Electric Vehicle Popularity on the Rise: A Quantitative Report on How Electric Vehicle Policy Within States Has Influenced Charging Infrastructure

Ari Drayman

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Abstract

The purpose of this research paper is to identify if there is a relationship between the number of electric vehicle policies within each state and charging infrastructure. This topic is important because in 2020, there are more electric vehicle policies and public charging stations/outlets in operation than ever before. After doing extensive research of prior literature written within this field, it was surprising to find that there were no studies looking at a possible relationship between the number of electric vehicle policies within each state and charging infrastructure presenting a gap in the research. The hypothesis is, in comparing states, those having more refined electric vehicle policy will have better electric vehicle charging infrastructure than will those having less refined electric vehicle policy. The method used to see if there is a relationship between the variables was a correlation and linear regression test. The findings of the test showed that there is a moderately strong relationship between the number of state electric vehicle policies and charging infrastructure lending support to the research hypothesis.

Introduction

The internal combustion engine (an engine powered by fossil fuels) has been powering vehicles since it was invented in 1876 by Nicholas Otto. At the time, this type of power train was (and still is) the most practical for vehicles as oil is easy to find and cheap to use. However, as cars became more mainstream and the interstate highway system was being formed, people started to realize that oil is a finite resource. This issue became a reality during the oil crisis and economic downturn in the 1970s where people had to wait in lines for hours to fuel their cars.

This caused Congress to take action as the newly founded Environmental Protection Agency developed the corporate average fuel economy standards (Bosworth, Crabtree, and Patty, 2017). This federal policy dictates a baseline fuel economy for all automakers selling vehicles in the United States. If the average fuel economy for their model line dips under the minimum fuel economy requirement, the car manufacturer will be fined heavily by the federal government. This regulation was enacted not only because of the oil crisis of the 1970s but also due to people's growing concerns about the combustion engine's impact on the environment.

As a result of the Environmental Protection Agency's corporate average fuel economy standards, regulations became more stringent and in the 1990s automakers started to have trouble keeping their vehicle fleets within the standards of the policy. This motivated car manufacturers to develop and build alternative-fueled vehicles that were fully battery operated because electric vehicles generate no tailpipe emissions (Bosworth, Crabtree, and Patty, 2017). By doing so, automakers were able to raise their fleet's average fuel economy within the government's regulations. This caused a new vehicle market to be born and as environmental concerns began to rise to all-time highs, demand increased for alternative-fueled vehicles. This is how electric vehicle policy was born.

Review of Literature

In the early stages of electric vehicle policy making, only a few state governments were incentivizing consumers to buy these vehicles with tax exemptions and high occupancy vehicle lane access as compensation for buying a vehicle with a limited range of travel (Bosworth, Crabtree, and Patty, 2017). However, the economic recession of 2008 provided the government with a new opportunity to offer electric vehicle subsidies at the federal level. As such, electric vehicle purchase subsidies were introduced in the Energy Improvement and Extension Act of 2008. This act passed alongside a bundle of acts intended to mitigate the growing financial crisis, including the first direct federal subsidy for electric cars, offering tax credits of up to $7,500 for electric vehicle purchases (Bosworth, Crabtree, and Patty, 2017). This federal tax credit is still in effect today for car manufacturers that have sold under 200,000 electric vehicles.

In addition to the $7,500 electric vehicle tax credit, there are two types of incentives that state electric vehicle policy uses to drive electric vehicle sales: direct and indirect incentives (Lingzhi, Lutsey, and Searle, 2014). Direct incentives have a monetary value associated with them and can be claimed in your tax returns or through a rebate. Indirect incentives provide convenience to electric vehicle owners such as access to high occupancy vehicle lanes and emissions testing exemptions (Lingzhi, Lutsey, and Searle, 2014). However, according to Wayne Winegarden, the average cost of battery electric vehicles is $41,835, significantly more than the average price of a new combustion engine vehicle being $34,077 (Winegarden, 2018). Reichmuth and Goldman from the Union of Concerned Scientists note, however, that the battery-pack manufacturing cost for electric vehicles is becoming more cost-efficient, bringing down the overall cost of battery-powered cars (Goldman and Reichmuth, 2017).

In 2015 Chen and Vergis found that there is an incentive policy that not only correlates to battery-electric vehicles but also applies to plug-in hybrid electric vehicles. They note that plug-in electric vehicles are eating into battery electric vehicle sales. During their study, they found that the "number of vehicle models available for purchase is significantly correlated with the plug-in electric vehicle market share " as approximately 48,000 plug-in hybrid electric vehicles were sold in the United States in 2013 (Chen and Vergis, 2015). Winegarden's (2018) study found support for this correlation. Specifically, Winegarden compared plug-in hybrid electric vehicles to battery electric vehicles benefits and found that plug-in hybrids occupy 3.5% of the United States vehicle market, while battery-powered cars occupy only .5%.

Since this is a new field evolving rapidly, some gaps exist within the research. Although the aforementioned articles find that electric vehicles are an important part of reducing oil consumption and transportation induced emission, are any of these direct or indirect incentives making a difference in people's car-buying decisions? According to Winegarden's (2018) study, 79% of electric vehicle car buyers had an adjusted gross income of over $100,000 in 2014 (Winegarden, 2018). Additionally, DeShazo looked at the current electric vehicle policies in the United States and concluded that policymakers make it too arduous for buyers to collect their incentives and rebates as well (DeShazo, 2016). Knowing this, one of the biggest gap in the research currently is the lack of data collection comparing policy to electric vehicle infrastructure and how they might be correlated to each other.

In the United States, the vehicle infrastructure for combustion engine cars has been fully developed since the second half of the twentieth century. Today, there are over one hundred thousand public gas stations where people can fuel their cars. According to the scholarship of Yutaka Motoaki (2019), there are two main advantages of public gas stations over electric vehicle charging stations: time and availability. At a gas station, a person can fill up their car in about five to ten minutes at nearly every time of the day. In most places across the United States, gas stations are open twenty four hours a day. On the other hand, the fastest electric vehicle charging stations take about twenty to thirty minutes to fully charge a car and they are not readily available as most public charging stations (besides Tesla Superchargers) are not open twenty four hours a day. Although Tesla superchargers are operational twenty four hours a day they cannot charge any other electric vehicles, limiting their network to only Tesla vehicle owners (Motoaki, 2019).

This brings in the correlation between electric vehicle infrastructure and incentives. In most cases, the states that have the best-developed public charging network and indirect incentives relating to the infrastructure of electric vehicles (access to high occupancy vehicle lane access and no emissions testing) have contributed to higher electric vehicle registration counts (Cattaneo, 2018). The states with highly developed electric vehicle infrastructure also offer higher subsidy rates for purchasing electric vehicles and make it easier for consumers to operate their cars much like a combustion engine vehicle shown in the study designs of the scholars (Lesser, 2018).

The most common method of study design used in research on electric vehicles has been teams of people comparing state direct and indirect incentives to consumer benefits. Such in-depth studies are useful by showing where state policymakers are implementing various incentives to encourage more people to buy electric vehicles. As a consequence of this study design, the findings of most of the geographical studies on this topic are difficult to generalize for a wider range of states, due to state policies and a narrow range of states covered by the studies. This was the case with a study linking direct and indirect electric vehicle incentives to consumer benefits (Lingzhi, Lutsey, and Searle, 2014). To gather their data, the authors looked at ten states with a large amount of direct and indirect incentives for battery electric vehicles and compared these incentives to the United States' national average. Lingzhi et al. found that in the states with more incentives, electric vehicle sales have dramatically increased. They determined that the most influential incentives are subsidies, high occupancy vehicle lane access, and emissions test exemptions (Lingzhi, Lutsey, and Searle, 2014). Additionally, the authors investigated what percentage of vehicle sales were battery-powered cars, which was about 0.38% in the United States on average in 2014. While this provides a detailed snapshot of state incentives, this data is outdated as the battery electric vehicle policy in several states has changed since 2014.

In a more recent study, Winegardern, (2018) focused on quantifying the subsidies offered for battery electric vehicles. He relied on the most up to date data from Chargepoint and the National Conference of State Legislatures (Winegarden, 2018). Similar to the findings of other studies (Lingzhi, Lutsey, and Searle 2014; Bosworth, Crabtree, and Patty 2017), Winegarden also found a correlation between direct/indirect incentives and consumer benefits.

While the literature on electric vehicle policy examines the relationship between incentives and consumer benefits, no study can find a sure answer to how electric car infrastructure has been influenced by the number of electric vehicle policies within states. Such a study would be relevant because as the number of electric vehicles become cheaper and less tedious to own, more people are to consider buying these cars, causing the demand for electric vehicle infrastructure to increase (Proudlove et al. 2019).

This study will consider the relationship between the number of electric vehicle policies currently active within each state and the amount of infrastructure each state has for these cars. As mentioned above, there seems to be a strong correlation between electric vehicle infrastructure and policies in the United States. The latest studies show that states who possess more direct/indirect incentives, measured by monetary value (direct) and convenience for vehicle owners (indirect), appear to have a better-developed infrastructure for electric vehicles to utilize (Rogotzke et al. 2019). Better developed infrastructure is measured by more charging stations and a higher charging station to outlet ratio. This is a trend that is quickly developing in the automotive market and it deserves scholarly attention. This topic is becoming more relevant during this time due to electric cars becoming more accessible to the average car buyer as the price of producing batteries decreases. Additionally, the range of electric vehicles on the market now is comparable to nearly all gas counterparts. What this means is, as more consumers start to buy electric vehicles, more states will start developing their electric vehicle infrastructure at a faster rate than in the past.

In prior literature, several studies have shown that the most active states in electric vehicle policy foster a higher level of electric vehicle infrastructure (Proudlove et al. 2019 and Rogotzke et al. 2019). In explaining this relationship, Proudlove and his constituents compared state electric vehicle charging infrastructure to the number of electric vehicle actions made by each state over the past fiscal year (Proudlove et al. 2019). They also looked at events in the automotive world that have impacted electric vehicle infrastructure. For example, many states used settlement funds from the Volkswagen emissions case to build charging infrastructure (Rogotzke et al. 2019). Also, according to the EVAdoption website, (which tracks key factors that help drive the mass adoption of electric vehicles), the states with the most charging locations have a higher charger location to outlet ratio than the median, which is 2.58 outlets per charging station ("Charging Stations By State", 2020). This would lead one to believe that these trends are important when it comes to the development of electric vehicle infrastructure in the future. If this is true, it would suggest that the states who are spending a lot of money on electric vehicle infrastructure have been focusing on building larger charging locations with more outlets and more frequent charging stations possibly due to demand from electric vehicle owners within these states.

Therefore, this study hypothesizes that, in comparing states, those having a more robust electric vehicle policy will have better electric vehicle charging infrastructure than will those having less refined electric vehicle policy. The null hypothesis of this study is that, in comparing states, those having a more refined electric vehicle policy will have similar electric vehicle charging infrastructure as will those having less refined electric vehicle policy.

Methodology

The first major concept that will be assessed will be electric vehicle policy. For this study, the concept will be defined as any law or incentive (direct and indirect) that is currently being followed within each state. The laws and incentives of each state will be measured on a scale giving a value of 0 to states that have 0 to 15 laws/incentives currently active, a value of 1 for states that have 16 to 32 laws/incentives currently active, and a value of 2 for states that have over 32 laws/incentives currently active. I have chosen this rating scale because the mean of the number of laws/incentives provided by the Alternative Fuels Data Center was approximately 23 and after finding this number, I thought it would be best to calculate a rating scale based on the standard deviation from the mean, which was approximately 18 ("State Laws and Incentives," 2020). Since nearly all of the states being tested fall within one standard deviation of the mean, I decided to measure half of a standard deviation to obtain more relevant information out of the dataset. Therefore, states that are given a value of 0 falls at or more than .5 standard deviations below the mean. States that are given a score of 1 fall between the mean and .5 standard deviations above it and states that are given a score of 2 falls more than .5 standard deviations above the mean.

The next concept I will address is the electric vehicle infrastructure. This will be defined as the number of public charging locations within each state as well as the number of public charging outlets each state possesses. This information is also provided by the Alternative Fuels Data Center (“Alternative Fueling Station Counts by State,” 2020). This data will be graded on a scale of 0-4. For this dataset, the mean of public charging stations is approximately 377 and the mean for individual public charging outlets is approximately 1087 per state. States that are more than .5 standard deviations below the mean for both public charging stations and outlets will receive a 0. States that have at or more than .5 standard deviations below the mean for only one charging category will receive a 1. States that fall within the mean for both categories will receive a 2. States that fall at or above .5 standard deviations of the mean for one charging category will receive a 3. States that fall at or above .5 standard deviations of the mean for both charging categories will receive a 4.

The study will perform two tests on the data provided by the Alternative Fuel Data Center including 49 states and the District of Columbia. The tests will look at the relationships between the number of electric vehicle policies in each state and the number of public charging stations/charging outlets each state has. I will be excluding California from this dataset because the state's numbers will heavily skew the rest of the dataset. The data points from California will also display a different story of how the rest of the country is doing in this field causing the results to become spurious. The independent variable will be the number of electric vehicle policies within each state. The dependent variables will be the number of charging stations and charging outlets.

This study will be using a correlation and linear regression test of the number state policies and the number of electric vehicle charging stations/outlets. A correlation test is used when the dependent and independent variables are interval level while a linear regression is used when both the dependent and independent variables are continuous. In the context of this study, state policies (the independent variable) is an interval variable. The number of public charging stations and charging outlets (the dependent variables) are all interval variables because they are being rated on a scale based on the standard deviation of scales of 0-2 for electric vehicle policy for each state and a scale of 0-4 for public charging stations/outlets. I will also be creating a linear scatter plot to see the relationship between the variables being tested from a visual standpoint. This test will hopefully yield the intended results.

As I indicated earlier in the paper there are currently no studies that have looked at the relationship between the electric vehicle state policy and infrastructure for these vehicles to operate. I am contributing to the gap in the research by looking at if the number of electric vehicle policies within states contributes to a larger amount of infrastructure or only to a higher percentage of vehicle sales. In the case of this study, a significant result would show that more policies in place would lead to greater levels of charging infrastructure, not just benefiting consumers who buy electric vehicles. This result would show that owners of electric vehicles in policy friendly states will have a better ownership experience since they will not have the burden of trying to find charging stations daily. This result would also show that since infrastructure benefits all electric vehicle owners, it would help consumers of different income brackets and the results would suggest that electric vehicle policy leads to benefits for electric car consumers. This point is displayed in graph three of Josh Goldman's article (Goldman 2016, “The State of the Electric Car Market in 4 Charts and Graphs”).

Results and Analysis

In an attempt to disprove the null hypothesis, a correlation and regression test was conducted to see the relationship between the independent and dependent variables. For the independent variable (Number of State Electric Vehicle Policies), the minimum is 5, the maximum is 44, the mean is 22.54, and the median is 20.50. For the first dependent variable (Number of Electric Vehicle Charging Stations), the minimum is 20, the maximum is 1658, the mean is 376.54, and the median is 260.5. For the second dependent variable (Number of Electric Vehicle Charging Outlets), the minimum is 35, the maximum is 4683, the mean is 1087.26, and the median is 678. The first test that was run was a correlation test due to its ability to measure the strength and direction of the relationship between interval level variables. At the significance level of 0.01, the correlation level was .539 for the number of electric vehicle charging stations and .502 for the number of electric vehicle charging outlets in relation to a state's number of laws and incentives. Table 1 shows the results of the correlation test run between the independent and dependent variables.

Table 1: Correlation				
		Number of State Electric Vehicle Policies	Number of Electric Vehicle Charging Stations	Number of Electric Vehicle Charging Outlets
Number of State Electric Vehicle Policies	Pearson Correlation	1	.539**	.502**
	Sig. (2-tailed)		.000	.000
	N	50	50	50
Number of Electric Vehicle Charging Stations	Pearson Correlation	.539**	1	.992**
	Sig. (2-tailed)	.000		.000
	N	50	50	50
Number of Electric Vehicle Charging Outlets	Pearson Correlation	.502**	.992**	1
	Sig. (2-tailed)	.000	.000	
	N	51	51	51
**Correlation is significant at the 0.01 level (2-tailed)				

As the data above demonstrates, there is a clear link between the number of state laws/incentives and the number of electric vehicle charging stations/outlets in each state. The Pearson correlations, known as r, are .502, .539, and .992. To test for causation and magnitude, a linear regression was used. Tables 2 and 3 show the results of the regression analysis for both dependent variables.

Table 2: Regression Analysis					
Model	Unstandardized Coefficients		Standardized Coefficients	T-value	Sig. (p-value)
	B	Std. Error	Beta		
(Constant)	17.625	1.549	N/A	11.379	.000
Number of State Electric Vehicle Policies	.013	.003	.539	4.429	.000
a. Dependent Variable: Number of Electric Vehicle Charging Stations					
b. Adjusted R^2 = .275					

Table 3: Regression Analysis					
Model	Unstandardized Coefficients		Standardized Coefficients	T-value	Sig. (p-value)
	B	Std. Error	Beta		
(Constant)	18.021	1.578	N/A	11.421	.000
Number of State Electric Vehicle Policies	.004	.001	.502	4.026	.000
Dependent Variable: Number of Electric Vehicle Charging Outlets					
b. Adjusted R^2 = .237					

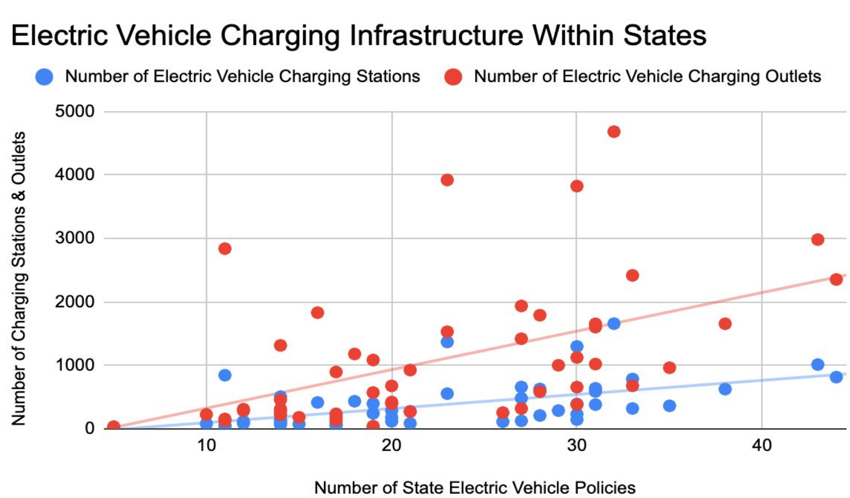
The first model yields the following function for the number of electric vehicle charging stations: Number of electric vehicle charging stations = 17.625 + .013*(number of electric vehicle policies). The second model yields the following function for the number of electric vehicle charging outlets: Number of electric vehicle charging outlets = 18.021 + .004*(number of electric vehicle policies). The y-intercept for the first regression analysis of 17.625 shows us that there are on average 17.625 charging stations if there were no state electric vehicle policies in place. The y-intercept for the second regression analysis of 18.021 shows us that there are on average 18.021 charging outlets if there were no state electric vehicle policies in place. However, since charging stations and outlets can only be measured in whole numbers, these values should both be rounded to 18.

The significance (p-value) of the relationship is .000 for both the number of charging stations and the number of charging outlets. Under the assumption that the null hypothesis is correct, we would obtain these results less than 1% of the time.

The regression coefficient of 17.625 and 18.021 tells us that the number of electric vehicle charging stations and charging outlets increases by that many with each additional state policy on electric vehicles. Putting these coefficients into context, as states increase the number of electric vehicle policies put into effect, we will see the mean of charging stations and outlets slowly increase across the United States. Knowing this, it becomes easy to see how this would limit the amount of electric vehicle charging stations and outlets being built across the country as putting policy into effect is very difficult to do and takes a long time. Additionally, if electric vehicle policies expire or are taken out of a state's legislation, this would lower the number of charging stations and outlets currently in operation.

The value of the adjusted R-squared for the first regression test is .275. This means that about 27.5 percent of the variation in the number of charging stations can be explained by the number of state electric vehicle policies. The value of the adjusted R-squared for the second regression test is .237. This means that about 23.7 percent of the variation in the number of charging stations can be explained by the number of state electric vehicle policies. The other 72.5 and 76.3 percent of the variation in the number of charging stations and outlets is explained by other factors, of which there are many. Therefore, the data describes a moderately strong relationship between the number of electric vehicle charging stations/outlets and the number of state electric vehicle policies as a PRE of .2 to .3 is considered a moderately strong relationship.

Additionally, a scatterplot was created for the dataset to add a visual representation of how the number of state electric vehicle policies and the number of charging stations/outlets interact with each other. In this scatterplot, the x-axis is defined with the number of electric vehicle policies in each state (independent variable) and the y-axis is defined with the number of charging stations/outlets (dependent variables). This graph paints a picture we could not see with the correlation and regression test displaying a visual relationship between electric vehicle policy and the number of charging stations/outlets. From the scatterplot, it shows us as the states have a higher amount of electric vehicle policies, the number of electric vehicle charging stations and outlets increases. The graph also displays how inconsistent the number of charging outlets within a state can be as opposed to the number of charging stations that are more consistent with their line of best fit.



Discussion

The correlation and regression test showed a positive correlation between the number of electric vehicle policies in states in relation to the number of electric vehicle charging stations/outlets. Because the level of significance for all the variables is .000, we reject the null hypothesis since the p value is less than 0.05. Therefore, the results of this study lend support to the research hypothesis that in comparing states, those having a more robust electric vehicle policy will have better electric vehicle charging infrastructure than will those having less refined electric vehicle policy.

The findings of this study are consistent with previous studies done within this field of academia. In the study looking at electric vehicle policies enacted in 2019 conducted by Proudlove and his coauthors (2019), they found that most states are starting to enact more policies as electric vehicles are starting to become more accessible to a wider array of consumers. In 2019, 49 states and the District of Columbia all made legislative and regulatory actions on electric vehicles (Proudlove et al. 2019). Additionally, nearly half of the country had 10 or more actions when it came to electric vehicle legislative activity including states that do not have a lot of electric vehicle chargers and outlets such as Mississippi which only has 67 charging stations and 224 outlets currently open for public use showing the states potential for possibly creating more electric vehicle infrastructure in the future (Proudlove et al. 2019 and "Alternative Fueling Station Counts by State," 2020).

The same story goes for states installing electric vehicle charging stations and outlets. When we compare the number of charging stations from the year 2017 from the EVAdoption website ("Charging Stations By State", 2020) to 2020 from the data provided by the Alternative

Fuels Data Center (“Alternative Fueling Station Counts by State,” 2020), every state and the District of Columbia has seen an increase of both charging stations and outlets open for public use (“Charging Stations By State”, 2020 and “Alternative Fueling Station Counts by State,” 2020). Since then, nearly all states have seen an increase in electric vehicle policy as well. For example, in 2017, Arkansas only had 49 charging stations and 101 charging outlets available for public use across the whole state. Yet in 2020, the state now has 88 charging stations and 285 charging outlets open for public use (“Charging Stations By State”, 2020 and “Alternative Fueling Station Counts by State,” 2020). In three years, Arkansas nearly doubled the number of charging stations and almost tripled the number of outlets available for people to use. Considering that Arkansas had some of the lowest amount of electric vehicle activity in 2019 this shows that a little bit of electric vehicle policy can go a long way in developing electric vehicle infrastructure within a state (Proudlove et al. 2019).

The results of the correlation and regression test, the scatterplot, and previous studies within academia show that the relationship between the number of electric vehicle policies in states and the number of charging stations/outlets is present. The research I have conducted shows that electric vehicle policy can influence electric vehicle charging infrastructure and that if more states keep taking strides in passing electric vehicle policy, we would see greater amounts of electric vehicle infrastructure being built for public use within each state causing electric vehicle sales to increase over time (Proudlove et al. 2019, Lingzhi, Lutsey, and Searle, 2014).

Limitations

Throughout the process of conducting this study, there were some limitations that presented themselves. To start, since this study was measured by comparing strictly the number of electric vehicle policies and charging stations/outlets within each state, it did not give me the ability to see how politics may play a role in this field or look at the different types of policies that each state possesses including direct and indirect incentives. In addition to this, there are different types of charging stations and outlets including level 1 120V AC charging, level 2 240 V AC charging, 480V DC fast charging, and Tesla supercharging that were not taken into account in this study (Rogotzke et al. 2019, Motoaki, 2019, Proudlove et al. 2019). This is important in the electric vehicle world because each type of charging station takes a different amount of time to charge a car. For a level one charger, it can add 15 miles of range to a vehicle per hour. For a level 2 charger, it can add anywhere from 30 to 90 miles of range per hour of charge. For a DC fast charger, it can add anywhere from 90 up to 200 miles in 30 minutes of charging (Rogotzke et al. 2019)

Scope for Further Research

As a result of this research I have conducted, there are some questions that have arisen from the wake of this study being, how have political parties played a role in developing electric vehicle policy and infrastructure? How has the infrastructure for other alternative fueling stations developed in the United States such as biodiesel, compressed natural gas, ethanol flex-fuel, hydrogen, liquified natural gas, and propane (“Alternative Fueling Station Counts by State,” 2020)? How have automakers redefined their vehicle lineups due to the growing popularity of electric vehicles? How much would California affect these tests and results? As time goes on, the answers to these questions will grow to define the changing automotive market and with it, our nation's future.

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