Impact of Electric Vehicle Adoption on Electricity Consumption and Generation

Atia Ferdousee*

October 27, 2020

ABSTRACT

The market share of electric vehicles (EV) is growing in the USA and there are substantial numbers of federal, state, and county-level incentives for EV consumers. These incentives are in place, primarily, to promote environmental concerns. This study focuses on two different but interrelated aspects of EV adoption. First, using monthly county-level data for 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, I find that there is significant negative relation between EV adoption and the share of electricity that comes from renewable sources. Although electric vehicles emit lower greenhouse gases than conventional vehicles, they require a significant amount of electricity for charging. If the electricity generation does not involve renewable or cleaner sources, public spending on EV adoption may not contribute to a cleaner environment as much as expected.

Keywords: Electric vehicle adoption, Residential and Commercial electricity consumption, Renewable electricity generation

*Atia Ferdousee, Ph.D. Candidate, Department of Economics and Finance, Middle Tennessee State University, Murfreesboro, TN 37212, email: af5g@mtmail.mtsu.edu

1. INTRODUCTION

The United States is the third-largest electric vehicle (EV) market, following China and Europe. The State of California alone adopted 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 important role to increase EV adoption. Consumer incentives are important, while upfront purchase cost remains 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). It is clear that the government tries to promote electric vehicles, mostly due to environmental concerns. The U.S. Department of Energy (DOE) report states 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 (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 were designed to help communities forge public-private partnerships to plan for and develop strategies to support the adoption of PEVs and charging infrastructure installation. The 16 awards, totaling $8.5 million, helped prepare U.S. communities in 24 states and the District of Columbia to adopt PEV technologies to reduce U.S. petroleum dependence and to build the foundation for a clean transportation system (DOE, 2014).

However, coal, natural gas, and nuclear fuels are the most-used electricity generation sources nationwide. Particularly natural gas and, to a certain extent, shale oil remains 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 Administration [EIA], 2020). It is clear that electricity generation still relies mostly on fossil fuel in the USA, which is primarily responsible for emitting the major air pollutants. Below two figures show the energy generation share and trend by sources.

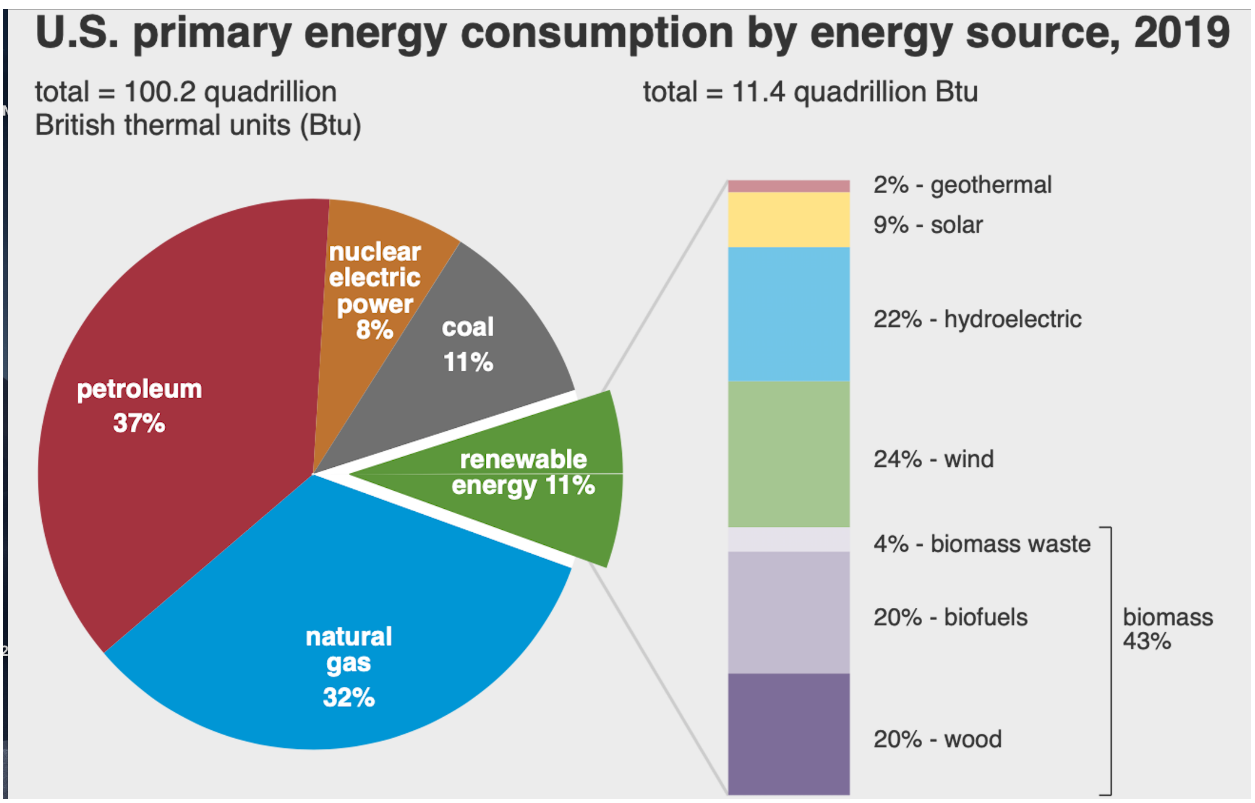

Figure1: U.S primary consumption of electricity share[1] by sources in 2019.

[1] Sum of the components may not equal to 100% due to independent rounding.

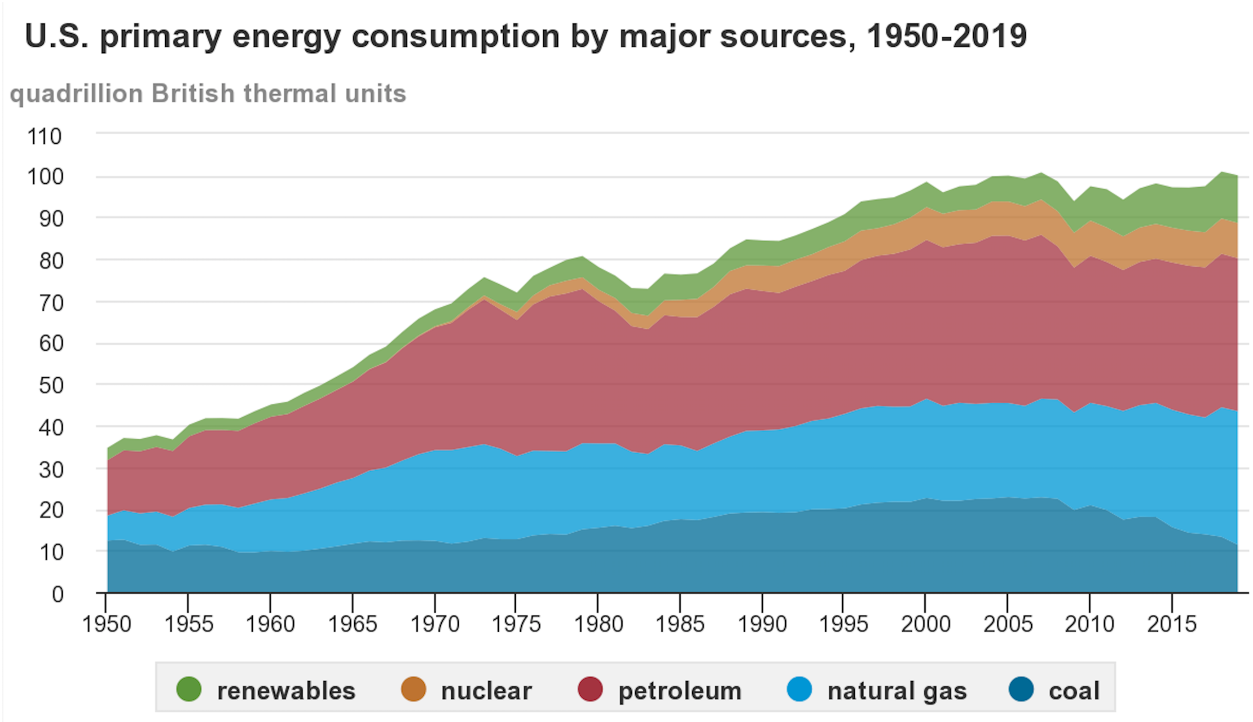

Figure 2: U.S primary energy consumption by major sources from 1950 to 2019[2].

A report prepared for the US Department of Energy contends, "Power plants are the largest source of sulfur dioxide (SO2) emissions 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).

The aim of this study is to examine the consequence of EV adoption on electricity consumption and, eventually, on the generation of electricity from renewable sources. As stated

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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

[2] Petroleum is petroleum products excluding biofuels, which are included in renewables.
Source: U.S Energy Information Administration, *Monthly Energy Review,* Table 1.3, April 2020, Preliminary data,

by the DOE website, an average EV's electricity consumption is 0.34 kWh/km, and an average American drives 46 km daily. So, per capita, monthly electricity consumption due to EV is 470 kWh. In the USA, the average residential electricity consumption per person is 909 kWh each month; that suggests a person's electricity consumption due to EV could be around 50% of one’s residential electricity consumption. The website also states that based on the national average of 12.6 cents/kWh, fully charging an all-electric vehicle with a 100-mile range and depleted battery would cost about the same as operating an average central air conditioner for six hours. These estimates indicate that EVs can cause an increase in electricity demand, so that electricity generation sources should also be considered cautiously at the policy level.

This study consists of two major parts. First, using county-level monthly data from California for the year from 2010 to 2019, it estimates the effect of EV adoption on residential and commercial electricity consumption. By employing fixed-effect panel regression, this study finds that each electric vehicle charging station significantly increases the residential and commercial electricity consumption by 89.5 MWh monthly. 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 EV adoption and renewable electricity generation. However, by analyzing ten years of electricity generation information in California, this study finds a significant negative impact of EV adoption on renewable energy sources.

The rest of this study is organized as follows: first, I give a brief literature review in section 2. In section 3, I present an overview of the data, and section 4 discusses the model specification. I present the result of our analysis in section 5 before concluding in Section 6, along with some discussions about whether the incentive policies are sufficient to achieve the goals of a clean environment.

2. LITERATURE REVIEW:

Analysis of electricity consumption due to the adoption of electric vehicles is absent in the economics literature so far. Most studies about EV adoption focused on purchasing patterns due to incentives using various consumer choice models. However, electricity consumption due to adoption of new technologies are available. Su (2019), in his study about residential electricity demand in Taiwan, found that the effects of urbanization and energy poverty have a significant effect on energy consumption. He used the adoption of 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.

Holtsmark et al. (2014) studied Norwegian subsidy policies for EV purchasers and concluded that as a result of these policies, the sales of EVs in Norway increased rapidly. 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 the driving range of most EV is low, the policy gives Norwegian households incentives to purchase a second car, again stimulating the use of private cars instead of public transport and cycling. This study also analyzed the emission level due to production of two models of EVs and their batteries. All of these lead to more pollution. Authors concluded that the EV policy cannot be justified.

There are several environmental engineering fields of studies that address this question with different aspects. 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 off-peak charging is more beneficial than peak charging and 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.

Muratori (2018) found that even if the total PEV market share remains limited, high PEV adoption clusters can be found in certain areas. The results show that the introduction of one single PEV in a residential distribution network consisting of six households can potentially increase the distribution transformers' peak load factor if Level 2 (a type of EV charger) charging is considered, which can lead to a significant decrease in the expected transformer life. In general, the higher charging level significantly exacerbates the impact of PEV charging on the residential distribution infrastructure.

However, Rolim et al. (2012) collected information about driving behavior by interviewing eleven EV drivers in Lisbon, Portugal with on-board diaries, including km traveled, kWh charged, and the number of trips per day for five months duration. Results indicate that the EV's adoption impacted everyday routines on 36% of the participants, and 73% observed changes in their driving style. Compared to conventional internal combustion engine vehicles running on gasoline or diesel, EV reveals considerable reductions in both energy consumption and CO2 emissions.

Nonetheless, Nicholas et al. (2015) estimate to what extent PEVs are more environmentally friendly, for most pollutant species than conventional passenger cars in Texas, after recognizing the emissions and energy impacts of battery provision and other manufacturing processes. 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. The use of coal for electricity production is a primary concern for PEV growth, but there is benefit of energy security benefits of electrified vehicle-miles. As conventional vehicle emissions rates improve, it appears that power grids must improve emissions technologies and/or shift toward cleaner generation sources to compete on an emissions-monetized basis with conventional vehicles in many locations. Moreover, while PEV pollution impacts may shift to more remote (power plant) locations, dense urban populations remain most strongly affected by local power plant emissions in many Texas locations.

3. DATA:

This study examines empirical data in order to estimate the effect of EV adoption on electricity consumption as well as the relationship of electricity generation by renewable sources. Primarily, I use California's county-level monthly data for the year 2010-2019 to find the effect on electricity consumption. California's EV rebate program also started at the beginning of 2010. California state has 58 counties. So, there are 6960 monthly observations in the dataset. I have collected Electricity consumption and revenue data for different sectors from the California Energy Commission. I then use this information to calculate electricity prices also.

For the EV adoption data, I have to use a proxy variable because original EV registration data is not easily accessible. California state has a rebate program for EV purchasers, which started in 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 qualified 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). I discuss more detail about this CVRP program and also other incentives for electric vehicle supply equipment (EVSE), such as charging station, in the Appendix A.

EV charging Station information is provided by the U.S. Department of Energy and National Renewable Energy Laboratory. In the data set, there is information about the opening date of each station or charging ports. I cumulate the numbers of active stations at the monthly level of each county. 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. There are three types of charging stations available currently. Level 1, level 2, and DC fast. These three charging require different volts and amps and also take a different range of times to charge EV. In my model, however, I did not differentiate these types of stations as this study focuses on electricity consumption as a whole, not the intensity of the flow of electricity at particular times.

Information on population per county and three different housing units like single-unit, multi-unit, and the Mobile unit, are collected from the California state association of counties. I collect per capita personal income data from the Bureau of Economic Analysis (BEA), U.S. Dept 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).

The maps below show the population density, average total electricity consumption of ten years, Average per capita electricity consumption, total electric vehicle and charging station adoption level at the end of 2019 by counties. The last one shows the percentage of electricity that comes from renewable resources in each county.

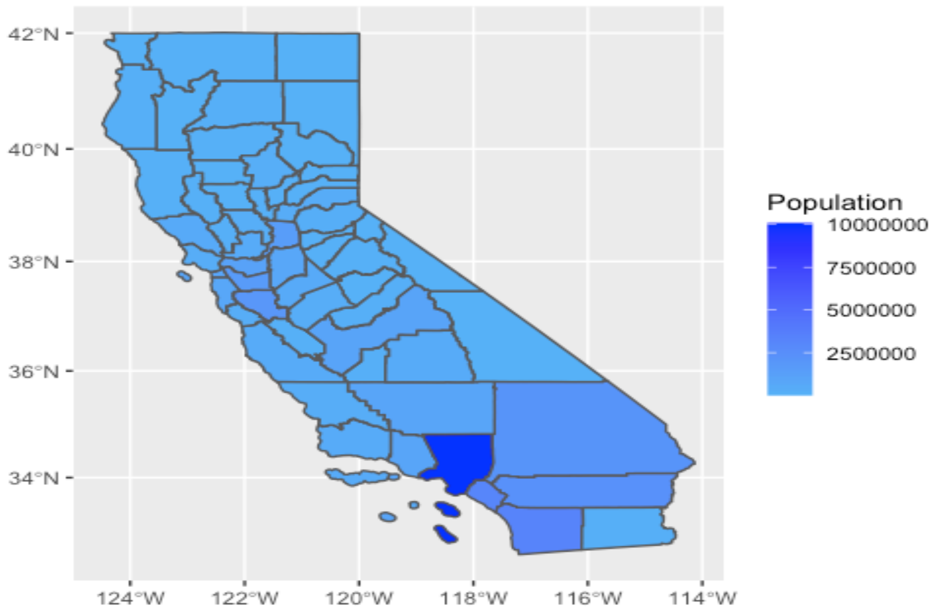

Figure 3: The average population by county in California.

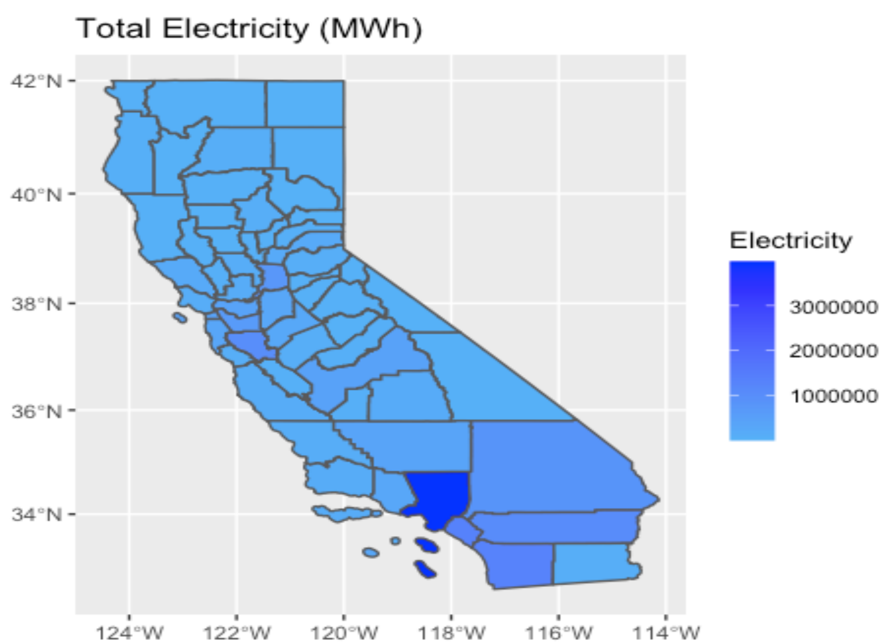

Figure 4: Average total electricity (Both residential and commercial) consumption by counties

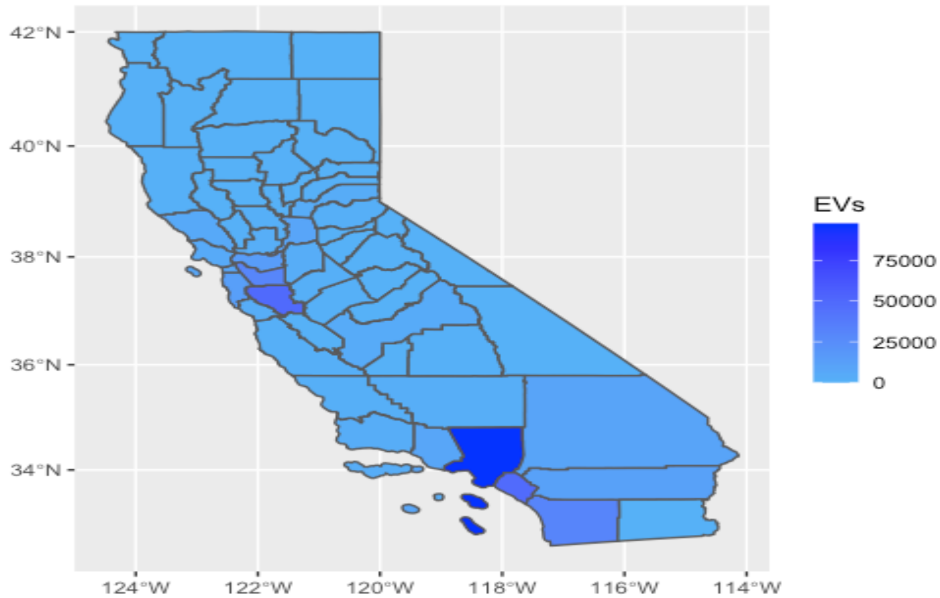

Figure 5: Total EV adoption at the end of 2019 by counties.

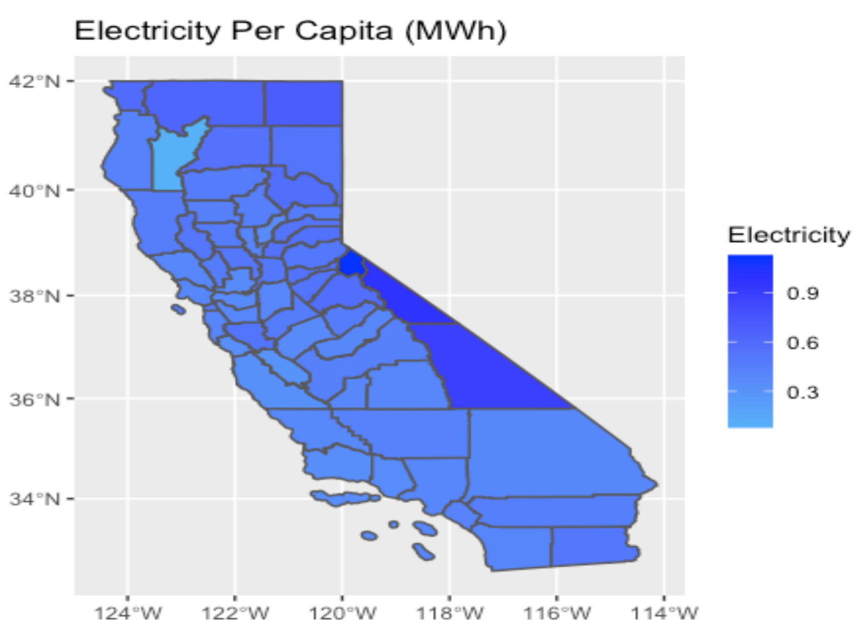

Figure 6: Per capita average electricity consumption by counties.

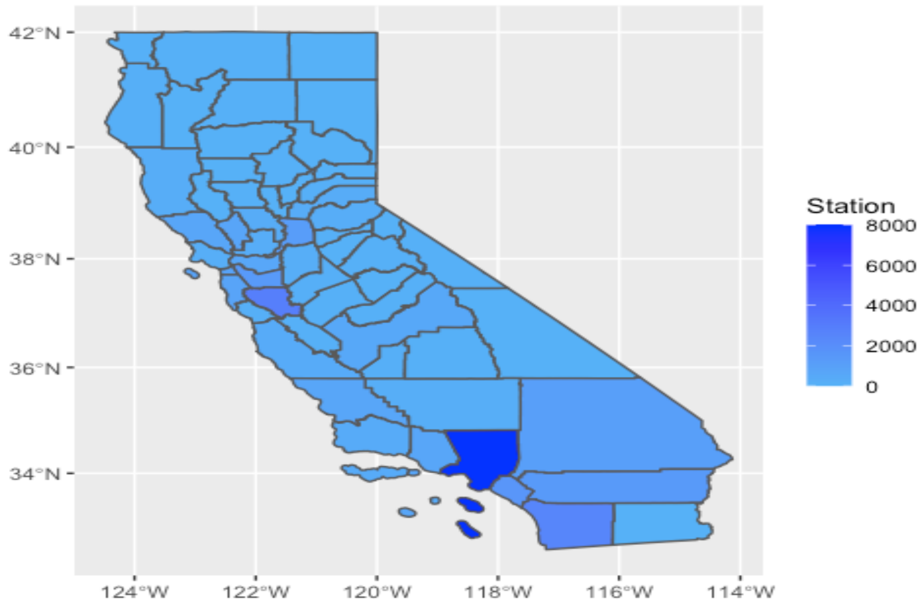

Figure 7: Total charging station at the end of December 2019 by counties.

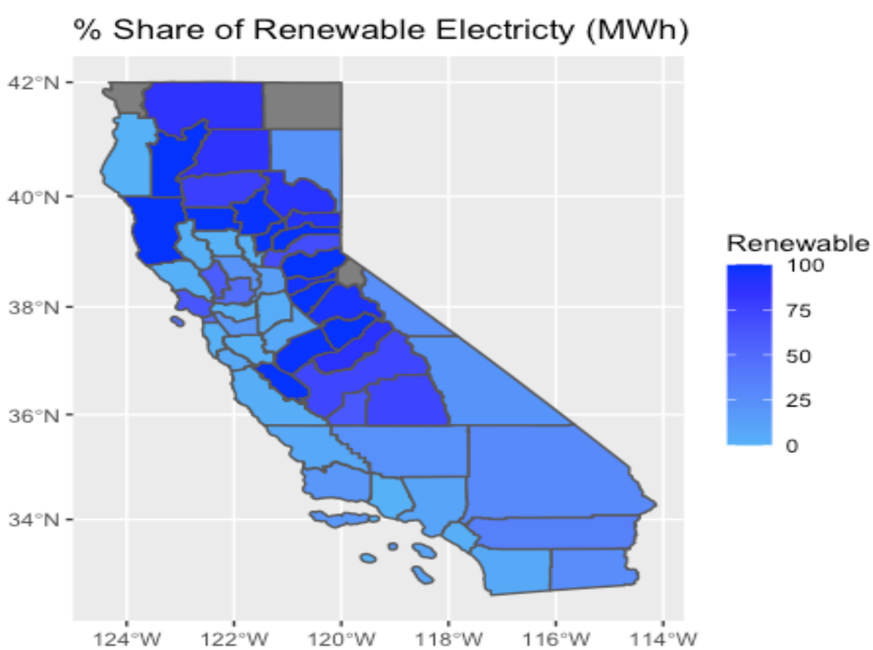

Figure 8: Percentage of electricity comes from renewable sources.

Although I did not control for anything to depict the intensity of EV and Station adoption and electricity consumption, these maps might give a general idea about the counties we are going to discuss about. Table 1 shows the summary statistics of the variables I use 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.

TABLE 1− SUMMARY TABLE

Variables	Mean	St Dev	Min	Max
EV	2052.9	7428.94	0	97538.0
Station	147.7	494.12	0	8016.0
Income ($)	48742	18026.32	26715	134275
Population	666968	1449639.95	1154	10283729
Residential Electricity (MWh)	130518.4	257371.51	328.6	2555402.7
Commercial Electricity (MWh)	149504	336388.80	93	2746909
Residential Electricity Price ($)	159.83	38.77	0.0105	1200.34
Weighted Average Price ($)	151.7	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 observation (N)= 6960				

TABLE 2− PER CAPITA AVERAGE ELECTRICITY CONSUMPTION (MWh) OF TEN HIGHEST AND TEN LOWEST EV ADOPTING COUNTIES.

	Per capita Electricity Consumption	
Year	Highest ten EV Adopting Counties	Lowest ten EV Adopting Counties
2010	5.195661	7.729343
2011	5.202825	7.449097
2012	5.236772	7.349705
2013	5.169420	7.818618
2014	5.180664	7.276375
2015	5.113932	7.279233
2016	5.060803	7.557632
2017	5.133418	7.712501
2018	4.987629	7.450165
2019	4.954126	7.672754
Welch Two Sample t-test: t = -34.764, p-value = 3.568e-14		

Moreover, I have collected electricity generation data of California State at yearly level by counties for 2010 to 2019 from the US Energy Department to estimate the effect of EV adoption on the types of electricity generation by renewable sources. In California, major electricity sources are coal and natural gas. Major renewable electricity sources are Hydroelectric, solar and wind. Figure- 9 below shows the trend of the electricity generation by sources in California State as a whole for the past ten years and Table 3 shows the summary statistics of the electricity sources.

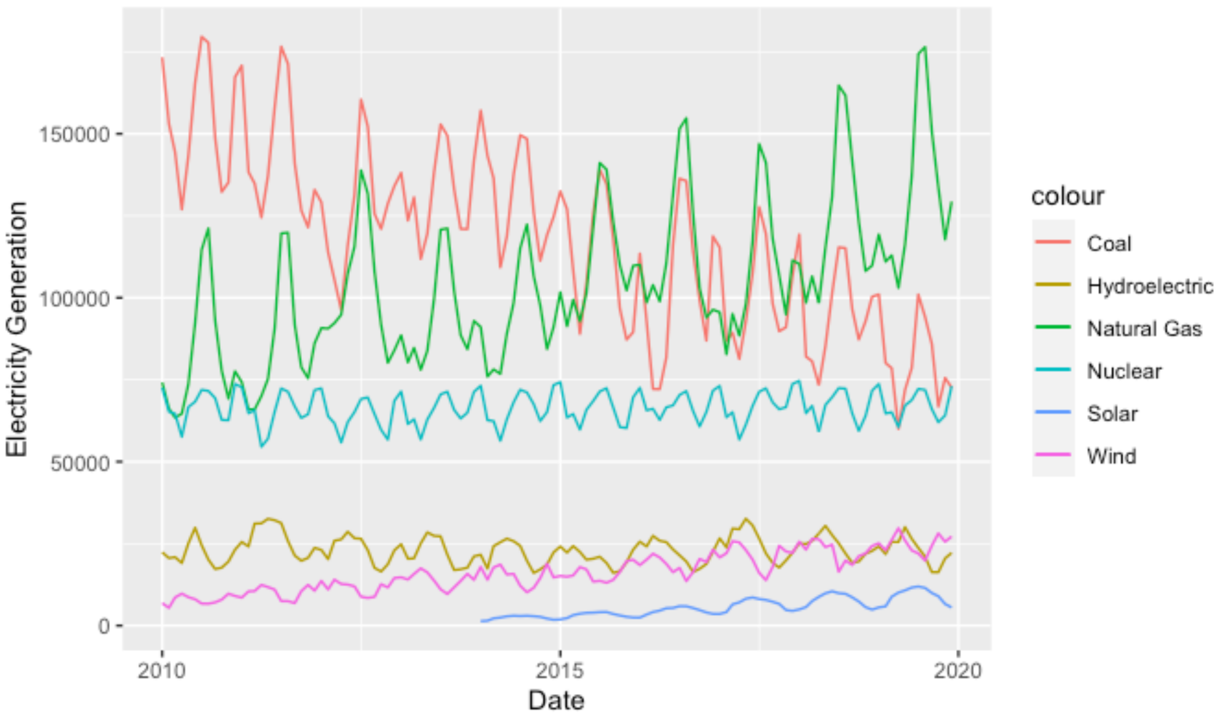

Figure 9: Electricity generation of California by sources. Three major sources are non-renewables (Source: EIA, 2020)

From the Figure-9, we can see that the solar production did not start in California until December 2013. Renewable electricity share in the total electricity production remains very low in this ten-year period in California.

TABLE 3: SUMMARY STATISTICS OF ELECTRICITY GENERATION BY SOURCES.

		Non-Renewable			Renewable		
	All Fuel	Coal	Natural Gas	Nuclear	Hydroelectric	Solar	Wind
Minimum	287800	60008	63431	54547	16074	1375	5432
Average	340978	118088	104483	66475	23060	5566	16249
Maximum	418693	179600	176458	74649	32607	11941	29711
Number of observation (N) = 580							

According to this data, in December 2019, total electricity generation in California was 337253.09 thousand MWh, and Hydroelectric, solar, and wind combined generated 54929.56 thousand MWh electricity, which is only 16% of the total electricity generation. The other three sources, like Coal, Natural Gas, and Nuclear, contribute the most to California's electricity production. Table 4 shows the average percentage share of electricity that comes from renewable resources in the ten most EV adopting and ten least EV adopting counties.

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	379538	27958	Modoc	NA	0	20
Santa Clara	0.8831	208307	8430.2	Sierra	92.75	18.7	11
Orange	1.6723	176010	5160.6	Alpine	NA	13.60	61.7
San Diego	6.1137	116925	10552	Lassen	20.979	23.1	24.8
Alameda	17.7320	118198	4713	Trinity	100	46.50	25.0
Contra Costa	0.64937	55773	1123.8	Colusa	0	46.0	23
San Mateo	0	54804	1797.6	Glenn	100	59.70	0
Riverside	34.184	36840	5231	Mono	24.40	51.50	380.6
San Bernardino	27.99	29062	3606	Plumas	89.50	57.30	28.9
Sacramento	13.575	27828	6185	Inyo	20.706	78.60	43.2

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. 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. People charge their EVs either at home or at the charging stations. Apart from public charging stations, there are numbers of private charging stations in California, and many EV owners adopt relatively simple Level 1 EVSE or the slightly more complex Level 2 EVSE at their residents. 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 (CVRP, 2020). So, in my model, I exclude other sectors like the agricultural sector, industrial sector etc. from this analysis. The electricity consumption for county i at time t is specified as-

$$ELECTRIC_{it} = b_0 + b_1\, EV_{it} + b_2\, INCOME_{it} + b_3\, POP_{it} + b_4\, HH_{it} + b_5\, STATION_{it} + b_6 HOTMONNTH_{it} + b_7\, COLDMONTH_{it} + b_8\, PRICE_{it} + b_9 t + b_{10} i + u_{it}$$

Here, ELECTRIC is the monthly residential and commercial electricity consumption for each county. EV is the number of electric vehicles 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 sum of the numbers of applications for each county at monthly level. In my model I am assuming people file their application in the same month they purchase EV.

Moreover, the term STATION represents the charging stations of EV in each county. Apart from installing charging connectors at home, numbers of EV owners charge their cars in the station rather than in their homes, mostly because of its fast-charging capacity. So, this variable also should have a positive relationship with the outcome variable and so that also is another variable of interest. In my data, I have the opening date of each station or charging connector which are still active in 2020. Just like EV variable, I take the cumulative sum of the numbers of stations for each county at monthly level. In my model, however, I primarily use STATION variable and EV variable separately as they both should account for the EV adoption. However, I use these two variables together also to see the EV effect while controlling for STATION, and vice versa.

Remaining variables are control variables. The term HH is the type of household size. Households with a different number of members may have a different electricity-consuming pattern. The demand-side economies of scale, or the network effect, would be examined through this variable. In other words, 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 household size on electricity consumption would be negative. I have three separate variables to account for the household size. These are “Single” for Single housing unit, “Multi” for Multi-housing unit, and “Mobile” for Mobile housing unit. Multi housing units should have a negative effect on electricity consumption on the residential sector and single and mobile units are expected to have a positive effect.

"i" and "t" stand for county fixed effect and time fixed effect respectively. More specifically, time fixed effects accounts for year- month level in this model.

HOTMONTH and COLDMONTH are two separate count variables, which represent the climate factor 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 degrees Fahrenheit or more temperature as hot days and 32 Degree Fahrenheit or less as cold days (Alberini, et al., 2017).

The term PRICE is the weighted average electricity price of the residential and commercial sector, 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 residents will consume more electricity, so the influence of the population would be positive.

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,

$$\begin{aligned} RENEWABLE_{it} = {} & b_0 + b_1\, EV_{it} + b_2\, INCOME_{it} + b_3\, POP_{it} + b_4\, SIZE_{it} + b_5\, STATION_{it} \\ & + b_6 HOTYEAR_{it} + b_7 COLDYEAR_{it} + b_8 PRICE_{it} + b_9 t + b_{10} i + u_{it} \end{aligned}$$

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 the t represents a year, and HOTYEAR/ COLDYEAR accounts for the average hot/cold degree years.

5. RESULT

5.1 EFFECT OF EV ADOPTION ON ELECTRICITY CONSUMPTION

As I mentioned earlier, utility companies define different sectors based on rate classes; Residential charging of EVs typically falls under residential consumption and non-residential electric vehicle usage and their charging typically falls under what the utility defines as their commercial sector. So, in my model, I look at these two sectors combined.

Table 5 represents the primary results 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 and in the second column, I use the charging station as my explanatory variable without EV in it. In the third column, I keep both EV and charging station as explanatory variable and they both are significant at 1%. 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. This is a two-way fixed-effect model where I control for county-fixed effect and year- month fixed effect. We can see that, in column (2), the charging station has a coefficient of 89.85, and this result is highly significant. This means one extra charging station or connector can increase monthly electricity consumption by 89.85 MWh. Also, the first column shows that the EV adoption increases 4.389 MWh of electricity consumption in the residential and the commercial sector. It is worth mentioning that our rebate data covers around 74% of the total EV registration according to the CVRP website. So, this result should be at least one quarter higher in reality. The population has a significant positive result on consumption also. Nevertheless, both single housing units and multi-housing units have negative impacts. Mobile housing impact, however, has a positive impact on electricity consumption. Hot degree months have a highly significant positive effect.

Table 6 shows different specification. I use logged value for EV, Charging station, Income, population, and weighted price. For the housing units, I take percentage of single housing among the three types. 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. This time, both EV and Charging station shows significant positive effect on electricity consumption. However, when I take both of them as explanatory variables, only charging station is significant. This time, single housing unit shows positive effect and the cold months are significant at 1% level.

TABLE 5: EFFECT ON RESIDENTIAL & COMMERCIAL CONSUMPTION

Variables	(1)	(2)	(3)
EV	4.39*** (0.53)	×	2.51*** (0.57)
Charging Station	×	89.86 *** (7.97)	75.64*** (8.59)
Income	-0.23 (0.15)	0.072 (0.15)	--0.056 (0.15)
Population	0.86*** (0.08))	0.996 *** (0.081)	0.98*** (0.08)
Weighted Price	128.13 *** (44.499)	147.36*** (44.38)	156.58*** (44.37
Single HH	-5.17 *** (0.696)	-5.69*** (0.69)	-6.25*** (0.70)
Multi HH	-6.69*** (0.54)	-8.68*** (0.59)	-9.87*** (0.64)
Mobile HH	22.88 *** (6.56)	14.13** (6.40)	20.11*** (6.53)
Hot Months	154556.07*** (10027.86)	152400.97*** (9983.571727)	153383.73*** (9972.41)
Cold Months	16743.29* (8814.75)	16934.10* (8776.95)	16617.48* (8765.24)
County Fixed effect	✓	✓	✓
Time Fixed effect	✓	✓	✓

*Notes: *** p<.001, ** p<.0, * p<.05. standard errors reported in parenthesis*
Number of observations = 6960

TABLE 6—DIFFERENT SPECIFICATION

Variable	(1)	(2)	(3)
Log(EV)	0.0112406 ***	×	-0.0017252
	(0.0041150)		(0.0076108)
Log(Station)	×	0.0101491***	0.0112859 ***
		(0.0037258)	(0.0039154)
Log (Income)	-0.0019946 ***	0.0156444	0.0175215
	(0.0211244)	(0.0222206)	(0.0219260)
Log(Population)	0.5965913 ***	0.7139990 ***	0.7036524 ***
	(0.1296985)	(0.1597625)	(0.1641407)
Log(weighted price)	0.0903052 ***	0.1005355 ***	0.0984768 ***
	(0.0142248)	(0.0173861)	(0.0174884)
% of single HH	0.0111144*	0.0167992 **	0.0173948 **
	(0.0067377)	(0.0072459)	(0.0072336)
Factor(80-85)	0.1836024 ***	0.1917442 ***	0.1876538 ***
	(0.0128315)	(0.0138159)	(0.0136066)
Factor(>90)	0.4451724 ***	0.4526880 ***	0.4464716 ***
	(0.0358259)	(0.0407515)	(0.0401146)
Factor(25-30)	0.2568198 ***	0.3352906 ***	0.3168814 ***
	(0.0320408)	(0.0329991)	(0.0364106)
Factor(20-24)	0.5662467 ***	0.5948542 ***	0.5942605 ***
	(0.1235598)	(0.1184903)	(0.1166572)
County Fixed Effect	✓	✓	✓
Year Fixed Effect	✓	✓	✓

Notes: *** p<.001, ** p<.01, p<.05. standard errors reported in parenthesis

Number of observations = 580

Table 7 represents the result for the residential electricity consumption only. 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 station. This is also a two-way fixed effect model. In column (1), EV shows a coefficient of 0.947 for residential electricity consumption. This result is significant at 1% level. So, one extra EV adoption can cause 0.94 MWh residential electricity consumption monthly. The population has a significant positive result on consumption, multi-unit housing has a significant negative effect, and hot degree months have a significant positive effect as we expected. Charging station numbers also affect residential electricity consumption positively, and significantly. One charging station increases 34.947 MWh residential electricity consumption monthly. However, in the column (3), EV does not have any significant effect, but charging station is still highly significant and has a positive effect on residential electricity consumption.

TABLE 7: EFFECT ON RESIDENTIAL CONSUMPTION

Variables	(1)	(2)	(3)
EV	0.95*** (0.35)	×	0.87 (0.38)
Charging Station	×	34.95*** (5.28)	34.45*** (5.70)
Income	-0.126 (0.098)	-0.043 (0.096)	-0.047 (0.098)
Population	0.307 *** (0.053)	0.36*** (0.054)	0.362*** (0.054)
Residential Price	11.01 (20.25)	17.72 (20.22)	17.87 (20.23)
Single HH	-0.64 (0.46)	-1.116 ** (0.46)	-1.135** (0.467)
Multi HH	-2.22*** (0.355)	-3.62 *** (0.388)	-3.66*** (0.427)
Mobile HH	6.559 (4.35)	5.077 (4.25)	5.28 (4.35)
Hot Months	123801.73*** (6646.38)	123194.82*** (6627.68)	123227.57*** (6629.68)
Cold Months	4618.35 (5837.476)	4647.54 (5821.67)	4638.67 (5822.21)
County Fixed effect	✓	✓	✓
Time Fixed effect	✓	✓	✓

*Notes: *** p<.001, ** p<.01, p<.05. standard errors reported in parenthesis*
Number of observations = 6960

5.2. ELECTRICITY GENERATION IN CALIFORNIA

Natural gas, coal, nuclear, hydroelectric, solar, and wind are the major electricity generation sources in California. Among these, hydroelectric, solar, and wind are considered clean, renewable sources. As California State 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. To analyze the relationship between EV adoption and renewable energy sources, I construct a variable, which is the percentage share of electricity that comes from renewable sources in each county. Then, I run a two-way fixed-effect model to see the effect. 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. However, experts sometimes debate about biomass and geothermal sources' nature over whether these should be considered renewable and cleaner resources or not. Both of these sources emit a considerable amount of CO_2 and heat into the atmosphere (U.S. Energy Information Administration, 2019). However, in this analysis, I analyze the renewable sources both with and without considering these two sources as renewable sources.

Table 7 shows the result of the impact of EV adoption on renewable sources of energy. In the table, column (1), (2), (5) include biomass and geothermal, and the other only consider hydroelectricity, solar and wind.

The result shows that EV adoption does not increase renewable electricity generation. Instead, variable EV shows a negative effect on renewable sources generation. When I account for both charging stations and EV, EV shows a highly significant negative impact on renewable sources. Although the coefficient is small, this negative effect is crucial for the policy perspective. It means more EV adoption is accompanied by decreased adoption of renewables sources. However, when the station is considered as an explanatory variable, I do not find any significant effect.

TABLE 8 —EFFECT OF EV ADOPTION ON RENEWABLE ENERGY SOURCE

	(1)	(2)	(3)	(4)	(5)	(6)
Electric Vehicle	-.000084*** (0.000029)	×	-0.000125*** (-3.13)	×	-0.000094*** (0.00003)	-0.000143*** (0.00004)
Charging Station	×	0.000189 (0.00047)	×	0.00036175 (0.5577)	0.00061 (0.00048)	0.00099 (0.00067)
Population	-0.0000389 (0.000053)	-0.000029 (0.000054)	-0.0000614 (-0.8488)	-0.0000446 (-0.6009)	-0.000027 (0.000054)	-0.000043 (0.000073)
Income	0.0002** (0.0001)	0.00016 (0.00010)	-0.0000079 (-0.06)	-0.000071 (-0.51)	0.00022** (0.00010)	0.000024 (0.00014)
Weighted Price	-0.0074* (0.004)	0.00145 (0.00045)	-0.1398** (-2.03)	-0.100 (-1.43)	-0.006658 (0.00408)	-0.0104 (0.0056)
Single HH	0.00186*** (0.0040)	0.0015*** (0.00045)	0.00198*** (3.23)	0.00134** (2.18)	0.001749*** (0.000456)	0.00179 *** (0.00062)
Multi HH	0.00186** (0.000447)	-0.000217 (0.00040)	0.001251** (2.58)	-0.00028 (-0.4963)	0.000408 (0.000452)	0.00067 (0.00062)
Mobile HH	-0.0025 (0.00408)	0.000096 (0.00402)	-0.00335 (-0.5995)	0.00065 (0.1181)	-0.002724 (0.00408)	-0.00356 (0.0056)
Hot months	3.052 (13.916)	1.445 (14.055)	7.365 (0.388)	4.93 (0.2569)	2.38010 (13.91657)	7.413 (19.038)
Cold months	-0.0025 (0.00408)	-1.479 (4.446)	5.4989 (0.91)	5.773 (0.95)	-1.376569 (4.40158)	5.898 (6.021)
Biomass	✓	✓	×	×	✓	×
Geothermal	✓	✓	×	×	✓	×
County Fixed effect	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✓	✓	✓

*Notes: *** p<.001, ** p<.01, p<.05. standard errors reported in parenthesis*
Number of observations = 580

6. DISCUSSION AND CONCLUSION:

Apart from the rebate programs for EV and EVSE, California has 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 dollars since 2010 (California public utilities commission, 2020). Nikolewski (2019) contends the breakdown of California's all EV incentive programs' total spending, which is $2.46 billion for a period of approximately ten years. As I stated earlier, all of these incentives are stemmed from environmental concerns. In general, experts agree that electric vehicles are cleaner than other conventional vehicles powered by diesel or gasoline while driving; EV emits fewer pollutants in the atmosphere. Nevertheless, increased electricity demand due to EV and its supporting infrastructure is absent in the policy discussions. If this issue is not addressed correctly, there would be unintended consequences on public spending and, most importantly, on the environment. Although California is trying to reduce the coal-based power plants in recent years, coal is still one of its primary electricity sources along with natural gas and nuclear. These power plants emit a significant amount of greenhouse gas and other pollutants, as discussed earlier. 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 sources of electricity production.

Nonetheless, 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. In this study, I cannot account for the imported electricity sources. This would be a scope for the future research. Another interesting aspect of this research could be the analysis of adoption of small-scale customer-sited solar photovoltaics (PV) in California. This is known as behind-the-meter generation and the predominant technology is residential solar PV. In 2019, there was about 16,000 GWh of self-generation from solar PV (California Energy Commission, 2019, slide 8). But there is no data available at county level to see the relationship of the EV adoption with the PV adoption.

However, this study finds that EV adoption significantly increases the electricity consumption in residential and commercial sectors. Along with that, it finds evidence that EV adoption is accompanied with the fewer adoption of renewable power plants. Specifically, we see a significant decrease in the renewable source usage when considering the electric vehicle as an explanatory variable. These results should be an important viewpoint for policymakers. Considering the average number of charging stations per county, EV adoption increases monthly residential and commercial electricity consumption by 4.74%. Based on California's average energy generation, this would yield 159267.86 MWh (19.64%) electricity in non-renewable sources generation in a year. Evaluating the true environmental impact of government EV incentives 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 may not be as effective as it would be if accompanied by increased adoption of renewables.

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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. As long as 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 state for the California Air Resources Board (CARB). [17] In my dataset, there are a total 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. 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 percent 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. Those that have already met their two-rebate limit will remain ineligible for an additional rebate. 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 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[3] 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 take advantage of rebates for installing commercial charging stations for public use and thus generate a new revenue stream (fees for charging). In California, there are nineteen separate utility incentives and ten air district incentives for the commercial installation of EV charging station

[3] 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).