Electric Vehicles & Air Pollution

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ESM 195

Abstract

Automobile usage has contributed largely to pollution that can have broad sweeping impacts in local regions such as poor air quality and health issues. Electric vehicles, through market forces and California policy, have been pushed as a solution for this issue. Thus, it is important to study and understand the real impact of electric vehicle usage on reducing criteria pollutants such as PM2.5 and ozone since these are the most common pollutants emitted from gasoline automobiles. Data for electric vehicle usage was collected from the California Department of Motor Vehicles (DMV) and pollution data was collected through California Air Resource Board (CARB). Looking at the counties of interest, it was found that there was a strong correlation between electric automobile use and PM2.5 and no correlation between electric automobile use and ozone, presumably due to other factors. This suggests that electric vehicle usage does have an impact on levels of certain pollutants and may be a solution for reducing air quality impacts from the transportation sector in California. Though the study was limited by an inability to capture every factor that influences air pollution, it is clear that electric vehicle usage does impact air quality of some pollutants. We recommend that California place additional taxes on gasoline automobiles based upon income, and make subsidies for electric vehicles more readily available.

Author Biographies

Matthew Slifer: My name is Matthew Slifer and I am a fourth year undergraduate pursuing a degree in Environmental Science and Management with a concentration in natural resource management. I have done various research projects on the effect urban planning has on the environment with topics such as transportation and housing. I also have experience with ArcGIS and ENVI, both of which are commonly used to analyze, understand, and monitor environmental conditions.

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Miri Kim: My name is Miri, and I'm a third year student, majoring in Environmental Science and Management, with an emphasis on natural resource management. I've done research projects and papers on the interaction between urban planning and the environment, as well as housing availability in cities. I'm also familiar with GIS, and its importance as an analytical tool for observing and monitoring human impacts on the environment.

Kyle Krueger: My name is Kyle Krueger, and I'm a 4th year environmental science and management major (natural resource management track.) Though I am a science major, I have developed some knowledge in policy and government through outside internships in the California State Assembly, the California Department of Justice, and local government experiences. I have also spent the past year studying air pollution in the San Joaquin Valley, and so I am familiar with air pollution issues from a policy standpoint. I look forward to connecting my knowledge of policy to the transportation and air pollution issues that we are studying.

Introduction

Air quality has been a perennial issue largely impacting human health over the world. The Environmental Protection Agency(EPA) aims to diminish the risk of pollutants on human life by establishing air quality standards to regulate six common air pollutants: carbon monoxide, lead, ground-level ozone, particulate matter, nitrogen dioxide and sulfur dioxide (EPA,1971). Photochemical smog, a composite of pollutants such as ozone and particulate matter, is one of the notorious phenomena stemming from air pollution, and it reduces the visibility in the environment and causes approximately three million global mortality per year (Chen et al., 2007). The transportation sector greatly contributes to the formation of photochemical smog in the world. Additionally, cars release nitrogen dioxide, a precursor to ozone. Ozone triggers both acute and chronic damage to the human body; it can irritate the respiratory tract and cardiovascular system(Chen et al., 2007).

California is also highly automobile dependent with 85% of residents over the age of 16 having a driver's license with the vast majority of that group using automobiles as their primary means of transportation (California's Transportation System, 2018). The transportation sector in California is responsible for the majority of California's air pollution. In particular, automobile use accounts for one third of all greenhouse gas emissions in the state and half of carbon monoxide and nitrous oxide emissions (California's Transportation System, 2018). Consequently, with these two factors it is clear that the transportation sector is a large contributor to pollution and emissions in the state.

Geography and climate within the state of California worsen the effects of air pollution emitted by transportation. According to the World Health Organization, 10 of the most polluted cities in the United States were located in the Central Valley (Berg, 2011). It is important to note that the Central Valley, and much of California, is surrounded by steep mountainous terrain with valleys in between. This geographical feature creates a naturally occurring inversion layer of warm air which traps smog, particulate matter, and other pollutants near the surface (Berg, 2011). A similar phenomenon can be seen in the LA basin due to frequent warm weather, dryness, and the region's geography, resulting in high ozone levels ("Air Quality", 2016).

Rapid technological advancements and increasing climate and environmental awareness has contributed to the growth of the EV industry. Governments, such as the state of California, have been promoting policy measures and monetary incentives and infrastructural incentives (charging stations) have had the greatest impact on the rise of EV sales and usage. (Reitmann & Leiven, 2018). Automotive battery production has increased 33% from 2019 to 2020, and average battery costs have declined by 13% (International Energy Agency, 2021). However, growth of EVs is not evenly distributed, but led by a handful of wealthy areas. Regions with high purchasing power have higher percentage of EVs than do regions with lower purchasing power, indicating that economic factors play an integral role in electric mobility.

In California, the California Air Resources Board (CARB) is the primary agency responsible for mobile source emissions, and has set ambitious electric vehicle goals in order to reduce greenhouse gas emissions. CARB's electric vehicle goals for the State of California include a requirement for 35% of car sales in California by 2026 to be electric vehicles, followed by a requirement that 100% of car sales be for electric vehicles by 2035 (Ronanye, 2022).

CARB offers a number of incentives for EV adoption, such as point-of-sales rewards for EV customers to reduce upfront costs. Such incentives and electric vehicle targets have already had measurable impacts on the relative number of electric vehicles in California (Najman, 2022). California has 425,300 registrations of electric vehicles, the highest of any state (Najman, 2022). Given the amount of resources dedicated to incentivizing electric vehicle adoption in California, understanding the impacts of electric vehicles on localized air pollution is warranted. The objective of the study is to answer the question: How has the increase in electric vehicles in California over time impacted California air quality, at the aggregate and local levels? The results of this study will inform the impacts of electric-vehicle related policies on air pollution in California, and how such policies can be changed to reduce the costs or increase the benefits of electric vehicles.

Methods

Site Selection

We decided to observe the impact of EV on air quality for 9 different counties, Alameda, Fresno, Kern, Los Angeles, Marin, Orange, San Francisco, San Joaquin, and Yolo County, in California. When choosing the study sites, we took into consideration multiple different factors that relate to air quality. We aimed to capture areas of a range of income levels because it is possible that high income levels correlate with more electric vehicles, since individuals in high income areas are likely to have more purchasing power for electric vehicles. We also aimed to capture a range of geographies, since air quality varies across California's diverse topography. We wanted to ensure that we captured counties that varied in these factors, so that we can better capture variances in air pollution and electric vehicle market penetration.

First, in looking at income, Marin, San Francisco, Alameda, and Orange County, have high per capita income ($58,000 - $36,000) and median household income ($91,000-$73,000). (U.S. Census Bureau, 2014). This may have an influence on the number of total EV registration, as compared to counties in lower income brackets, such as Fresno, or Kern who are on the lower end of the spectrum, and average $20,000 and $47,000 in per capita and median household income, respectively (U.S. Census Bureau, 2014).

We also considered various geological features of different counties, since this can also play a role in the concentration of pollutants. Keeping these factors in mind while selecting counties ensured that our study included counties of a diversity of relevant characteristics.

Data Collection

In order to assess the effect of electric vehicles on local air pollutants, we collected data on both the percentage of electric vehicles (per county) and the level of air pollutants (per county). We chose the year 2020 for our analysis, due to 2020 being the most recent year that data is available on air quality by county. Choosing the most recent year possible ensured that the types of the electric vehicles that we studied were as reflective as possible of electric vehicles currently on the road.

For our air quality data, we consulted the California Air Resources Board's (CARB's) website. We analyzed PM2.5 and Ozone (State) because they are two of the most common types of pollutants from vehicles, as discussed in the introduction. CARB has data for air quality through the year 2020, and CARB's website includes tools that allow such data to be summarized by county (CARB 2020). Though both national and state statistics were available for PM2.5 and ozone on CARB's website, we used state statistics for both ozone and PM2.5. State statistics are based on California's data sampling methods, whereas national statistics are based on federal data sampling methods (CARB 2020). We used state statistics because we aim for our study to credibly inform California's statewide policies as much as possible, and thus chose to respect California's more stringent air quality sampling methods. We first used CARB's tools to summarize data by county for PM2.5 pollution, and we recorded the annual average PM2.5 levels, measured in micrograms per cubic meter, for each county in our study (CARB 2020). We also used CARB's tools to summarize data by county for ozone. We recorded ozone's maximum 8 hour averages per year, measured in parts per million (ppm), for each county in our study (CARB 2020).

The website EV Hub provides data on the total number of electric vehicles registered in California at a given time; such information was originally drawn from the California Energy Commission ("State" 2022). Though the website does not explicitly specify if the number of total electric vehicles are for automobiles or all vehicles (including trucks, etc.), a detailed purview of the website's spreadsheets of registered electric vehicles finds only registered electric automobiles ("State" 2022). Thus, we chose to focus our study on the percentage of automobiles that are electric vehicles, since data was available for electric automobiles. Data on the total number of automobiles registered in California (by county) was taken from the California Department of Motor Vehicles website ("Estimated" 2020). The number of registered electric vehicles by county was divided by the number of total registered automobiles by county to gain a new variable, the percentage of automobiles per county that are electric vehicles. This new variable is important because the aim of the study is to measure how the penetration of electric vehicles in a market affects air quality, not how the total number of vehicles affect air quality.

Analysis

For our analysis, we ran multiple linear regressions to analyze the impact that the percentage of electric automobiles have on PM2.5 levels and ozone. We chose a linear regression because the slope of a linear regression can give useful information about how one variable affects another. We also expect that the correlation between electric vehicle penetration and local air pollution will be linear, since each additional electric vehicle likely reduces or increases pollutants by a set amount. Thus, a linear regression is likely to capture the necessary data. In our regressions, the independent variable was the percentage of automobiles that are electric, and the dependent variable was the level of the respective air pollutant.

Each linear regression included the generation of an R squared value, which is a measure of how much of the dependent variable's variance can be explained by the independent variable. There is no commonly accepted minimum value of significance for R squared values across all fields. However, one researcher proposed that an R squared value of 0.75 provides substantial evidence that changes in a dependent variable are a result of the independent variable (Henseler, 2009). Based on this research, we considered 0.75 to be the minimum R squared value for which it could be confidently said that the independent variable affected the dependent variable.

The first of our linear regression studied how PM2.5 pollution (in micrograms per cubic meter) varied with the percentage of automobiles that are electric. Our second linear regression studied how ozone concentration (in ppm) varied with the percentage of automobiles that are electric.

Results

1 | Quantifying the usage of electric vehicles in California

Our initial data findings of electric vehicles indicated basic information such as counties, vehicle registration, electric vehicle registration, annual average PM2.5, and ozone concentration in the three regions: Central Valley, Southern California, and the Bay Area (Table 1). We summarized our data in Figure 1 regarding the impact of average household income across different counties on the local usage of the percent of electric vehicles.

When we compared the percent use of electric automobiles on road, our result showed that counties in the bay area have the highest usage of electric vehicles, accounting for at least 4.1% on-road vehicle, and counties in the central valley have the lowest usage of electric vehicles on road, ranging from 0.7% to 2.4% (Table 1).

Table 1. Information on the electric vehicle and vehicle registration and air pollutants concentration in different counties selected for analyzing the usage of electric vehicles in 2020

Regions	Counties	Total EV(autos) on the Road 2020	Total vehicle registration (autos) 2020	PM2.5 in mg/cm^3	Ozone in parts per million
Central Valley	Kern	3222.00	466959.00	19.70	0.11
	Fresno	5481.00	558939.00	20.30	0.11
	San Joaquin	5918.00	468481.00	14.80	0.08
	Yolo	2948.00	122169.00	13.00	0.08
Southern California	Los Angeles	154234.00	6361987.00	16.30	0.14
	Orange County	76706.00	2258772.00	12.40	0.12
Bay Area	San Francisco	16134.00	393968.00	10.50	0.06
	Alameda	45785.00	1066131.00	11.80	0.09
	Marin	9657.00	193195.00	8.70	0.06

Sources: California Air Resources Board, The Department of Motor Vehicles (2020), Ruder(2022)

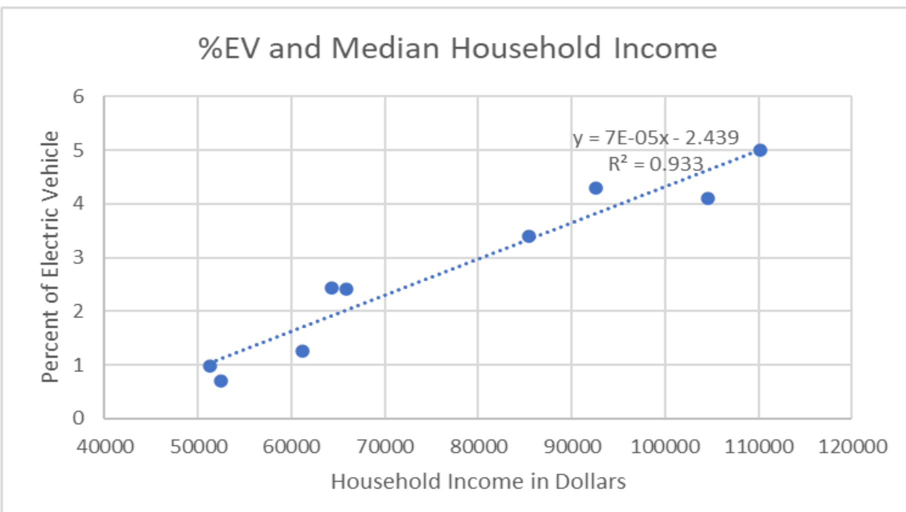

Figure 1. The linear regression analysis between the impact of household income and the percent use of electric vehicles on road. The x-axis represents the average household income in dollars and the y-axis represents the percent of electric vehicles.

Source:Indexmundi (2018)

Figure 1 demonstrates a strong linear trend that as the household income increases, the usage of electric vehicles elevates at the same time. The statistical analysis with 0.933 R^2 values indicates that the average household income is crucially important to determine whether local residents are desired to purchase an electric vehicle. It suggests that household income needs to be considered in evaluating the impact of electric vehicles on air quality.

2 | Connecting electric vehicles usage to air pollutants

The results of regression analysis are shown in both Figure 2 and Figure 3 to help us visually understand the correlation between the usage of electric vehicles and air pollutants concentration.

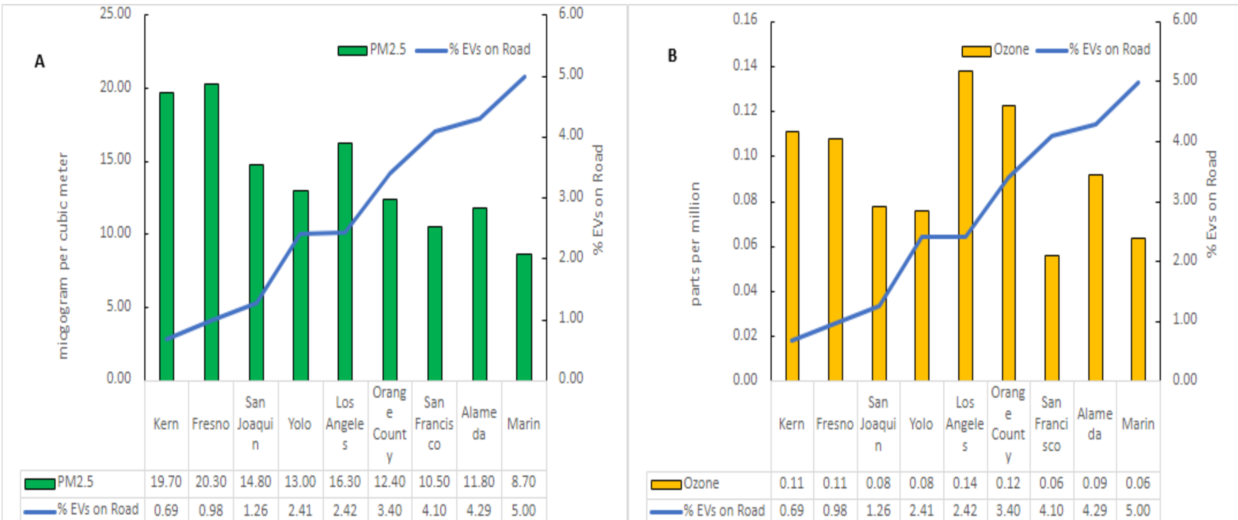

Figure 2. Combination of air pollutants PM2.5 and Ozone concentration and EV usage (automobiles) on the road in nine counties.

Sources: CARB, DMV 2020

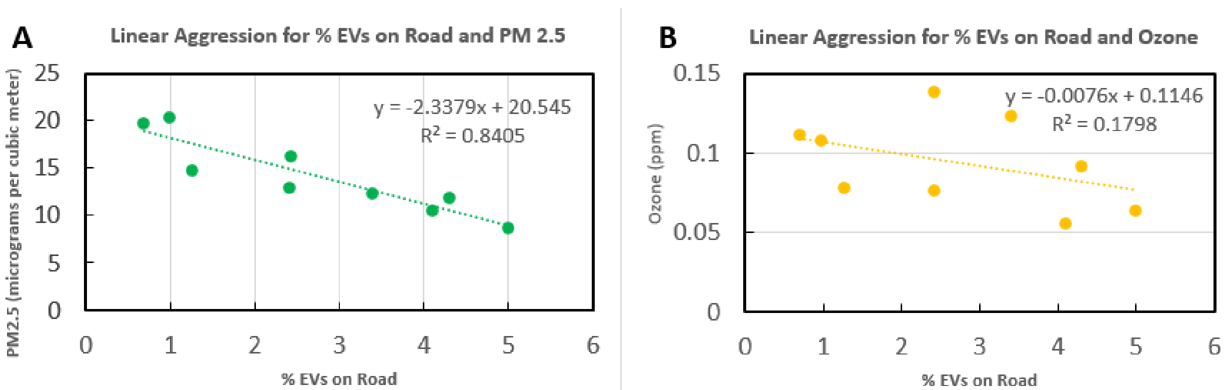

Figure 3. The linear regression line between air pollutants concentration and %EV on use. The x-axis shows the percent of EVs (automobiles) on the road, (A)the y-axis is the PM2.5 concentration in mg/cm3,(B)the y-axis is the ozone concentration in ppm.

We can see that there is a general trend of decreased PM 2.5 levels when there is a higher percentage of EV usage on the road (Figures 2A&3A). Counties with higher electrical vehicle usage usually had lower levels of PM 2.5. Our statistical analysis of these two factors resulted in the R^2 value of 0.8405. This reveals that there is a high correlation between the presence of electrical vehicles on the road and the level of PM 2.5.

Our data reveal that there is little to no relationship between ozone concentration and the percent of electrical vehicles present(Figures 2B&3B). When we ran a statistical analysis between the two variables, we got a R^2 value of 0.1798. This r-squared value indicates a weak correlation or no relationship between electric vehicle usage and ozone concentration. It unveils that counties such as Los Angeles and Orange County had the highest ozone concentration out of all the ones that we looked at despite their highest electric vehicles usage(Figure 3B).

Discussion and Recommendations

Our results displayed a strong correlation between PM2.5 pollution and the proportion of electric vehicles, and a lack of correlation between ozone and electric vehicle usage in the counties. At first glance, this would appear to indicate that increased usage of electric vehicles can result in PM2.5 emission reductions, especially given the high R^2 value of 0.8405 (indicating that changes in our dependent variable, PM2.5 emissions, were a response to changes in our independent variable, electric vehicle usage.) However, our study was limited due to the wide variety of other variables which our simple linear regression was unable to incorporate.

Median household income is one variable that is highly correlated with the percent usage of electric vehicles in every county. This demonstrates that the affordability of electric vehicles is an important factor to consider when analyzing the influence of electric vehicle usage on air quality. However, it also raises the possibility that PM2.5 pollution and electric vehicle usage are both responding to another variable (income) rather than affecting one another, since higher income levels could also be associated with less PM2.5 pollution. Other factors, such as topography and sustainable practices of an area's residents, could also be the cause of the trends in both PM2.5 pollution and electric vehicle usage that we discovered. Topography is also a particularly complex variable that involves multiple factors (the distribution of nearby elevation, etc.). This would make it difficult to capture in a regression model, even though topography is well-documented as having a significant influence over pollutants (A.C., 2006).

Other studies have demonstrated that although on-road vehicles only contribute to 12.8% of total emission of PM2.5, their uneven spatial emission of PM 2.5 has a more significant impact on many communities across the county compared to the point sources like electrical power plants (Li& Managi, 2021). Since burning fuels in on-road transportation can directly emit a tremendous amount of PM2.5, electric vehicles can lower the dependence of fuel burnings to gain energy from the on-road vehicles to reduce PM2.5. It is congruent with our assumptions that using electric vehicles potentially leads to a better local air quality. Therefore, there is reason to believe that not all of the correlation observed between electric vehicles and PM2.5 pollution was caused by other factors.

Ozone concentration surprisingly had an extremely weak or no correlation with the percent of electric vehicles on roads. One explanation is that, as opposed to PM 2.5 that is directly emitted into the atmosphere, ozone is secondarily generated from a photochemical reaction, for which VOCs and NOx are precursors (Atkinson, 2000). 87.5% of volatile organic compounds are naturally released from vegetation such as plants and trees, with the transportation sector contributing to at least 50% of total anthropogenic NOx emission in the atmosphere (Shao et al., 2009). Although the usage of electric vehicles can diminish the NOx concentration, it hardly emits a considerable amount of VOCs to alter the formation of ozone. It partially explains the weak correlation between the usage of electric vehicles and ozone concentration across 9 counties.

Through our analysis, we observed that air quality is impacted by a plethora of variables so, it can be difficult to deduce decreasing PM2.5 levels to be the result of the rising percentage of EVs on the road. Mainly, there was a lack of a more comprehensive and localized data that is needed to reach a more informative and definitive conclusion for the impacts of electric vehicles on air quality. Therefore, we recommend more localized data monitoring and collection of air pollutant sources, such as domestic fossil fuel use, cleaning formulas, beauty products etc, that contribute to air quality so that it can be studied with more precision.

Although the CARB has already set ambitious goals towards decreasing EV emissions, more specific and regulated policies are recommended for the continued advancement of the usage of EVs. This can include devising non-subsidized policies for point source entities, or educating the public on air quality issues.

In seeing that the rising EVs do correlate with decreasing PM2.5 levels, California should incentivise the electric automobile industry. However, since the rise in EV registrations are also consistent with increasing income, we should focus the subsidies on making EVs less exclusive by making them more economically accessible to people of lower income brackets. The policies should recognize that the income disparity serves as a significant barrier in the unequal distribution of air pollutants and create policies addressing the income gap.

Coupled with the implementation of policies for more equity, California should disincentivize non-electric vehicles by placing small taxes upon registration of such a vehicle. The amount can be determined based on income, so that it doesn’t create an additionally excessive financial burden on vehicle ownership. The intent for this policy is not in punishing non-electric vehicle owners, but to guide their decisions towards a more environmentally conscious decision.

Conclusion

Transportation has significant statewide and county wide impacts on California’s air quality. The rise of the number of EV vehicles and use on the road leads to a lower transportation burden on California's air quality since the transportation sector contributes a large amount of air pollutants. This study specifically analyzed the air pollutants PM2.5 and ozone. Fossil fuel use from motor vehicles significantly affects the concentration of PM2.5 and ozone, so it serves as a good indicator for the impact of EVs. Concentration of PM2.5 among the counties studied, generally decreasing trend with increased EV registrations, indicating that an increased EV usage strongly correlates with improving air quality. While decreasing PM2.5 displayed a stronger correlation with increasing EV vehicles, trends for the concentration for ozone had a more ambiguous pattern, in which a clear correlation could not be drawn. Given that there was a weaker correlation between ozone and EV's, we were able to see that certain air pollutants are susceptible to other variables unrelated to transportation. Economic, geographic, and topological were some of the factors that resulted in independent impacts for electric vehicle usage in each county. To better understand these trends, California should continue to closely monitor the impact of EV on air quality, through the concentrations of air pollutants at a local level. Income, geographical features, location, etc are additional factors that cause heterogeneity on the impact of EVs, across California. Therefore, the state should also localize policies and regulations for electric vehicles, in order to better reflect the environmental needs and condition of each county.

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