some of the conventional vehicles when fueled by "dirtier" electricity grids (powered mostly by coal). They suggest that in some locations like Colorado and the U.S.'s Midwest driving an efficient (gasoline-powered) hybrid-electric vehicle will emit less GHG than driving a PEV. However, they also note that places like the Pacific Northwest, which sources a large portion of electricity from non-emitting hydroelectric dams, enjoy very low per-mile GHG emissions relative to conventional vehicles.

This paper differs from the existing literature which claims that in most cases, the adoption of EV or PEV will reduce greenhouse gas (GHG) emissions and improve air quality (Rolim et al., 2012; Smith 2010). This study, however, does not necessarily intend to invalidate their findings that alternative vehicle technologies have the potential to reduce fuel dependency and reduce $CO_2$ emissions, and EVs emit less tailpipe GHG while driving than conventional vehicles. Our study is rather more interested in estimating the energy usage due to EV adoption and whether this excess energy is coming from cleaner sources or not, which aspects are mostly ignored at the policy level.

## 3. DATA

This study examines empirical data to estimate the effect of EV adoption on electricity consumption and the relationship between electricity generation by renewable sources. This study uses California's county-level monthly data for the year 2010–2019 to find the effect on electricity consumption. California has 58 counties, so, there are 6960 monthly observations in the dataset. Electricity consumption and revenue data are collected from the California Energy Commission. I then use this information to calculate electricity prices also.

In this study EV represents both Plug-in-Hybrid Vehicles (PEV) and Battery Electric Vehicles (BEV). I use EV rebate date as a proxy for the EV adoption data as original EV registration data by counties is not publicly accessible. California has a rebate program for EV purchasers since 2010. The California Air Resources Board's Clean Vehicle Rebate Project (CVRP) provides rebate checks to California individuals, businesses, and government agencies to purchase or lease eligible clean vehicles, including plug-in hybrid, all-battery, and fuel-cell electric vehicles. According to the CVRP website, rebated vehicles constitute a majority (74%) of new clean-vehicle sales in the state (Center for Sustainable Energy, 2015). We assume that there are no differences in rebate rates across counties. I discuss more detail about this CVRP program and other incentives for electric vehicle supply equipment (EVSE), such as charging stations, in Appendix A.

EV charging Station information is provided by the U.S. Department of Energy and National Renewable Energy Laboratory. In this study, I use connectors and stations interchangeably. In one station, there might be more than one connector to charge more vehicles at a time. I use the number of total connectors in my model. Currently, there are three types of charging connectors available. Level 1, level 2, and DC fast. These three settings require different volts and amps and take a different range of times to charge EV (Alternative Fuel Data Center, 2019). In my model, however, I do not differentiate these types of stations since this study focuses on electricity consumption, not the intensity of the electricity flow at times.

Information on different housing units like single-unit, multi-unit, and mobile units, are collected from the California State Association of Counties (2020). I collect per capita personal income, population, and employment data from the Bureau of Economic Analysis (BEA), and the U.S. Department of Commerce website. I collect average monthly temperature per county information from the National Centers for Environmental Information of National Oceanic and Atmospheric Administration (NOAA) to control for the weather (NOAA, 2020).

Figures 3-5 show the average total electricity consumption of 10 years, total electric vehicle, and charging station adoption level at the end of 2019. Figure 6 shows the percentage of electricity that comes from renewable resources in each county.

Although I did not control for any variables in these maps, these figures might give a general idea about the variables of interest and their relationships considered in this study. Table 1 shows the summary statistics of the variables used in this study. Table 2 represents the average per capita electricity consumption for ten most EV adopting counties and ten least EV adopting counties annually for the study period.

Moreover, I have collected electricity generation data of California at the yearly level by counties for 2010 to 2019 from the California Energy Commission to estimate the effect of EV adoption on

**Figure 3:** Average electricity consumption by counties

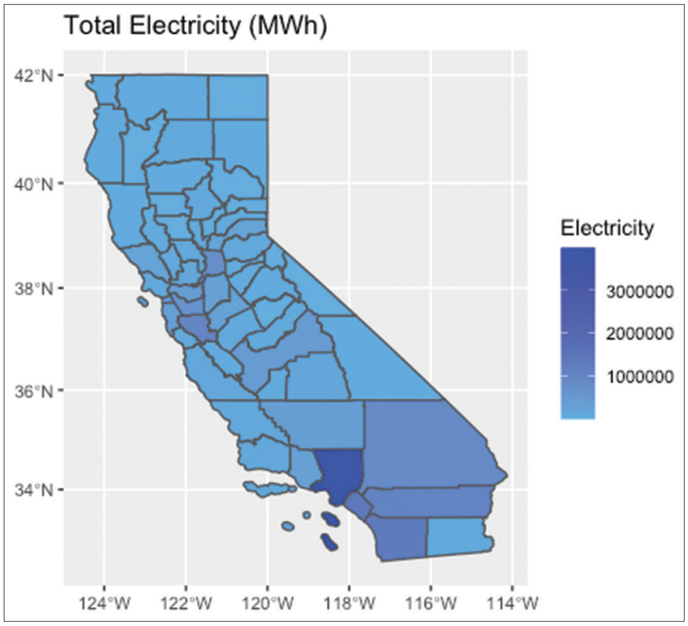
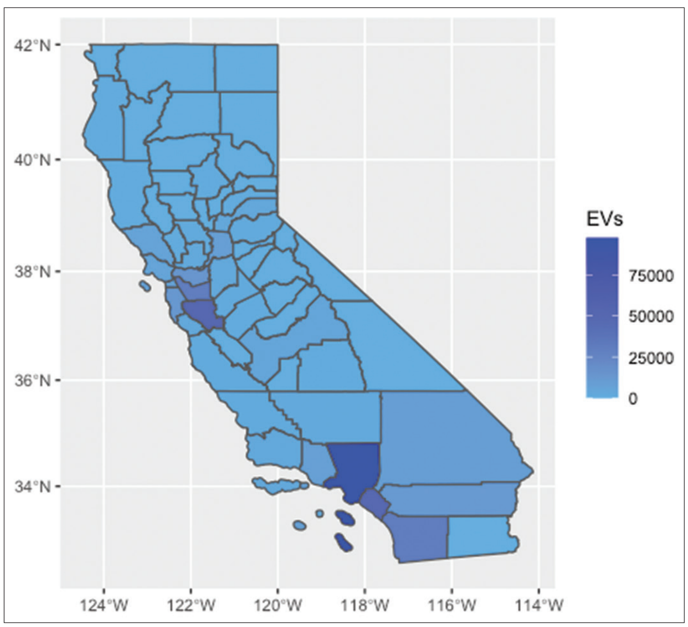



**Figure 4:** Total EV adoption at the end of 2019 by counties




the types of electricity generation by renewable sources. In California, primary electricity sources are coal and natural gas. Major renewable electricity sources are Hydroelectric, solar, and wind. Figure 7 shows the electricity generation trend by sources in California for the past 10 years, and Table 3 shows the summary statistics of the electricity sources.

From Figure 7, we can see that solar production did not start in California until December 2013. Renewable electricity share in the total electricity production is relatively low in these 10 years in California.

According to this data, in December 2019, total electricity generation in California was 337253.09 thousand MWh. Hydroelectric, solar, and wind combined generated 54929.56 thousand MWh electricity,

**Figure 5:** Total charging station at the end of December 2019 by counties

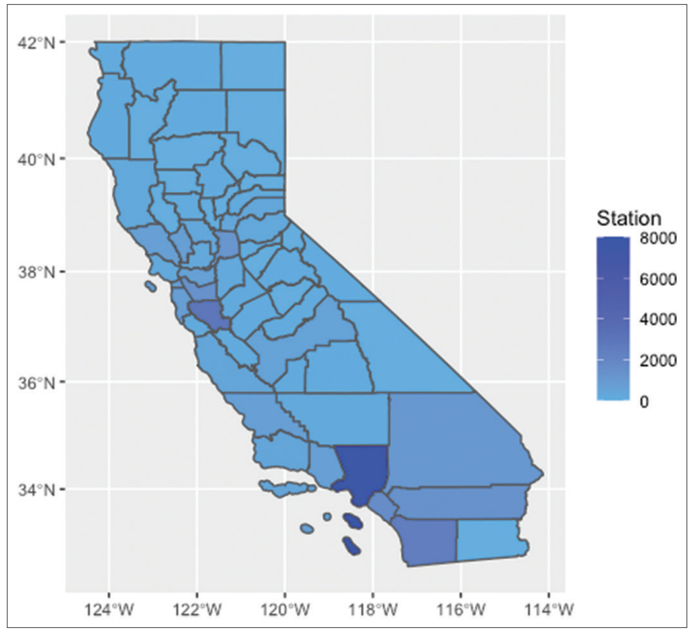
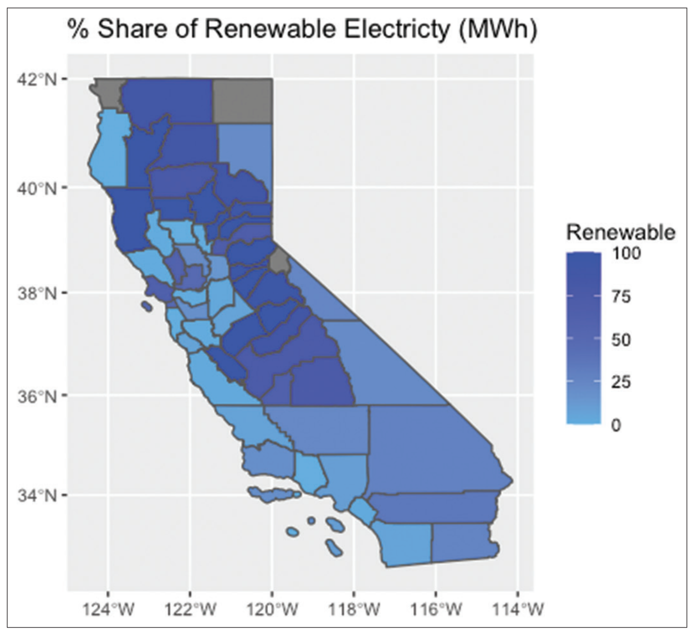



**Figure 6:** Percentage of electricity comes from renewable sources




only 16% of the total electricity generation. The other three sources, coal, natural gas, and nuclear, contribute the most to California's electricity production. Table 4 shows the average percentage share of electricity from renewable resources in the ten most EV adopting and ten least EV adopting counties.

## 4. METHODOLOGY

### 4.1. EV Adoption on Electricity Consumption

This study constructs a two-way fixed-effect linear regression model where the dependent variable is the monthly electricity consumption over time. This method allows us to measure the electricity usage in county level because of EV adoption. Previous

**Table 1: Summary table**

| Variables | Mean | St Dev | Min | Max |
|---|---|---|---|---|
| EV | 2052.90 | 7428.94 | 0 | 97538 |
| Station | 147.7 | 494.12 | 0 | 8016 |
| Income ($) | 49061 | 18090.95 | 26717 | 141735 |
| Population | 665831 | 1441469 | 1047 | 10105708 |
| Employment | 382226 | 879935.8 | 970 | 6685737 |
| Residential Electricity (MWh) | 130518.40 | 257371.51 | 328.60 | 2555402.70 |
| Commercial Electricity (MWh) | 149504 | 336388.80 | 93 | 2746909 |
| Residential Electricity Price ($) | 159.83 | 38.77 | 0.0105 | 1200.34 |
| Weighted Average Price ($) | 151.70 | 34.36 | 35.5 | 635.3 |
| Single housing | 155818 | 292312.52 | 1049 | 1965018 |
| Multi housing | 74368 | 205912.60 | 106 | 1545580 |
| Mobile housing | 9654 | 14608.09 | 32 | 80315 |
| % of Electricity share from renewable source (MWh) | 46.93 | 40.08 | 0.000 | 293.58 |

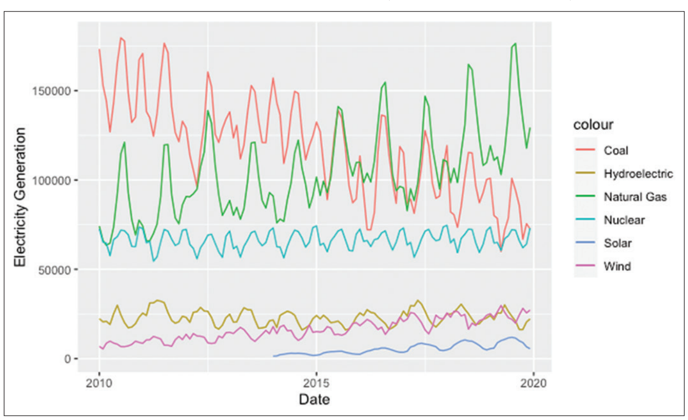
Number of observations (N) = 6960

**Table 2: Per capita average electricity consumption (MWh) of ten highest and ten lowest EV adopting counties**

| Year | Per capita Electricity Consumption | |
|---|---|---|
| | Highest ten EV Adopting Counties | Lowest ten EV Adopting Counties |
| 2010 | 5.196 | 7.729 |
| 2011 | 5.203 | 7.449 |
| 2012 | 5.237 | 7.351 |
| 2013 | 5.169 | 7.819 |
| 2014 | 5.181 | 7.276 |
| 2015 | 5.114 | 7.279 |
| 2016 | 5.061 | 7.558 |
| 2017 | 5.133 | 7.713 |
| 2018 | 4.988 | 7.450 |
| 2019 | 4.954 | 7.673 |

Welch Two Sample t-test: t = −34.764, p = 3.568e-14

**Figure 7:** Electricity generation of California by sources. Three major sources are non-renewables (Source: EIA, 2020)




studies accounted the issue in several different ways. In Economic policy level, the local level usage could be a useful aspect to look at.

I look at residential and commercial electricity because, according to the California Energy Commission, electricity consumption due to EV charging is mostly under residential and commercial sectors. So, in my model, I exclude other sectors like the agricultural sector, industrial sector, etc., from this analysis. EV owners charge their EVs either at home or at the charging stations. Apart from public charging stations, there is a number of private charging stations in California. People in nearby residents also share the charging facilities with neighbors using mobile apps. For example, California-based startup EVMatch and ampUp are these types of initiatives, which by using people can share their residential charging connectors with others and earn money (California Clean Vehicle Rebate Project, 2020). The electricity consumption for county i at time t is specified as-

$$Log(ELECTRIC_{it}) = b_0 + b_1 Log(EV_{it}) + b_2 Log(STATION_{it}) + b_3 Log(POP_{it}) + b_4 Log(SINGLE_{it}) + b_5 Log(EMPLOY_{it}) + b_6 Log(INCOME_{it}) + b_7 Log(HOTMONTH_{it}) + b_8 Log(COLDMONTH_{it}) + b_9 Log(PRICE_{it}) + \delta_t + \phi_i + u_{it} \quad (1)$$

Although, I use log transformed variables as well as unlogged variables for my analysis, I find it more convenient to interpret the log transformed one as this relationship simply shows the elasticity of the variables.

In equation (1), *ELECTRIC* is the monthly residential and commercial electricity consumption for each county. *EV* is the number of electric vehicle rebate application numbers in a specific county and month, and this is our primary variable of interest. In the dataset, there is information about the application date. I take the cumulative numbers of applications for each county at the monthly level. In my model, I assume people file their applications in the same month they purchase EV. The term *STATION* represents the charging connectors of EVs in each county. Apart from installing charging connectors at home, many EV owners charge their cars at a station rather than their homes, primarily because of its fast-charging capacity. So, this variable should also have a positive relationship with the outcome variable. In my data, I have the opening date of each station or charging connector. Like the *EV* variable, I take the cumulative sum of the number of stations for each county at the monthly level. However, in my model, I primarily use the *STATION* variable and *EV* variable separately as they both should account for electricity consumption. However, I also use these two variables together to see the effect of *EV* while controlling for *STATION* and vice versa because although these two predictor variables are interrelated, they also can be adopted separately. For example, charging connectors can be installed in the least EV adopting places for commuters.

The remaining variables are control variables. The term *SINGLE* is the percentage of single housing in each county. There are three types of housing available, which are Single, Multi, and Mobile housing. Households with a different number of members may have a different electricity-consuming pattern. People living in the same household can share their electricity services, such as cooking or watching TV together. Thus, if the demand-side economies of scale exist, the effect of different types of households should have different effects on electricity consumption.

*HOTMONTH* and *COLDMONTH* are two separate variables

**Table 3: Summary statistics of electricity generation by sources**

| All Fuel | Non-Renewable | | | Renewable | | |
|---|---|---|---|---|---|---|
| | Coal | Natural Gas | Nuclear | Hydroelectric | Solar | Wind |
| Minimum | | | | | | |
| 287,800 | 60,008 | 63,431 | 54,547 | 16,074 | 1,375 | 5,432 |
| Average | | | | | | |
| 340,978 | 118,088 | 104,483 | 66,475 | 23,060 | 5,566 | 16,249 |
| Maximum | | | | | | |
| 418,693 | 179,600 | 176,458 | 74,649 | 32,607 | 11,941 | 29,711 |

Number of observation (N)=580

**Table 4: EV adoption and renewable electricity generation for ten highest and lowest EV adopting counties**

| Highest EV adopting counties | | | | Lowes EV adopting counties | | | |
|---|---|---|---|---|---|---|---|
| County | % of renewable electricity | EVs | Station | County | % of renewable electricity | EVs | Station |
| Los Angeles | 9.686 | 379,538 | 27,958 | Modoc | NA | 0 | 20 |
| Santa Clara | 0.8831 | 208,307 | 8,430.2 | Sierra | 92.75 | 18.7 | 11 |
| Orange | 1.6723 | 176,010 | 5,160.6 | Alpine | NA | 13.60 | 61.7 |
| San Diego | 6.1137 | 116,925 | 10,552 | Lassen | 20.979 | 23.1 | 24.8 |
| Alameda | 17.7320 | 118,198 | 4,713 | Trinity | 100 | 46.50 | 25.0 |
| Contra Costa | 0.64937 | 55,773 | 1,123.8 | Colusa | 0 | 46.0 | 23 |
| San Mateo | 0 | 54,804 | 1,797.6 | Glenn | 100 | 59.70 | 0 |
| Riverside | 34.184 | 36,840 | 5,231 | Mono | 24.40 | 51.50 | 380.6 |
| San Bernardino | 27.99 | 29,062 | 3,606 | Plumas | 89.50 | 57.30 | 28.9 |
| Sacramento | 13.575 | 27,828 | 6,185 | Inyo | 20.706 | 78.60 | 43.2 |

representing the climate factors, like average hot/cold degree months when people use more electric appliances like air coolers and heaters would positively influence electricity demand. I consider 86° Fahrenheit or more temperature as hot days and 32° Fahrenheit or less as cold days (Alberini et al., 2017). So, if the average monthly temperature is above 86°, the *HOTMONTH* variable would be equal to 1, otherwise 0. Similarly, if the average monthly temperature is below 32°, the *COLDMONTH* variable would be equal to 1, otherwise 0.

The term *PRICE* is the weighted average electricity price of the residential and commercial sectors, which I calculated from electricity consumption and the revenue information. The term *INCOME* is the per capita personal income for each county. Based on the demand theory, the price effect is expected to be negative, while the income effect is expected to be positive on electricity demand. The term POP represents the population for each county, which is the number of potential electricity users. This variable also controls the size of each county. A county with more residences will consume more electricity, so the population's effect would be positive. The variable EMPLOY is the total employment in each county, which controls for any unobserved economic activity for electricity consumption and purchasing EVs.

$\delta$ and $\phi$ stand for county fixed effect and time fixed effect, respectively. More specifically, time fixed effects account for the year-month level in this model.

### 4.2. Renewable Electricity Generation due to EV Adoption

To address the second question of this study, I again employ the two-way fixed-effect model. The electricity from renewable sources in county i and year t would be,

$$RENEWABLE_{it} = b_0 + b_1 Log(ELECTRIC_{it}) + b_2 Log(INCOME_{it}) + b_3 Log(POP_{it}) + b_4 Log(SINGLE_{it}) + b_5 Log(EMPLOY_{it}) + b_6 Log(PRICE_{it}) + \delta_t + \phi_i + u_{it} \quad (2)$$

Here, *RENEWABLE* is the percentage share of the electricity generation that comes from renewable sources in a specific county and year. Other variables are the same as the first specification, except that temperature control is excluded. Electricity generation is supposed to be independent of temperature. Electricity use, Income, population single housing, electricity price and employment status are expected to have effects on renewable electricity generations. Here, our variable of interest is ELECTRIC which accounts for the electricity use at county level.

## 5. RESULTS

### 5.1. Effect of EV Adoption on Electricity Consumption

Table 5 represents the results of the unlogged analysis of the effect of EV adoption on both residential and commercial sectors together. I use a weighted average price for these two sectors. The three separate columns in the table represent different model specifications. In the first column, I use EV as my explanatory variable without the charging station in it. I use the charging station as my explanatory variable without EV in the second column. In the third column, I keep both EV and charging station as an explanatory variable. Although charging stations and EVs should be correlated, it is worth looking at the EV effect while controlling for the charging station and vice versa. As we know, least EV adopting counties might also want to build more stations for travelers. This study adopts a two-way fixed-effect model where I control for county-fixed effect and year-month fixed effect. In column (2), the charging station has a coefficient of 29.71, and this result is highly significant, which means one extra charging station or connector can increase monthly electricity consumption by 29.71 MWh. In column (3), while accounting for both EV and Station, this coefficient is 27.16.

Table 6 shows the logged analysis, which represents the primary results of the effect of EV adoption on both residential and commercial sectors together. In this specification all the predictor and the outcome variables are log-transformed. For the weather control, this time, I use numbers of dummy variables with a range of 5° bins for both hot and cold months. I had to drop one of these dummies because none of these months fall under the range of 30–35° Fahrenheit.

**Table 5: Effect on residential and commercial consumption**

| Variables | (1) | (2) | (3) |
|---|---|---|---|
| EV | 0.695 | ╳ | 0.318 |
| | (0.447) | | (0.701) |
| Charging Station | ╳ | 29.71*** | 27.16*** |
| | | (7.49) | (9.93) |
| Income | 0.231 | 0.819** | 0.772* |
| | (0.310) | (0.401) | (0.412) |
| Population | 0.418*** | 0.613*** | 0.608*** |
| | (0.074) | (0.097) | (0.098) |
| Weighted Price | 134.74** | 174.97** | 171.91** |
| | (55.16) | (78.68) | (79.72) |
| Single HH | 7,885.49 | 9,493.09 | 10,160.81 |
| | (720.71) | (7176.01) | (7358.46) |
| Employment | −0.123*** | −0.297*** | −0.308*** |
| | (0.0431) | (0.056) | (0.059) |
| Hot Months | 169,478.93*** | 192,259.71 | 191,572.84*** |
| | (11725.16) | (13742.45) | (13843.41) |
| Cold Months | 17,198.96 | 24,458.90 | 25,233.86 |
| | (12,556.87) | (15,029.43) | (16,430.62) |
| County Fixed effect | ✓ | ✓ | ✓ |
| Time Fixed effect | ✓ | ✓ | ✓ |

***P<0.001, **P<0.01, *P<0.05. Standard errors reported in parenthesis. Number of observations=6960

**Table 6: Robustness check specifications for electricity consumption on EV adoption**

| Variable | (1) | (2) | (3) |
|---|---|---|---|
| Log (EV) | 0.0062 | ╳ | 0.0006 |
| | (0.0042) | | (0.0079) |
| Log (Station) | ╳ | 0.0105*** | 0.0118*** |
| | | (0.0037) | (0.0039) |
| Log (Income) | 0.0299 | 0.1909** | 0.1536* |
| | (0.0712) | (0.0847) | (0.0843) |
| Log (Population) | 0.6727*** | 0.8640*** | 0.8324*** |
| | (0.1592) | (0.1986) | (0.2056) |
| Log (Weighted price) | 0.0947*** | 0.1021*** | 0.0984*** |
| | (0.0142) | (0.0175) | (0.0176) |
| Log (Employment) | 0.1077 | 0.0831 | 0.0915 |
| | (0.1055) | (0.1247) | (0.1318) |
| Log Single HH | 0.8180* | 1.3947*** | 0.0195** |
| | (0.4259) | (0.4580) | (0.0084) |
| Factor (80–85) | 0.1833*** | 0.1921*** | 0.1879*** |
| | (0.0128) | (0.0138) | (0.0136) |
| Factor (>90) | 0.4467** | 0.4529*** | 0.4465*** |
| | (0.0358) | (0.0406) | (0.0400) |
| Factor (25–30) | 0.2557*** | 0.3325*** | 0.3145*** |
| | (0.0321) | (0.0329) | (0.0363) |
| Factor (20–24) | 0.5465*** | 0.5751*** | 0.5781*** |
| | (0.1233) | (0.1181) | (0.1163) |
| County Fixed Effect | ✓ | ✓ | ✓ |
| Year Fixed Effect | ✓ | ✓ | ✓ |

***P<0.001, **P<0.01, P<0.05. Standard errors reported in parenthesis. Number of observations=580

In this specification charging station again shows a significant positive effect on electricity consumption. We can interpret that a 1% increase in charging station installation increases the electricity consumption by 0.012%. According to our average county-level electricity usage data, this 0.012% would yield 33.04 MWh electricity consumption per country per month. This time, single housing unit shows a positive effect. All the temperature variables are positively significant at a 1% level.

Table 7 represents the result for the residential electricity consumption only. As before, In the first column, I use EV as my explanatory variable without the charging station in it, and in the second, I use the charging station as my explanatory variable without EV in it. Column (3) shows the result for both EV and charging stations. This model is also a two-way fixed-effect model. In column (2), Station shows a coefficient of 18.22 for residential electricity consumption. This result is significant at a 1% level. So, one extra charging station adoption can cause 18.22 MWh of residential electricity consumption monthly. The population has a significant positive result on consumption, employment has a significant negative effect, and hot degree months have a significant positive impact as we expected. In column (3), EV does not have any significant effect, but the charging station is still highly significant and has a positive effect on residential electricity consumption.

## 5.2. Electricity Generation in California

Natural gas, coal, nuclear, hydroelectric, solar, and wind are the primary electricity generation sources in California. Among these, hydroelectric, solar, and wind are considered clean, renewable sources (National Geographic, 2020). As California is concerned about the environment and trying to impose public policies to reduce pollutants, it is worth looking at the electricity generation pattern and whether the EV adoption policies are accompanied by more secure and cleaner power plants. In this case, the dependent

**Table 7: Effect on residential consumption only**

| Variables | (1) | (2) | (3) |
|---|---|---|---|
| EV | 0.152 | ╳ | −0.179 |
| | (0.294) | | (0.461) |
| Charging Station | ╳ | 18.22*** | 20.13*** |
| | | (4.92) | (6.53) |
| Income | −0.003 | 0.279 | 0.289 |
| | (0.202) | (0.262) | (0.269) |
| Population | 0.245*** | 0.393*** | 0.392*** |
| | (0.049) | (0.064) | (0.064) |
| Residential Price | 7.257 | 16.16 | 16.74 |
| | (22.88) | (32.45) | (32.77) |
| Single HH | 6,525.89* | 7,330.94 | 6,972.81 |
| | (3,754.08) | (4,709.09) | (4,828.14) |
| Employment | −0.058** | −0.191*** | −0.189*** |
| | (0.028) | (0.037) | (0.039) |
| Hot Months | 137,806.95*** | 158,027.64*** | 157,450.91*** |
| | (7,707.42) | (9,029.48) | (9,093.58) |
| Cold Months | 4,888.51 | 8,853.32 | 9,288.32 |
| | (8,247.63) | (9,871.24) | (10,790.26) |
| County Fixed effect | ✓ | ✓ | ✓ |
| Time Fixed effect | ✓ | ✓ | ✓ |

***P<0.001, **P<0.01, *P*<0.05. Standard errors reported in parenthesis. Number of observations=6960

**Table 8: Effect of electricity usage on renewable energy source**

| | (1) | (2) | (3) | (4) | (5) Unlogged |
|---|---|---|---|---|---|
| Log (Electric Vehicle) | 0.3217 | ╳ | −2.40 | ╳ | ╳ |
| | (1.55) | | (2.89) | | |
| Log (Charging Station) | ╳ | 0.5540 | 0.8954 | ╳ | ╳ |
| | | (1.51) | (1.60) | | |
| Log (Electricity) | ╳ | ╳ | | −34.78 | −0.0000085** |
| | | | | (21.05)* | (0.0000036) |
| Log (Population) | −20.12 | 5.23 | −21.30 | −9.08 | 0.000016*** |
| | (61.50) | (82.50) | (85.44) | (54.31) | (0.0000036) |
| Log (Income) | −36.15 | −59.65* | −68.78** | −4.51 | 0.000022 |
| | (25.35) | (32.63) | (33.79) | (22.66) | (0.000015) |
| Log (Weighted Price) | −1.87 | 0.9975** | 0.0235 | −0.0906 | −0.005500 |
| | (6.66) | (9.81) | (9.85) | (5.94) | (0.003900) |
| Log (Employment) | 120.97*** | 121.81 | 144.80** | 139.65 | −0.0000024* |
| | (42.60) | (51.00) | (56.02) | (39.85) | (0.0000012) |
| Log (Single HH) | −43.18 | −34.87 | 0.2921 | 125.79 | 2.55 |
| | (151.93) | (178.57) | (181.66) | (148.02) | (3.01) |
| County Fixed effect | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year fixed effect | ✓ | ✓ | ✓ | ✓ | ✓ |

***P<0.001, **P<0.01, P<0.05. Standard errors reported in parenthesis. Number of observations=580

variable is the percentage share of electricity that comes from renewable sources in each county. This is also a two-way fixed-effect model except for this time, the data is yearly. So, the time fixed effect represents the year fixed effect. Other variables remain the same.

In California, most renewable electricity comes from hydroelectric power. Solar and wind follow hydroelectricity. There are some biomass and geothermal electricity production as well.

Table 8 shows the result of the impact of EV adoption on renewable sources of energy. In the table, column (1), (2), (3), and (4) shows the logged analysis of variables. Column (5) shows the result for unlogged variables. In this case, electricity is measured in thousand MWh. In the first three columns, I use EV and Station as explanatory variables. However, it seemed more logical to have Electricity itself as the explanatory variable, shown in column (4), and column (5), as high electricity demand or usage should affect the energy mix of the electricity generation decision. According to the U.S. Energy Information Administration, electricity demand is one factor that influences the mix of energy sources for electricity generation. Intermediate load generating units (rather than Baseload units, which supply electricity at a nearly constant rate) comprise the largest generating sector and provide load responsive operation between baseload and peaking service. In general, the demand profile varies over time, and intermediate sources are technically and economically suited for following changes in load. Natural gas-fired combined-cycle units, which currently provide more generation than any other technology, generally operate as intermediate sources.

The result shows that neither EV adoption nor Station increases renewable electricity generation. Instead, when I use Electricity as the explanatory variable, it shows a significant negative impact on renewable energy sources. In this specification, the dependent variable, the percentage of electricity from renewable sources, is not log-transformed, but all the predictor variables are log-transformed. We can interpret that a 1% increase in electricity consumption decreases the renewable energy share by 0.34%. It means more EV adoption, or in other words, more electricity usage is accompanied by decreased adoption of renewable sources.

## 6. DISCUSSION AND CONCLUSION

In addition to the rebate programs for EV and EVSE, California has enacted several other incentives to adopt electric vehicles, including HOV lane access, zero-emission transit bus tax exemption, and nine other regional incentive programs. The state rebate program for EVs alone has already spent $823 million since 2010 (California Public Utilities Commission, 2020). Nikolewski (2019) provides the breakdown of California's all EV incentive programs' total spending, which is $2.46 billion for approximately 10 years. As I stated earlier, all of these incentives have been introduced in response to environmental concerns. In general, experts agree that electric vehicles are cleaner than other conventional vehicles powered by diesel or gasoline while driving because EVs emit fewer tailpipe pollutants in the atmosphere. Although California is trying to reduce its coal-based power plants in recent years, coal is still one of its primary electricity sources, along with natural gas and nuclear energy. These power plants emit a significant amount of greenhouse gas and other pollutants, as discussed earlier. Besides, hydroelectricity is the major source of renewable options in California. Solar and wind exist to a limited extent. So, there are rooms for renewable resources to be escalated as one of the primary electricity production sources.

This study has some limitations. California is the biggest importer of electricity as well. In 2018, almost one-third of California's electricity supply came from generating facilities outside the state (EIA, 2020). I cannot account for the imported electricity sources in this study, which would be the scope for future research. Another interesting aspect of this research could be analyzing the adoption of small-scale customer-sited solar photovoltaics (PV) in California, known as behind-the-meter generation, a predominant technology in residential solar PV. In 2019, solar PV self-generated about 16,000 GWh of energy (California Energy Commission, 2019, slide 8).

This paper argues that EVs do involve pollution or emission. If not tailpipe, it shifts the pollution level to energy production points. Complementing some existing environmental engineering studies, this study finds that EV adoption significantly increases electricity consumption in residential and commercial sectors, and energy usage is accompanied by a lower adoption of renewable power plants. Considering the average number of charging stations per county, EV adoption increases monthly residential and commercial electricity consumption by 0.012%. Based on California's average energy generation, this would yield 33.04 MWh. Besides, a 1% increase in electricity consumption is associated with 0.34% of the decrease in the renewable electricity share. These results should be an essential viewpoint for policymakers. Evaluating government EV incentives' true environmental impact should weigh the reduced gasoline engine emissions against the increased fossil fuel or nuclear consumption during electricity generation. Unless California adopts cleaner sources of power plants, billions of dollars of public spending on EV adoption will not be as effective as it would be if accompanied by increased adoption of renewable energy sources.

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# A. APPENDIX

## A.1. CLEAN VEHICLE REBATE PROJECT

The Clean Vehicle Rebate Project (CVRP) promotes clean vehicle adoption by offering rebates of up to $7,000 for the purchase or lease of new, eligible zero-emission vehicles, including electric, plug-in hybrid electric, and fuel cell electric vehicles. Until funds are available, eligible California residents can follow a simple process to apply for a CVRP rebate after purchasing or leasing an eligible vehicle. The Center for Sustainable Energy (CSE) administers CVRP throughout the California Air Resources Board (CARB) state [17]. In my dataset, there are a total of 371892 rebate application records.

*Income Eligibility*

- Income Cap: Higher-income consumers are not eligible for CVRP rebates if their gross annual incomes are above the income cap. The income cap applies to all eligible vehicle types except fuel-cell electric vehicles. The present income cap is mentioned below-
  1. $150,000 for single filers
  2. $204,000 for head-of-household filers
  3. $300,000 for joint filers.

- Increased Rebate: Consumers with household incomes less than or equal to 300% of the federal poverty level are eligible for an increased rebate amount. Increased rebate amounts are available for fuel-cell electric vehicles, battery electric vehicles, and plug-in hybrid vehicles.

*Rebate Limit*

Individual and business applicants are not eligible to receive more than one CVRP rebate either via direct purchase and/or lease as of December 3, 2019. Traditional rental and car share fleets are subject to limits of 20 rebates per calendar year. Public fleets are limited to 30 rebates per calendar year.

*Vehicle Eligibility*

Eligible vehicles must meet requirements that include, but are not limited to, the following:

- Be on the list of Eligible Vehicles which meet required emission standards.
- Be new as defined in the California Vehicle Code (CVC) Section 430 and manufactured by the original equipment manufacturer (OEM) or its authorized licensee. Vehicles considered new vehicles solely for the determination of compliance with state emissions standards are not eligible.
- Be registered as new in California. Vehicles may not be purchased, leased, or delivered out of state. Purchases/leases must be made via a California purchase or lease contract. Vehicles ordered online and delivered outside of California are not eligible. The seller's address, as reflected on the purchase or lease agreement, must be in California.
- Have an odometer reading below 7,500 miles at the time of purchase or lease.

*Funding Availability*

If funds are not available at the time of application, people may still apply and be placed on a rebate waitlist. Rebates for approved applications on the waitlist will be issued if additional funding from the state of California becomes available.

## A.2. CHARGING STATION REBATE

*Rebates for Residential Level 2 Charging Stations*

Numbers of California utility providers and air districts[1] offer rebates to make home Level 2 charging stations more affordable. Some of the rebates also help offset the cost of installing the charging station at the EV owner's home if additional electrical work is required. The minimum rebate amount is $400, and the maximum is $4000 based on the location and EVSE type. In California, the most popular charging is Level 2 charging. The median installation cost of a Level-2 charger is $1,200 (Idaho National Laboratory, 2015).

*Rebates for Commercial EV Charging Stations*

Property owners can get rebates for installing commercial charging stations for public use and thus generate a new revenue stream (charging fees). In California, there are nineteen separate utility incentives and ten air district incentives for the commercial installation of an EV charging station

1 Air districts refer to county or regional agencies throughout California that have primary responsibility for controlling air pollution from stationary sources and administer various air pollution-related rebate programs and initiatives. California has 23 Air Pollution Control Districts (APCDs) and 12 Air Quality Management Districts (AQMDs).