Charging Forward

The Impact of State Incentives on Electric Vehicle Adoption and Emission Reduction Targets

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Abstract

This paper examines state and county-exclusive incentives on battery electric vehicle (BEV) registration in the United States. Using two main methods, a differences-in-differences method and a sigmoidal growth rate equation, I examine the impact of non-federal incentives on the total amount of electric vehicles between 2017 and 2022, as well as estimate the years that each state will reach its net-zero goals for carbon emissions in the transportation sector. I hope to provide a deeper understanding of the effectiveness of incentive policy, based on differing levels of incentive policy between regions, in order to best increase electric vehicle adoption in a cost-effective method. In addition, I hope that my estimates of net-zero projections will serve as a beneficial comparison to track states' respective progress towards sustainable energy in vehicles. These findings can be used to assist policymakers in determining appropriate BEV adoption policies based on regional consumer demographics and needs, as well as visualize a timeline for the next century of rapid electric vehicle growth.

1. Introduction & Statement of Research Question:

In the past ten years, concerns about reducing carbon emissions have risen exponentially. The focus on developing “green” technology, or systems that maximize the use of natural resources, is being promoted at an all-time rate, given the assumption that transitioning towards these systems will mitigate the effects of long-term climate change. Transportation, including the use of traditional gas-fueled cars, contributes to over 28% of greenhouse gas emissions–the largest of any economic sector in the United States.

To reduce the harmful impact of internal combustion engines, the United States has provided large subsidies that lower the production and manufacturing costs of lithium-ion battery and electric vehicle plants. President Biden’s Inflation Reduction Act not only creates jobs in the US clean energy economy, but makes the costs of energy more affordable for businesses and consumers. One of the main focuses of this cost reduction plan to the purchasers of BEVs is vehicle sales, which includes incentives that subtract from the overall cost of a new eligible battery electric vehicle upon approval.

Electric vehicle incentives and tax rebates are primary contributors to the uptake of new clean energy vehicles. As part of the Energy Improvement and Extension Act of 2008, a federal tax credit of $7,500 was introduced to entice consumers to switch towards the clean model, and this credit was attributed to around 30% of all electric vehicle sales in a 2016 study. Jenn et al. (2018) found that for every $1,000 of federal tax credit, there is a 2.6% increase in EV sales.

Despite the scarcity of EV charging stations and the uncertainty of a new form of fuel, consumers are gravitating towards electric vehicles because of their growing affordability.

However, not all of these models are sticking around. The Chevrolet Bolt, introduced in 2016 as a cutting-edge electric vehicle that combined durability with affordability, was once viewed as a stepping stone to EV accessibility. Priced at around $27,000 while meeting the eligibility for the $7,500 federal tax credit, among other state incentives, the total up-front price of the model once fell under $20,000 for prospective buyers. The model was so ground breaking upon release that it pushed Tesla to release the Model 3, an affordable substitute to Tesla's popular luxury Model X and Model Y SUVs. Now, Chevrolet is discontinuing the Bolt at the end of 2023, citing that they are less able to turn a profit. Instead, they are focusing on boosting production for the Silverado EV and GMC Sierra pickup trucks, each priced in the $50,000 range.

While the federal tax credit has boosted EV sales, there are a growing number of state incentives that further incite the attractiveness of clean models, further reducing the cost for qualified consumers. State incentives have a range of requirements, including installing a new home charging station, falling under a maximum income range, and meeting a battery capacity kWh standard, but collectively promote the notion that electric vehicles are a suitable substitute for gas-fueled cars. However, not all states offer regional incentives, raising the question of their effectiveness.

This study will measure the impact of state-exclusive incentives on battery electric vehicle registrations in the United States, with three models:

1. A differences-in-differences model that measures the effects of state-exclusive incentives on state-based BEV registration.

- This model highlights the impact that incentives have on states' BEV registrations, comparing registration levels of states with incentives to states without incentives.
- This groups all incentive-offering states (of at least $1,000) and non-offering states into aggregate parties, rather than comparing states on an individual basis.

2. A differences-in-differences model that measures the effects of county-exclusive incentives on BEV sales in Californian counties.

- California is the state that leads electric vehicle uptake by a wide margin, so it was most informative to analyze differences within the state's regions.
- The same analysis as mentioned above will be conducted for California counties, separating all incentive-offering counties (of at least $500) from non-offering counties.

3. A logistic growth model that measures states' individual net-zero timelines.

- This growth curve will provide a rough estimate for the approximate year when each state will reach net-zero carbon emissions through electric vehicles.
- States' net-zero targets are calculated as a percentage of the Paris Agreement's net-zero target of 240,000,000 BEVs by 2050.

These approaches will use differences-in-differences regressions, with states offering at least $1,000 of state incentives serving as the treatment group and those that don't serving as the control group, three years before and after the intervention year 2020. The growth curve will expand on each state's total available incentives by showing how these policies contribute to regional climate goals.

Due to many state incentives being introduced in 2020 because of elevated climate change awareness, this year serves as the best way to examine the implementation effectiveness of state incentives. The model will also account for factors such as state median income, political affiliation, and total clean energy laws enacted by the government per year, per state.

This study will not only attempt to measure the effect of incentives on total electric vehicle registrations, but also on the incentives' capability to achieve the projected vehicle sales necessary to meet the goal of having net zero emissions by 2050. A holistic representation of each state's BEV adoption policies will be presented to compare states' necessary BEV targets and their relative success in achieving these targets.

Ultimately, this study will examine if incentives are effective; not only at increasing electric vehicle registrations at the target growth rate, but also at reaching their net-zero goals through BEV adoption. Because available state incentive dollars fluctuate widely, with California offering over $45,000 in collective incentives compared to 25 states not offering any state-exclusive incentives, this research will attempt to give insight into the effectiveness of state incentives.

2. Brief Overview of Existing Evidence & Approach of Investigation

There is extensive existing research on the efficiency of battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV) incentives, but these primarily look at the federal tax credit of $7,500. This study will instead provide a more detailed report of how state and county-based incentives, including incentives for clean energy and low-income rebates, influence electric vehicle uptake in such locations in comparison to those where incentives are not offered.

To assess the economic impacts of US state and county incentives, data from the California Energy Commission (CEC), California Air Resources Board (CARB), Alternative Fuels Data Center (AFDC) Laws and Incentives Data, and North Carolina Clean Energy Technology Center (NCCETC) will be used. The number of registered electric vehicles is collected at the state level from the AFDC for each year from 2017-2022, while the number of electric vehicle sales is collected at the county level for all counties in California from the CEC.

The vehicle category for electric vehicle state registrations is battery electric vehicles (BEV), or vehicles powered solely by the use of a battery. This excludes plug-in hybrid electric vehicles (PHEV) that use a battery as only a partial fuel source. The trends of PHEV and hybrid electric vehicle (HEV) registrations will also be measured, but these variables will only serve to accompany the primary BEV variable.

The vehicle category for electric vehicle sales by Californian county is zero-emission vehicles (ZEV), which includes all BEVs and hydrogen fuel cell electric vehicles (FCEV). For simplicity reasons, this study will refer to all zero-emission vehicles as BEVs instead of ZEVs, as FCEVs account for less than 1% of total ZEV sales.

This study provides a differences-in-differences regression that measures the effect of BEV dollar incentives on electric vehicle uptake, in terms of both total registrations and sales per year. The regressions put a focus on the year 2020, where incentives were established at the state level at an increased rate due to elevated environmental and political concerns. Because so many incentives were put into practice during 2020, due to the popularity of climate change initiatives at the time, this study will effectively provide evidence of incentive impact on ZEV uptake. The treatment group for the state registration regression will be states that offered at least $1,000 of maximum incentive dollars for state residents, while the control group will be states that did not offer at least $1,000 of maximum incentive dollars. The pre-treatment period will be years 2017-2019 and the post-treatment period will be 2020-2022, allowing for a three-year interval both before and after the incentive boom takes place.

A similar setup is given for the county sales regression, as the treatment group will be California counties that offered at least one county-specific incentive of $500 maximum incentive dollars, while the control group will be California counties that did not. In order to record a more unbiased progression of BEV and

ZEV uptake, this study uses the per capita total registrations and sales per 10,000 residents in each region. This specification later allows for the regression to be statistically significant, whereas testing only for differences between the total registration and sales numbers did not. This regression will ultimately give the changes in per capita BEV uptake between incentive-available states and non-incentive-available states in the period 2017-2022.

3. Literature Review

3.1 Quantitative Approaches to Understanding Incentive Impact

This literature review is organized in two parts, first including work on incentive policy at the federal, state, and global levels and then a demographics survey collected by the California Vehicle Rebate Project (CVRP). Each study helps provide a deeper range of background into incentive policies based on scaled factors, such as the $7,500 federal tax credit and Norway's 40% tax reduction. In addition, the CVRP's surveys will be discussed in more detail in the discussion section.

3.1.1 Jenn, Springel, and Gopal (2018)

Jenn et al. (2018) assess how monetary incentives affect the average sales of electric vehicles in the United States. The researchers found that for every $1,000 offered in either tax credits or rebates from the federal level, there is an increase of 2.6% in average sales of electric vehicles. The study used vehicle registration data from the National Renewable Energy Laboratory that contains all new vehicle registrations by model, month, and state among all 50 US states from 2010-2015. This data was used to examine EV markets between states, and the results showed that in addition to population size, regulatory policy is a key contributor to EV growth. These regulatory policies, found in California, Oregon, Maine, Vermont, New York, New Jersey, Massachusetts, Rhode Island, Connecticut, and Maryland, require automakers to sell EVs in each of the ten states. Additionally, the study accounted for the customer-perceived vehicle price, which was attributed to customers not being aware of incentives being offered in their state of residency. The per capita sales for each state are highly dependent on this level of customer perception, as per capita sales of EVs can differ drastically between states, even those that have similar levels of incentives offered. The study measured registration rates for a variety of incentive types, including individual credit, fleet credit, HOV lane access, inspection exemption, registration fee reduction, time of use (TOU) rate, and charging infrastructure. This source examined a broader range of incentives from both the federal and state levels and from the years 2010-2015.

3.1.2 Hardman, Chandan, Tal, & Turrentine (2017)

Hardman et al. (2017) explain how incentives should be constructed to support longevity and consumer purchasing decisions, rather than short-term incentives that are only effective after the sale. In this study, the researchers found that incentives that were only instituted for a short period were largely ineffective, as vehicle purchasers needed to see that they would benefit from the incentives before they were taken out of practice. For example, the federal tax credit of $7,500 was originally available to all electric vehicle purchasers, but is now only available to vehicles with a maximum manufacturer's suggested MSRP of $80,000 and consumers with maximum individual income limits of $150,000, as an update mentioned in the Inflation Reduction Act. Additionally, the study encouraged the increase in incentives for PHEVs that had higher electric ranges. According to the study's research, households with PHEVs that had electric ranges between 36-53 miles drove 45% of their total household's mileage on the electric range, which is a higher percentage than it is for household owners of BEVs that had electric ranges between 73-105 miles. The study stated that there should be differing incentives for PHEVs with lower ranges, PHEVs with greater ranges, and BEVs to promote effective energy efficiency and emissions benefits, instead of using the same incentive value for all models of electric vehicles. Since PHEVs with lower electric ranges were deemed to be less energy efficient than PHEVs with greater electric ranges, they should be priced with a significantly lower incentive to entice purchasers to seek out electric vehicles with longer electric ranges.

3.1.3 Tal and Nicholas (2016)

Tal et al. (2016) discuss the effectiveness of the federal tax credit on electric vehicle purchases on consumer purchasing desirability. In this study, the researchers conducted a preference survey of over 2,882 PHEV owners in 11 states to assess their dependence on the $7,500 federal tax credit in purchasing a new PHEV. While the research examined PHEV purchasing decisions, the data is useful in finding similar trends in BEV uptake based on the federal tax credit. The study found that nearly 30% of all PHEVs were traced back to the federal credit of $7,500, but also that low-income purchasers were most dependent on incentives when considering an electric vehicle. High-end BEV models instead showed significantly less reliance on incentives, as those who purchased these models generally had higher incomes and cared more about the performance, technological, and environmental factors of the model than its available financial incentives. This was especially the case when comparing the dependency rate on the federal tax credit for a high-end and low-end BEV, the Tesla Model S and the Nissan Leaf. According to the survey, 86.1% of buyers of the Tesla Model S would still purchase that BEV without the federal tax credit. In comparison, only 50.9% of buyers for the Nissan Leaf would have still purchased that model without the federal tax credit. This change shows that having a high income generally decreases a purchaser's dependence on BEV incentives.

3.1.4 Sheldon (2022)

Tamara Sheldon (2022) discusses the impact of US policy incentives on electric vehicle uptake, considering the income demographics of those customers who are granted the incentives. The study showed that subsidies are the leading motivator to customers purchasing a new BEV, given that the biggest barrier to BEV adoption is the up-front cost. Sheldon's research demonstrated that high-income households were indeed more likely to purchase an electric vehicle, with over 73.4% of BEV sales and 60.1% of PHEV sales in the year 2015 coming from households with incomes over $100,000. More surprisingly, 78% of federal tax credits and 83% of the total credit were claimed by the same household income demographic, suggesting that wealthier households are more inclined to utilize incentives in their vehicle purchasing decisions. This research supports concerns that new BEV and PHEV models appear unaffordable to the majority population given their high up-front cost, which may reduce the awareness of available incentives for those individuals who narrow down the possibility of buying an electric vehicle at all before learning more about the incentives.

3.1.5 Camara, Holtsmark, and Misch (2021)

Camara et al. discuss the effectiveness of the electric vehicle uptake in Norway on passenger car emissions. Norway has an exceptionally large number of registered BEVs and has a significantly higher share than in other countries, and this difference can be traced back to its large value of incentives and policies contributing to the uptake of BEVs. Specifically, Norwegian residents are not subjected to the value-added tax (VAT) and one-off motor vehicle registration tax, which includes exemption from the tax's weight-based component and green component, on BEV purchases. For the purchase of a new BEV, incentives can contribute to more than 40% of the tax cost under certain conditions. The paper runs a regression to test the effect of BEV purchases on car emissions, using household emissions as the left-hand side variable. Results showed that the uptake of BEVs did reduce emissions, but only with a large cost of fiscal incentives. Because many dirty internal combustion engine (ICE) vehicles inhabit Norway in addition to the high BEV population, there is still a long way to go before emissions are significantly reduced. Nearly all electric vehicle owners also own at least one other conventional ICE vehicle, which minimizes the cumulative green effect of the vehicles. This study shows that incentives may need to be raised significantly for several decades before they adequately contribute to the reduction of emissions.

3.1.6 Clean Vehicle Rebate Project

The Rebate Survey conducted by the California Clean Vehicle Rebate Project shows the relative value that new PEV purchasers have in their decision-making process to buy a new vehicle. The survey statistics state that the overall importance of the program's state rebate (the CVRP program) to respondents did not change in the last 10 years, remaining at a 46% approval rate in 2013-2015 and in 2017-2020 with only minor dips in between the years. Additionally, respondents showed only a slight increase in overall willingness to purchase a PEV with the rebate in comparison to not having the rebate, increasing from 46% in 2013-2015 to 56% in 2015-2016, back down to 50% in 2017-2020. These results demonstrated that while being a considerable motivating factor in purchasing a new PEV, the CVRP rebate was only valued by approximately half of new electric vehicle owners. The CVRP rebate offers up to $3,500 for the purchase or lease of new, eligible zero-emissions vehicles for California residents, and consumers are ineligible for the rebate if their individual gross annual income exceeds $150,000. Residents must only apply within three months after the purchase of a new ZEV to be accepted for the rebate. This survey will be discussed in depth in the discussion section of this paper.

3.2 Contribution to Existing Literature

This paper will contribute to the existing literature by focusing specifically on the numerical impact of state and county-specific incentives on per capita BEV, PHEV, and HEV sales. In comparison, most past studies only examine the impact of the federal tax credit offered by the US government. This study also provides a recent overview of incentives offered in the last decade from 2017-2022, while other studies have primarily used data from the early 2010s. Earlier data such as these do not accurately account for the burst of incentives put into effect in the 2020 period. Additionally, this study provides both a broader view and a more in-depth view of incentive effectiveness by looking at incentives among states and California counties. Including these factors and comparing them to each region's median household income through their per capita level will help account for biases in financial, political, and environmental similarities in consumer characteristics. This study will also indicate whether factors such as income, political affiliation, and population size influence incentive effectiveness.

Potential weaknesses of this research include a generalized sample for incentives, as the incentives included in the data set only assess the maximum amount of available incentives offered for each county or state. These available incentives may be income-restricted or mutually exclusive as a result, meaning that not all residents of each region would be eligible for all incentives. Additionally, incentives are implemented at various times, making it difficult to associate the intervention to an exact date.

4. Data and Variables Selection

4.1 BEV State Registration

Data on total BEV, PHEV, and HEV registrations per state are sourced from the AFDC Laws & Incentives Data, which was originally derived by the National Renewable Energy Laboratory with data from Experian Information Solutions. This dataset includes the total registrations per state for battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), and hybrid electric vehicles (HEV). The data also accounts for conventional ICEVs, including gasoline, diesel, and unknown fuel vehicles. The total EV numbers are chosen by each state's number of vehicles registered in the full calendar year, including the range of 2017-2022. Each of the fifty states' EV numbers is included in the differences-in-differences regressions to provide a collective representation of each state's incentive effectiveness. Additionally, there were exactly 25 states that offered a state-exclusive maximum incentive (of at least $1,000) and 25 states that did not offer such an incentive, so this breakdown allowed for an equal amount of observations (6 years * 25 states = 150 observations) in both the treatment and control samples. The BEV, PHEV, and HEV total registrations were then divided by the total population of each state for each year to calculate the registration rate per capita. These per capita values were then multiplied by 10,000 to determine the amount of BEV, PHEV, and HEV registrations per 10,000 state residents. This variable, called "BEVper10000," was used in the main differences-in-differences regression.

Table 1: *Summary Statistics for State Registrations*

Variable	*Obs.*	*Mean*	*Std. Dev.*	*Min.*	*Max.*
BEV	300	22,110.67	72,811.76	100	903,600
BEVper10000	300	22.80	27.67	0.55	231.52
PHEV	300	12,419.33	37,678.02	100	361,100
PHEVper10000	300	13.74	12.53	1.01	92.52
HEV	300	97,666	177,392	3,700	1,514,000
HEVper10000	300	132.47	58.32	40.04	387.91
E85	300	494,865	492,947	39,900	3,250,000
CNG	300	8,066.33	11,524.74	0	79,300
Gasoline	300	4,667,410	5,147,129	448,600	3.11e+07
Diesel	300	160,199.30	165,245.20	11,200	1,107,000
MedIncome	300	71,254.75	11,791.74	46,159	108,200

Source: Alternative Fuels Data Center

4.2 BEV County Sales

Data on total BEV sales per county in the state of California are sourced from the California Energy Commission database. This data includes the light-duty zero-emission vehicle (ZEV) population per county for each year from 2017-2022. While this data set does not include the collective totals for vehicles falling under the PHEV, HEV, E85, CNG, gasoline, diesel, and unknown fuel types, it instead offers a more in-depth look at BEV uptake while controlling for state policies, political affiliation, and other general characteristics. It was important to distinguish BEV growth in the state of California, the clear state leader in electric vehicle adoption and total offered incentive dollars, by Californian counties to see which regions benefited the most from incentives specific to their residency. It is additionally important to note that not all Californian residents of each county offering ZEV incentives are qualified for such incentives, as incentive programs have moved their focus towards low-income households and regions where large amounts of popular dealerships are located to increase sales. To qualify for many of these incentives, such as the Colton Electric Utility program for purchasing used ZEVs, customers must be enrolled in the Colton Electric service territory low-income program and the used vehicle must be registered to a residence in the Colton Electric Utility territory. However, many incentive programs also only offer rebates for the purchase or lease of brand-new eligible ZEVs, which are typically higher-end and cater to a high-income consumer base. One popular incentive programs in the state of California is the California Clean Vehicle Rebate Project (CVRP), which is sponsored by the California Air Resources Board and administrated by the Center for Sustainable Energy.

5. Methodology

5.1 State Regressions

Two main methods are used to examine results on the state level, including an ordinary least squares regression and a differences-in-differences regression. The primary variables "BEV" and "BEVper10000" in the data set represent the total number of registered BEVs and the number of registered BEVs per 10,000 people, respectively. Each dependent variable is categorized by state and year, with all fifty states and years 2017-2022 included. The range of years was intentionally selected to observe the change in BEV uptake before and after the selected intervention in 2019, with 2017-2019 serving as the pre-intervention period and 2020-2022 serving as the post-intervention period. The year 2020 was selected as the intervention year to represent the significant increase in US rebate policies provided in early 2020, which in turn resulted in a national rise in BEV sales.

A full list of included variables are listed below.

Table 2: *State registration variables*

1. *BEV Registration by State*

BEV	Total battery electric vehicles
PHEV	Total plug-in hybrid electric vehicles
HEV	Total hybrid electric vehicles
E85	Total ethanol-fueled vehicles
CNG	Total compressed natural gas-vehicles
Gas	Total gas-fueled vehicles
Diesel	Total diesel-fueled vehicles
Year	Year (2017-2022)
Incentive	Value of 1 if the state offers at least $1,000 total available incentive dollars, 0 if not

Utility	Value of 1 if the state has 10+ utility actions related to BEVs (non-monetary features that appeal to prospective purchasers), 0 if not
Political Affiliation	Value of 1 for Democratic state, 2 for Republican state (majority party vote in 2020 presidential election)
MedIncome	Median Income in each state per year

Source: Alternative Fuels Data Center

The main independent variable of interest is "Incentive" which is a binary variable that indicates if a state offers collective rebate dollars over $1,000. This variable is binary for simplicity reasons, with each state receiving a "1" if it offers at least $1,000 of tax rebate dollars and a "0" if it does not offer a state-limited incentive. By chance, there were exactly 25 states that offered at least $1,000 in BEV purchasing incentives and 25 states that did not offer any incentives. The other independent variables included in this theoretical model are "MedIncome," "Utility," "PoliticalAff," which refer to a sample's average state income, total available state BEV-related utility actions, and political affiliation, respectively.

The data set includes the electric vehicle registration rate per capita, "BEVper10000," as a continuous variable with a range between 0.50 and 231.50 vehicle units. This variable was calculated by taking the total EV registrations per state in the years 2017-2022 and dividing them by the total state population of the corresponding year. "PoliticalAff" is a binary variable that represents each state's majority political party affiliation in the 2020 U.S. presidential election, with states earning a "1" if they voted primarily Republican and a "0" if they voted primarily Democratic. The two major parties, the republican party and the democrat party, were the only political affiliations considered for this variable.

The variable “MedIncome” represents the yearly median income for each state, in which each figure was taken from the US Census Bureau.

The data set includes the binary variable “Utility,” which represents each state’s level of total utility and policy actions committed within the state in the year 2023. Specifically, an action related to electric vehicle utility provision can be defined as a measure relating to rebate and grant programs; registration, mileage, or charging fees for electric vehicles; planning activities; rate design for electric vehicle charging; and state procurement of electric vehicles. The variable gives an output of “1” if a state recorded at least 6 utility actions in the second quarter of 2023, and it gives an output of “0” if a state recorded less than 6 utility actions during this period. This binary variable was created from the data set that originally categorized each state by their utility actions, including categories for “no action,” “1-2 actions,” “3-5 actions,” “6-9 actions,” and “10 or more actions.” Conveniently, there are 25 states that committed at least 6 utility actions and 25 states that did not. The North Carolina Clean Energy Technology Center (NCCETC) published this data in August, 2023.

Finally, the variables “State” and “Year” represent the state and year of each sample, with all 50 states except the District of Columbia represented and years 2017, 2018, 2019, 2020, 2021, and 2022 used. Given that 2020 represented a year of a large spike in government and state-provided incentives for electric vehicle purchasing, the differences-in-differences regression that is run uses years 2017-2019 as the pre-intervention period and 2020-2022 as the post-intervention period. The “State” variable is used as a key factor in finding the impact of state-provided incentives on the real uptake of electric vehicles based on each state’s varying policies and demographics.

A breakdown of the main differences-in-differences model is shown below, as well as the list of OLS regressions run.

Table 3: *State Differences-in-Differences table*

1. BEV Differences-in-Differences Model (States)

	Pre-intervention *(2017-2019)*	***Post-intervention*** *(2020-2022)*
Control *(States that do not offer at least **\$1,000** of total available incentives)*	0, 0	0, 1
Treatment *(States that do offer at least \$1,000 of total available incentives*	1, 0	1, 1

Figure 1: *State regressions*

OLS Regressions

(1) $BEV_i = \beta_0 + \beta_1 \cdot Year_i + \epsilon_i$

(2) $BEV_i = \beta_0 + \beta_1 Incentive_i + \beta_2 Utility_i + \beta_3 PoliticalAff_i + \beta_4 MedIncome_i + \beta_5 State\_bin_i + \beta_6 Year_i + \epsilon_i$

(3) $BEV_i = \beta_0 + \beta_1 PHEV_i + \beta_2 HEV_i + \beta_3 E85_i + \beta_4 CNG_i + \beta_5 Gasoline_i + \beta_6 Diesel_i$ $\beta_7 Incentive_i + \beta_8 Utility_i + \beta_9 PoliticalAff_i + \beta_{10} MedIncome_i + \epsilon_i$

(4) $BEVper10000_{i,State} = \beta_0 + \beta_1 PHEVper10000_i + \beta_2 HEVper10000_i + \beta_3 Incentive_i + \beta_4 Utility_i + \beta_5 PoliticalAff_i + \beta_6 MedIncome_i + \beta_7 Diesel_i + \beta_7 yr2018_i + \beta_8 year2019_i + \beta_9 year2020_i + \beta_{10} year2021_i + \beta_{11} year2022_i + \epsilon_i$

Differences-in-Differences Regression

(5) $BEVper10000_{i,State} = \beta_0 + \beta_1 \cdot treated_i + \beta_2 \cdot time_i + \beta_3 treated \cdot time_i + \epsilon_i$

5.2 California County Regressions

The second dataset for California county BEV sales contains similar numbers of BEV sales, but in the form of sales because of the available data. "BEVper10000" represents the number of BEV sales per 10,000 people between 2017-2022. 56 counties are included besides the exceptions of Modoc and Sierra, given this data was not available. The range of years was intentionally selected to observe the change in BEV uptake before and after the selected intervention in 2019, with 2017-2019 serving as the pre-intervention period and 2020-2022 serving as the post-intervention period. The year 2020 was selected as the intervention year to represent the significant increase in US rebate policies provided in early 2020, which resulted in a country-wide rise in BEV sales–particularly in California.

Table 5: *California County Sales Variables*

2. *BEV Sales by County (California)*

Year	Year (2017-2022)
Incentive	Value of 1 if the state offers at least $500 total available incentive dollars, 0 if not
MedIncome	Median Income in each state per year

The main independent variable of interest are "NumIncentives" and "DollarIncentives." Both are continuous variables that indicate the number of county-exclusive incentives offered by the county and the dollar value of the total available maximum incentives offered by the county, respectively. Similar to the state incentive breakdown, there were exactly 28 counties that offered at least $500 in BEV purchasing incentives and 28 counties that did not. The variable "MedIncome" represents the yearly median income for each state, in which each figure was taken from the US Census Bureau.

Table 4: *California County Differences-in-Differences table*

2. BEV Differences-in-Differences Model (California counties)

	Pre-intervention *(2017-2019)*	***Post-intervention*** *(2020-2022)*
Control *(Counties that do not offer at least **$500** of total available incentives)*	0, 0	1, 0
Treatment *(Counties that do offer at least $500 of total available incentives*	1, 0	1, 1

Figure 2: *California county sales regressions*

OLS Regression

$$(1)\ BEVper10000_{i,\,County} = \beta_0 + \beta_1 NumIncentives_i + \beta_2 DollarIncentives_i + \beta_3 MedIncome2023_i + \beta_4 yr2018_i + \beta_1 yr2019_i + \beta_5 yr2020_i + \beta_6 yr2021_i + \beta_7 yr2022_i + \epsilon_i$$

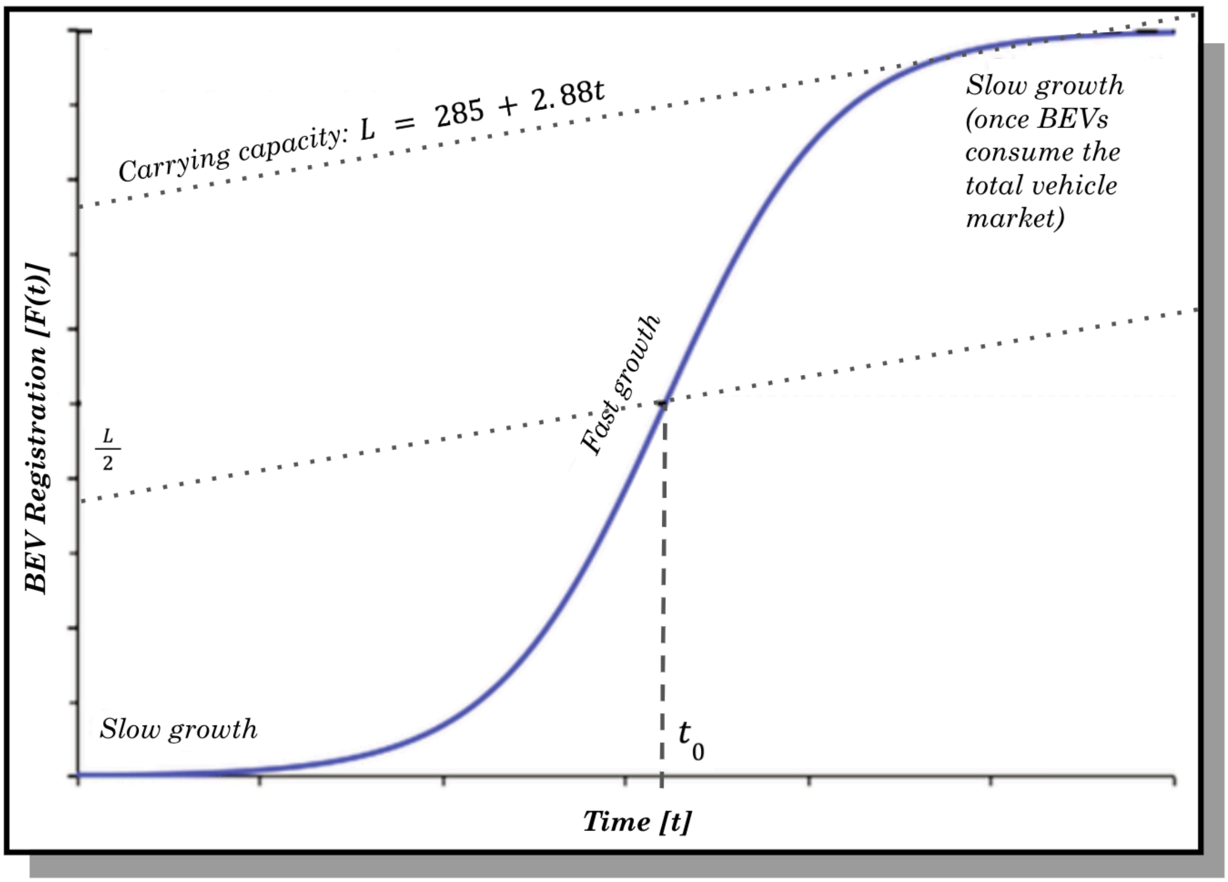
Differences-in-Differences Regression

$$(2)\ BEVper10000_{i,\,County} = \beta_0 + \beta_1 \cdot treated_i + \beta_2 \cdot time_i + \beta_3 treated \cdot time_i + \epsilon_i$$

5.3 Forecasting Analysis: Sigmoidal Growth Curve of BEV Registration

As a follow-up forecast to the differences-in-differences regression, a sigmoidal growth curve is used to predict the progression of BEV registrations until the year 2100. This growth curve intends to forecast the number of BEVs that will be documented in the next century, and the sigmoidal growth curve is a good match for a forecast of this type because it expresses the three distinct phases of theoretical BEV integration: a phase of exponential growth, a phase where growth is linear with passing time, and a phase where growth plateaus towards an asymptote.

Figure 3: *Sigmoidal Growth Function, BEV registrations by years*



5.3.1 Assumptions:

Given the complexities of making a forecast over 70 years into the future, multiple assumptions are used in the formation of these calculations, which are listed below.

A. Assuming that the number of total vehicles will increase linearly. The model accounts for this by using the equation $L = 285 + 2.88t$, which assumes that the US' total vehicle count will grow by 2.88 million cars each year (365,913,335 total vehicles in 2050, 509,959,964 total vehicles in 2100).

B. Assuming that the year 2100 will be the point where net-zero / 100% EV market share has already been achieved (just using this as a benchmark–this should not matter too much if it is right or wrong).

C. Assuming that the term "net-zero" is equal to 100% EV market share, or where electric vehicles are the only vehicles operated on the road.

D. Assuming that the number of EVs will follow the sigmoidal growth curve without major outliers and will eventually reach a point that is close to the total vehicle market share.

These assumptions are necessary for the construction of this model, as such a forecast will likely deviate from expected projections because of external factors, such as changes in market demand, changes in vehicle efficiency, and new technological developments, which are unpredictable. Nonetheless, this model acts as a method to test the rates of achieving certain totals of BEV registration, using independent variables for the BEV growth rate, year, and carrying capacity percentage of ICE vehicles. These variables will allow users to test the approximate amount of BEV vehicles that will be registered in a given year under different climate goals, thus determining the number of years that the US will reach theoretical net-zero emissions for transportation.

Table 6: *Sigmoidal Growth Function, Variables*

Variable	*Definitions*
$F(t)$	Amount of electric vehicles at year t
L	Maximum number of US electric vehicles when there is 100% EV market share → 365,000,000 (asymptote)
α	Carrying capacity percentage of ICE vehicles remaining once US reaches net-zero (10%)
t_{State}	t = number of years since 2022 (t = 28 → 2050)
t_0	t value of midpoint, where t = years
k_{State}	annual growth rate of electric vehicles
v_{State}	the state's share of BEV relative to the country's total
w_{State}	the state's share of vehicles (electric and non-electric) relative to the country's total
k_{State}	the state's annual growth rate of BEVs (calculated from 2016-2022 values)

5.3.2 Forecast Model Breakdown:

To calculate the curve for this graph, as well as for the indicators that allow for state variation in BEV share and total vehicle share, the following equations are used to estimate each state's projected net-zero year and required number of BEVs.

Figure 3: *Sigmoidal Growth Function, Variable Equations*

$$F(t) = \frac{(1-\alpha) * L}{1 + e^{-k(t - t_0)}}$$ ➡ *moving carrying capacity*

$$k = \left[\frac{L}{l}\right]^{\left(\frac{1}{N}\right)} - 1$$ ➡ *growth rate*

$$L = 285 + 2.88t$$ ➡ *total BEV registrations at time t*

First, $F(t)$ calculates the number of BEV registrations in the United States as a function of the country's carrying capacity, growth rate, and t_0 point. Second, k calculates the approximate rate of BEV growth of the US, using the ratio of the carrying capacity to the starting point. Since it was uncertain which value the carrying capacity would be, L in this case represents the number of US BEV registrations in 2022, meaning that the growth rate only accounts for the years 2017 to 2022. Finally, L calculates the rising number of total vehicles in each year, under the assumption that the number of total vehicles in the US will increase by 2.88 million vehicles per year and have 285 million registered vehicles in 2022. Thus, t represents the number of years since 2022. As a whole, the model theorizes that net-zero emissions will be reached once a region registers 90% of its total vehicle population as battery-electric.

This model relies on benchmarks set by external organizations to measure the required timeline for reaching net-zero emissions. First, the ICF Climate Center estimated that to meet a goal of 90% carbon emission reduction in the US by 2050 in accordance with the Paris Agreement, the US must reach 240 million BEV registrations by 2050. Second, the ICF modeled that under assumptions that the country continues to rely on current levels of funding and tax credits from the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA), the US will reach 93 million BEV registrations by 2050. This number has been rounded up to 100 million.

Given these projections, estimates were made to find the t_0 values of each BEV adoption track, which represent the year that the US will reach half of its carrying capacity for BEVs, otherwise known as the inflection point of the curve. These calculations rely on the expectation that 240,000,000 BEVs must be registered in the United States to meet net–zero emission goals, while only 100,000,000 BEVs are currently projected to be registered by the US in that time.

The following calculations were made to find t_0 for the current and Paris goal rates.

Figure 4: *United States Net-Zero Inflection Point Calculations*

Outlined goals for projected 2050 BEV registration totals:

1. 100,000,000 registered BEVs (current projected track)
2. 240,000,000 registered BEVs (goal outlined by Inflation Reduction Act)

$$100,000,000 = \frac{(1-0.90) * [285+2.88 * (28)]}{1+e^{-.0963(28-t_0)}} \rightarrow t_0 = 21.82 \approx 22$$

$$240,000,000 = \frac{(1-0.90) * [285+2.88 * (28)]}{1+e^{-.0963(28-t_0)}} \rightarrow t_0 = 39.34 \approx 39.5$$

As rough estimates, this means that the US is projected to reach half of its carrying capacity in registered BEVs at a current rate of 39.5 years from 2022 (2022 + 39.5 = 2062), falling short of the ideal rate of 22 years from 2022 (2022 + 22 = 2044). These two tracks, including both the current and ideal rates of BEV adoption, set the t_0 values of the rest of the model's calculations. Specifically, these values are used in the estimations of each state's net-zero year projection.

Finally, the current rate $C(t)$ is set equal to $P(28)$ to find the t years from 2022 that the United States will reach net-zero emissions.

Figure 5: *United States Net-Zero Timeline Calculations*

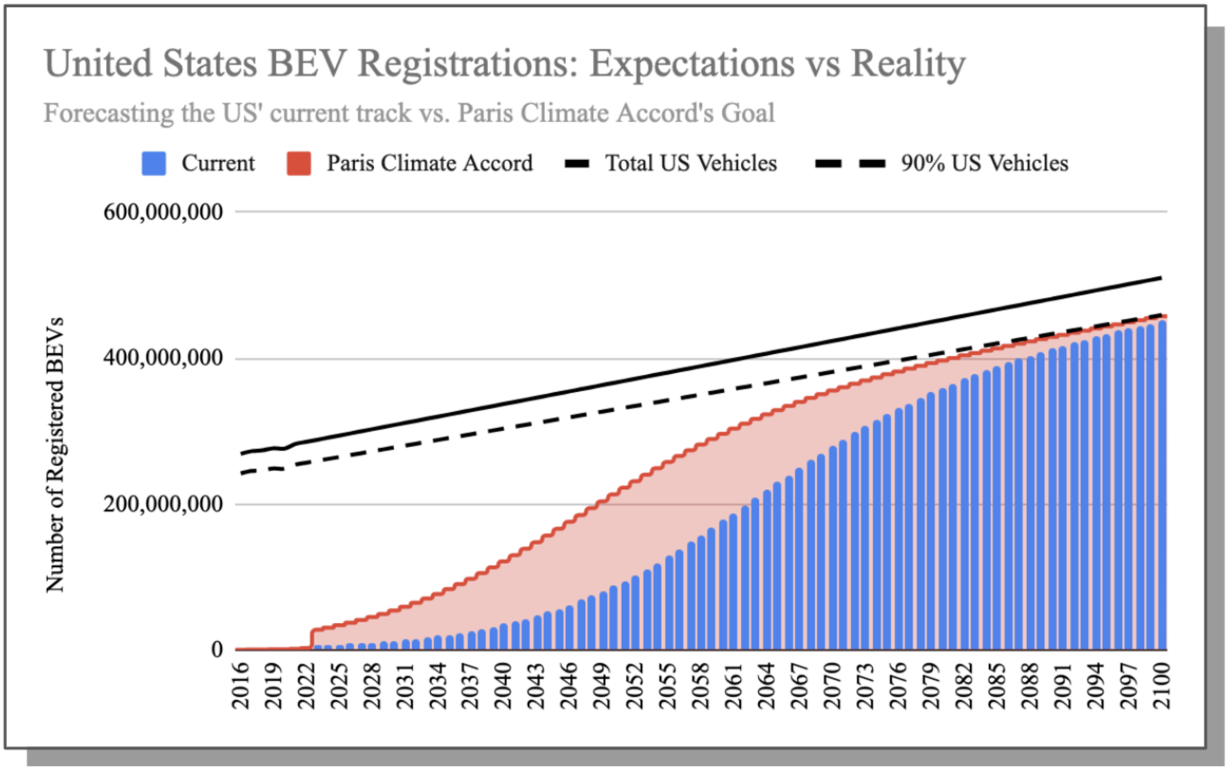
$$C(t) \;=\; \frac{(1-0.10) * (v * (285+2.885t))}{1+e^{-k(t-39)}} = P(28) \;=\; \frac{(1-0.10) * (w * (285+2.885t))}{1+e^{-k(t-22)}}$$

$$\downarrow$$

$$C(42.74) \;=\; P(28) \rightarrow US\ net\ zero\ in\ 2065$$

In this model, an estimate of approximately 43 years from 2022 is required for the United States to reach approximately 240,000,000 BEVs, or in 2065. This assumes that net-zero emissions will be reached once 90% of total registered vehicles are BEVs, according to 2050 vehicle numbers. Of course, the United States will not have a 90% BEV market share with only 240,000,000 registered BEVs in 2065, as the total number of vehicles will increase linearly over time as well, but the graph assumes that natural BEV adoption will substitute for this difference. A visual graph of the United States' estimated BEV growth is included below.

Figure 6: *United States Net-Zero Timeline, Current vs Ideal BEV Adoption Rates*



While this model certainly has errors, given that the model only partially accounts for the growing number of total vehicles per year and it is improbable to predict the exact trend of BEV adoption in the long term, the model attempts to show the discrepancy between the US' current and ideal rates of adoption. This discrepancy becomes more distinct in the state-by-state projections, which are shown in detail in the results section.

6. Results

6.1 State Registrations

From the first differences-in-differences model, the results show that state incentives have a positive effect on BEV registrations per 10,000 people. The differences-in-differences coefficient is 13.968, meaning that BEV registrations per 10,000 state residents increased by approximately 0.14% from the period of 2017-2019 to the period of 2020-2022 when there was an incentive of $1,000 offered in the state. Additionally, the graph of aggregate EV registrations per year shows that there is a significant increase in BEV uptake in states with regional-exclusive incentives.

Figure 7: *Differences-in-Differences regression, State BEV per capita*

```
. diff BEVper10000, t(treated) p(time)

DIFFERENCE-IN-DIFFERENCES ESTIMATION RESULTS
Number of observations in the DIFF-IN-DIFF: 300
            Before         After
   Control: 75             75          150
   Treated: 75             75          150
            150            150
```

Outcome var.	B~10000	S. Err.	|t|	P>|t|
Before				
Control	7.639			
Treated	15.175			
Diff (T-C)	7.537	3.921	1.92	0.056*
After				
Control	23.430			
Treated	44.935			
Diff (T-C)	21.505	3.921	5.49	0.000***
Diff-in-Diff	13.968	5.544	2.52	0.012**

```
R-square:    0.25
* Means and Standard Errors are estimated by linear regression
**Inference: *** p<0.01; ** p<0.05; * p<0.1
```

Figure 8: *OLS regression, State BEV total registrations*

```
. regress BEV PHEV HEV E85 CNG Gasoline Diesel Incentive Utility PoliticalAff MedIncome
```

Source	SS	df	MS			
				Number of obs	=	300
				F(10, 289)	=	576.66
Model	1.5095e+12	10	1.5095e+11	Prob > F	=	0.0000
Residual	7.5651e+10	289	261769098	R-squared	=	0.9523
				Adj R-squared	=	0.9506
Total	1.5852e+12	299	5.3016e+09	Root MSE	=	16179

BEV	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
PHEV	1.775682	.1672083	10.62	0.000	1.446581	2.104782
HEV	.0967331	.0591995	1.63	0.103	-.0197837	.2132499
E85	.0109341	.0088623	1.23	0.218	-.0065087	.0283769
CNG	-1.753587	.1293756	-13.55	0.000	-2.008225	-1.498949
Gasoline	-.0038368	.0013993	-2.74	0.006	-.0065909	-.0010826
Diesel	.103652	.018078	5.73	0.000	.0680707	.1392332
Incentive	-784.3978	2275.238	-0.34	0.731	-5262.537	3693.741
Utility	-4031.545	2534.669	-1.59	0.113	-9020.297	957.2076
PoliticalAff	1955.683	3113.129	0.63	0.530	-4171.599	8082.964
MedIncome	-.062782	.1040653	-0.60	0.547	-.267604	.1420399
_cons	6074.388	8520.114	0.71	0.476	-10694.95	22843.73

On an aggregate comparison, the states that offered $1,000 of regional incentives exceeded states that didn’t in BEV registration levels by a wide margin. In 2017, BEV registration surpassed a total of 300,000 units for incentive states while only reaching 56,000 units for non-incentive states, and these numbers jumped to 2,013,540 units for incentive states and only 422,870 units for non-incentive states in 2022. This discrepancy is large from a distance, but it is also important to consider factors like the population size of the states, given that many states that did offer incentives simply had a larger sampling size. To account for this factor, the model examines the change in average BEV registration for every 10,000 state residents, using a per capita basis, and the graph showed the same relative increase in growth for incentive states in comparison to non-incentive states.

6.2 California County Sales

In the county sales model, the results show that county incentives also have a positive, significant effect on BEV registrations per 10,000 people. The differences-in-differences coefficient is 13.476, meaning that BEV registrations per 10,000 county residents increased by approximately 0.14% from 2017-2019 to 2020-2022 when there was an incentive of $500 offered in the county. This figure is incredibly similar to the state differences-in-differences regression, which is affirming to see that incentives have similar effects on per capita sales.

Figure 9: *Differences-in-Differences regression, California county BEV per capita*

DIFFERENCE-IN-DIFFERENCES ESTIMATION RESULTS

Number of observations in the DIFF-IN-DIFF: **336**

	Before	After	
Control:	**84**	**84**	168
Treated:	**84**	**84**	168
	168	168	

Outcome var.	B~10000	S. Err.	|t|	P>|t|
Before				
Control	**8.021**			
Treated	**29.980**			
Diff (T-C)	**21.959**	**3.981**	**5.52**	**0.000*** **
After				
Control	**20.235**			
Treated	**55.670**			
Diff (T-C)	**35.435**	**3.981**	**8.90**	**0.000*** **
Diff-in-Diff	**13.476**	**5.629**	**2.39**	**0.017** **

R-square: **0.32**

* Means and Standard Errors are estimated by linear regression

**Inference: *** p<0.01; ** p<0.05; * p<0.1

Source: Alternative Fuels Data Center

6.3 Net-Zero Timeline: Paris Goal vs Current Growth

To calculate the number of years that it would require the United States to achieve its net-zero goals for transportation, the sigmoidal growth curve is used as a rough approximation. In this growth model, three unknown variables allow for flexibility in the calculated projections. These include the following:

Table 7: *Sigmoidal Growth Function, indicator definitions*

Parameters	
v_{State}	the state's share of BEV relative to the country's total
w_{State}	the state's share of vehicles (electric and non-electric) relative to the country's total
k_{State}	the state's annual growth rate of BEVs (calculated from 2016-2022 values)

Through these variables, the model allows for variation that may occur as a result of long-term economic factors. Specifically, they allow for changes across states. By inserting the corresponding values for each state into the growth model, users are able to estimate the number of years that the state will take to reach net-zero transportation emissions. These calculations are made by setting the following equations equal to each other:

Figure 10: *Sigmoidal Growth Function calculation method*

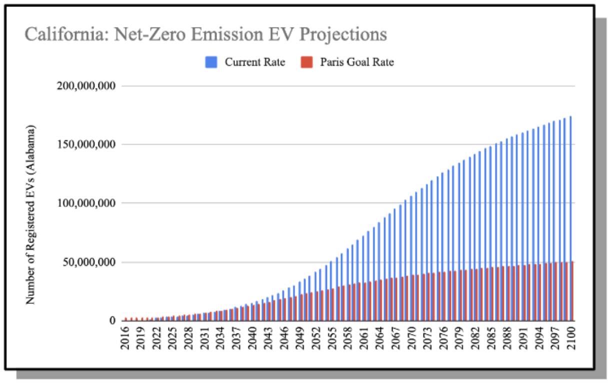
$$C(t) = \frac{(1-0.10) * (v * (285+2.885t))}{1+ e^{-k(t-39)}} = P(28) = \frac{(1-0.10) * (w * (285+2.885t))}{1+ e^{-k(t-22)}}$$

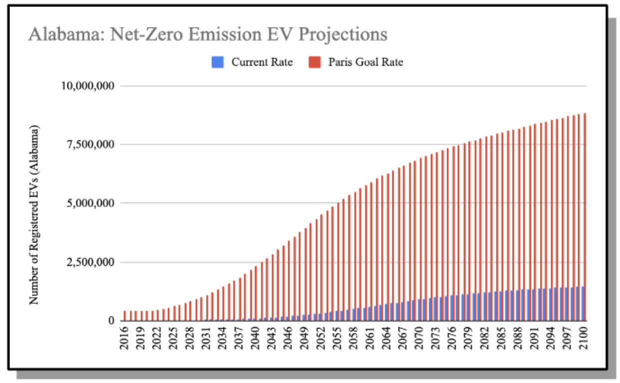
By equating the BEV amount of the US' current rate of adoption, $C(t)$, to the BEV amount of the US' ideal rate of adoption to reach net-zero emissions by 2050, $P(28)$, a user will be able to estimate the number of years that it will take to reach each state's portion of net-zero emissions through BEVs by solving for t. These calculations are made through a personalized graph in Desmos, found below.

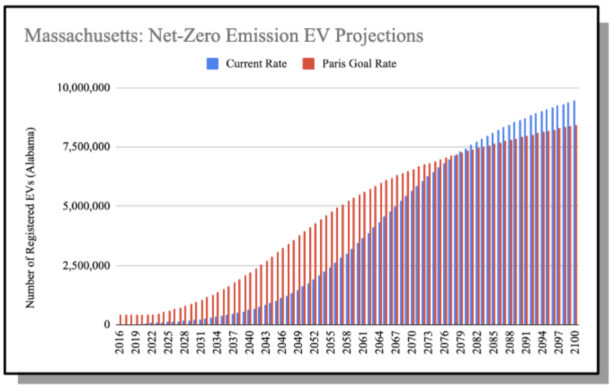
Current vs. Paris Goal Net-Zero BEV Growth Model, made in Desmos

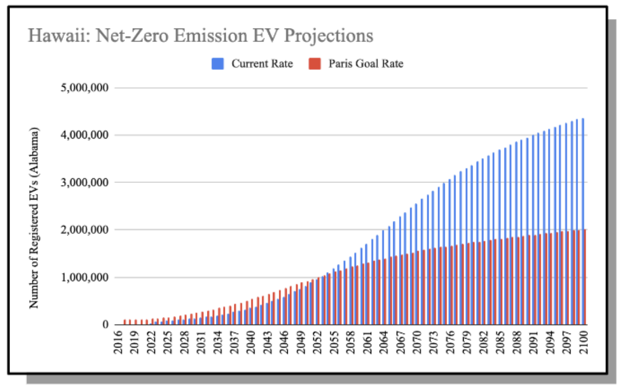
I looked at certain states in particular. States such as Massachusetts, which had a relatively similar level of BEV share ($v_{Massachusetts} = 2.10\%$) and total vehicle share ($w_{Massachusetts} = 1.85\%$), resulted in a t value of 40.35, where $C(40.35) = 3.96M$ BEVs. This means that the number of BEVs required to meet Massachusetts' state net-zero goal was 3,960,000, and that this level of registered BEVs would be met in approximately 40 years from 2022, or 2062.

Figure 11: *Net-Zero Emissions Timeline, by State (Alabama, California, Hawaii, Massachusetts)*









However, California's net-zero projection was calculated to come much sooner, as its $v_{California} = 38.82\%$) and total vehicle share ($w_{Massachusetts} = 11.12\%$) resulted in a t value of 18.18, where $C(18.18) = 13.864M$ BEVs in 2040. Alabama, on the other hand, has a much smaller BEV share than its total vehicle share, which projects the state to have a t value of 402.31, where $C(402.31) = 4.159M$ BEVs—only this time in 2424.

Table 8: *Net-Zero Projections, by State (Alabama, Massachusetts, California)*

State	v_{State} ***(BEV share)***	w_{State} ***(total vehicle share)***	k_{State} ***(growth rate)***	t_{State} ***(net-zero year)***	$P(28)_{State}$ ***(net-zero BEVs, millions)***
Alabama	*0.32%*	*1.94%*	*10.42%*	*402.31 (2424)*	*4.159*

Massachusetts	*2.10%*	*1.85%*	*10.31%*	*40.35 (2062)*	*39.568*
California	*38.82%*	*11.12%*	*9.45%*	*18.18 (2040)*	*13.864*

While Alabama, Massachusetts, and California have varying levels of BEV and total vehicle shares, it is the difference between their v_{State} and w_{State} values that has the most significant impact on states' net-zero timelines. This is shown through the equation below:

$$\Delta_{State} = \frac{v_{State}}{w_{State}}$$

This means that when a state's share of BEVs, relative to the United States as a whole, is higher than its total share of vehicles (including electric and non-electric vehicles, the model projects that states will reach their 2050 BEV target more quickly. Specifically, states with a Δ_{State} value exceeding 1.00 have a greater BEV share than the total vehicle share.

A comprehensive list of state calculations is included below:

Table 9: *Net-Zero Projections, by state*

Rank	*State*	v_{State} ***(BEV share)***	w_{State} ***(total vehicle share)***	k_{State} ***(growth rate)***	t_{State} ***(years since 2022)***	$Year_{State}$ ***(net-zero)***	$P(28)_{State}$ ***(net-zero BEVs, millions)***
1.	*California*	*38.82%*	*11.12%*	*9.45%*	*18.18*	*2040*	*13.864*
2.	*Hawaii*	*0.98%*	*0.44%*	*9.27%*	*29.43*	*2051*	*0.92*
3.	*Washington*	*4.60%*	*2.82%*	*9.54%*	*34.10*	*2056*	*5.933*
4.	*New Jersey*	*3.29%*	*2.22%*	*10.66%*	*36.27*	*2058*	*4.783*

5.	*Oregon*	*2.09%*	*1.42%*	*9.48%*	*35.63*	*2058*	*2.984*
6.	*Colorado*	*2.55%*	*1.81%*	*10.08%*	*36.69*	*2059*	*3.853*
7.	*Arizona*	*2.81%*	*2.15%*	*10.37%*	*38.01*	*2060*	*4.604*
8.	*Delaware*	*0.21%*	*0.17%*	*10.77%*	*39.07*	*2061*	*0.367*
9.	*Massachusetts*	*2.10%*	*1.85%*	*10.31%*	*40.35*	*2062*	*3.957*
10.	*Utah*	*1.14%*	*1.01%*	*10.07%*	*40.37*	*2062*	*2.149*
11.	*New York*	*3.58%*	*3.34%*	*10.33%*	*41.39*	*2063*	*7.147*
12.	*Maryland*	*1.76%*	*1.74%*	*10.41%*	*42.51*	*2064*	*3.729*
13.	*Vermont*	*0.23%*	*0.22%*	*10.15%*	*41.82*	*2064*	*0.469*
14.	*Florida*	*6.59%*	*6.80%*	*10.45%*	*43.38*	*2065*	*14.587*
15.	*Connecticut*	*0.92%*	*0.98%*	*10.02%*	*44.01*	*2066*	*2.083*
16.	*Virginia*	*2.12%*	*2.71%*	*10.46%*	*48.43*	*2070*	*5.814*
17.	*Nevada*	*1.20%*	*0.95%*	*10.36%*	*50.16*	*2072*	*4.159*
18.	*Georgia*	*2.34%*	*3.24%*	*9.12%*	*51.09*	*2073*	*6.755*
19.	*Texas*	*5.58%*	*8.16%*	*10.20%*	*52.71*	*2075*	*17.412*
20.	*Illinois*	*2.52%*	*3.90%*	*10.01%*	*54.95*	*2077*	*8.289*
21.	*Rhode Island*	*0.17%*	*0.28%*	*10.51%*	*57.69*	*2080*	*0.601*
22.	*New Hampshire*	*0.28%*	*0.50%*	*10.60%*	*62.38*	*2084*	*1.076*
23.	*North Carolina*	*1.74%*	*3.09%*	*10.38%*	*61.99*	*2084*	*6.619*
24.	*Minnesota*	*1.03%*	*1.95%*	*10.57%*	*66.83*	*2089*	*4.193*
25.	*Pennsylvania*	*1.85%*	*3.88%*	*10.47%*	*77.80*	*2100*	*8.327*
26.	*Maine*	*0.21%*	*0.49%*	*10.45%*	*94.72*	*2117*	*1.051*
27.	*New Mexico*	*0.29%*	*0.66%*	*10.45%*	*90.29*	*2122*	*1.416*
28.	*Oklahoma*	*0.49%*	*1.19%*	*10.43%*	*102.20*	*2124*	*2.552*
29.	*Alaska*	*0.09%*	*0.24%*	*9.58%*	*117.77*	*2140*	*0.505*
30.	*Ohio*	*1.46%*	*3.86%*	*10.39%*	*119.58*	*2142*	*8.271*
31.	*Michigan*	*1.21%*	*3.39%*	*10.67%*	*133.93*	*2154*	*7.305*
32.	*Tennessee*	*0.84%*	*2.38%*	*9.94%*	*132.99*	*2155*	*5.051*
33.	*Missouri*	*0.69%*	*1.99%*	*10.12%*	*138.04*	*2160*	*4.239*
34.	*Idaho*	*0.24%*	*0.70%*	*10.19%*	*141.07*	*2163*	*1.493*
35.	*Kansas*	*0.31%*	*0.92%*	*10.04%*	*144.49*	*2166*	*1.957*
36.	*Indiana*	*0.72%*	*2.21%*	*10.32%*	*154.32*	*2176*	*4.728*
37.	*Wisconsin*	*0.64%*	*2.05%*	*9.61%*	*161.39*	*2183*	*4.32*
38.	*South Carolina*	*0.51%*	*1.81%*	*10.49%*	*194.93*	*2217*	*3.886*
39.	*Nebraska*	*0.19%*	*0.69%*	*10.30%*	*200.58*	*2223*	*1.475*
40.	*Iowa*	*0.26%*	*1.36%*	*10.49%*	*334.18*	*2356*	*2.92*
41.	*Kentucky*	*0.29%*	*1.56%*	*10.45%*	*346.11*	*2368*	*3.346*
42.	*Alabama*	*0.32%*	*1.94%*	*10.42%*	*402.31*	*2424*	*4.159*
43.	*Louisiana*	*0.22%*	*1.37%*	*10.28%*	*414.43*	*2436*	*2.928*
44.	*West Virginia*	*0.07%*	*0.43%*	*11.19%*	*417.08*	*2439*	*0.937*

45.	*Montana*	*0.11%*	*0.76%*	*10.28%*	*470.63*	*2493*	*1.624*
46.	*Arkansas*	*0.17%*	*1.26%*	*10.86%*	*519.49*	*2541*	*2.726*
47.	*Mississippi*	*0.09%*	*0.85%*	*10.57%*	*684.37*	*2706*	*1.828*
48.	*South Dakota*	*0.05%*	*0.51%*	*10.67%*	*748.81*	*2771*	*1.099*
49.	*Wyoming*	*0.03%*	*0.31%*	*10.19%*	*751.30*	*2773*	*0.661*
50.	*North Dakota*	*0.03%*	*0.33%*	*9.87%*	*800.02*	*2822*	*0.699*

From this model, only two states are currently on track to reach their net-zero goals in 2050: California and Hawaii. Both of them boast BEV shares that more than double their total vehicle shares, far exceeding the median Δ_{State} of 0.46 (New Mexico). This means that this median state, New Mexico, has more than twice the share of total vehicles than the share of BEVs relative to the rest of the country—the opposite of those of California and Hawaii, which have a Δ_{State} of 3.49 and 2.23, respectively—and will expect to reach net-zero emissions in 2122. It is clear that the leading states in BEV registration, and specifically California are carrying the weight of other states' clean transportation goals, with most states a farther distance away from reaching emissions neutrality.

Table 10: *Summary Statistics, Sigmoidal Growth Function variables*

Variable	Obs	Mean	Median	Std. Dev.	Min.	Max.
v_{State} ***(BEV share)***	*50*	*2.00%*	*0.71%*	*5.51%*	*0.03%*	*38.82%*
w_{State} ***(total vehicle share)***	*50*	*2.00%*	*1.49%*	*2.06%*	*0.17%*	*11.12%*
k_{State} ***(growth rate)***	*50*	*10.25%*	*10.35%*	*0.41%*	*9.12%*	*11.19%*
t_{State} ***(years since 2022)***	*50*	*189.29*	*92.51*	*217.28*	*18.18*	*800.02*
$Year_{State}$ ***(net-zero)***	*50*	*2211*	*2120*	*217.19*	*2040*	*2822*
$P(28)_{State}$ ***(net-zero BEVs, millions)***	*50*	*4.07*	*3.17*	*3.66*	*0.37*	*17.41*

2023 EV Purchasing Laws & Incentives	*50*	*23.9*	*19.5*	*21.57*	*7.00*	*145*
2019 EV State & Utility Actions	*50*	*6-9*	*6-9*	-	*1-2*	*10 or more*
2019 Total Available Tax Credit / Rebate Amount (New EV)	*50*	*$2,876.98*	*$150.00*	*$6,806.72*	*$0.00*	*$45,299*

However, though it is the second-leading state in reaching its net-zero track, Hawaii does not offer state incentives for new BEV purchases. While certain Hawaii plug-in electric vehicles may qualify for the federal tax credit, as well as a state rebate program for the installation of upgraded EV charging systems, there are no point-of-sale incentives or tax credits for the sale of a new BEV within the state or state counties. This threw me off, as my initial differences-in-differences regression indicated that having state-exclusive incentives would lead to increased BEV registrations. This finding suggested that I was looking at my findings incorrectly, and instead should be examining states that showed high BEV performance first before looking at the strength of their incentive policy.

Table 11: *Available Incentives, Purchasing Laws, and Utility Actions, by state*

State	***Year (net-zero)***	$P(28)_{State}$ ***(net-zero BEVs, millions)***	***2023 EV Purchasing Laws & Incentives***	***2019 EV State & Utility Actions***	***2019 Total Available Tax Credit / Rebate Amount (New EV)***
California	*2040*	*13.864*	*145*	*10 or more*	*$45,299*
Hawaii	*2051*	*0.92*	*16*	*10 or more*	*$0*
Washington	*2056*	*5.933*	*45*	*10 or more*	*$2,200*
Oregon	*2058*	*2.984*	*41*	*10 or more*	*$7,500*
New Jersey	*2058*	*4.783*	*37*	*10 or more*	*$12,000*

Colorado	2059	3.853	54	10 or more	$8,000
Arizona	2060	4.604	30	10 or more	$0
Delaware	2061	0.367	13	6-9	$2,500
Massachusetts	2062	3.957	48	10 or more	$3,500
Utah	2062	2.149	22	3-5	$0
New York	2063	7.147	51	10 or more	$2,000
Vermont	2064	0.469	33	10 or more	$9,500
Maryland	2064	3.729	43	10 or more	$3,000
Florida	2065	14.587	20	3-5	$300
Connecticut	2066	2.083	36	10 or more	$10,500
Virginia	2070	5.814	35	6-9	$0
Nevada	2072	4.159	22	10 or more	$2,500
Georgia	2073	6.755	18	6-9	0
Texas	2075	17.412	23	10 or more	$2,500
Illinois	2077	8.289	24	10 or more	$4,000
Rhode Island	2080	0.601	19	3-5	$2,500
North Carolina	2084	6.619	30	10 or more	$0
New Hampshire	2084	1.076	14	3-5	$1,000
Minnesota	2089	4.193	32	10 or more	$0
Pennsylvania	2100	8.327	23	6-9	$3,100
New Mexico	2112	1.416	20	10 or more	$0
Maine	2117	1.051	16	10 or more	$3,500
Oklahoma	2124	2.552	21	6-9	$5,700
Alaska	2140	0.505	9	1-2	$1,000
Ohio	2142	8.271	12	3-5	$0
Tennessee	2155	5.051	9	3-5	$0
Michigan	2154	7.305	27	10 or more	$4,000
Missouri	2160	4.239	11	10 or more	$0
Idaho	2163	1.493	7	1-2	$0
Kansas	2166	1.957	7	3-5	$0
Indiana	2176	4.728	23	6-9	$0
Wisconsin	2183	4.32	21	10 or more	$0
South Carolina	2217	3.886	17	6-9	$0
Nebraska	2223	1.475	7	3-5	$4,000
Iowa	2356	2.92	15	6-9	$0
Kentucky	2368	3.346	8	6-9	$0
Alabama	2424	4.159	13	3-5	$0
Louisiana	2436	2.928	10	3-5	$0
West Virginia	2439	0.937	10	$0	$0
Montana	2493	1.624	11	6-9	$0

Arkansas	*2541*	*2.726*	*12*	*1-2*	*$0*
Mississippi	*2706*	*1.828*	*12*	*3-5*	*$1,250*
South Dakota	*2771*	*1.099*	*8*	*1-2*	*$0*
Wyoming	*2773*	*0.661*	*9*	*1-2*	*$0*
North Dakota	*2822*	*0.699*	*8*	*3-5*	*$0*

Though high BEV uptake equals more incentive policy for most states, many others also appear to be outliers, similar to Hawaii. Including Hawaii, seven states in the top 25 ranking states in net-zero timeline also do not offer any incentives for the new or old purchase of a BEV. Some of these states include Arizona, Utah, Virginia, and North Carolina, which all have large populations and significant BEV targets to reach. However, while all of these states do not offer state-exclusive incentives, some have still enacted a proportionally large amount of purchasing laws and incentives in the last year, such as Arizona, Virginia, and North Carolina. These improportionally large numbers may be related to features outside of the electric vehicle ownership itself, such as the installment of charging stations, HOV lane access, and even special parking permits, so such irregularities may not be as indicative of strong policy. It is interesting to note how these states can succeed in increasing BEV registration growth without the use of sale incentives, as I once considered these incentives to be the most cost-reductive and influential motivators for BEV uptake, but these results prove that my original predictions were not completely correct.

It is important to note that this model does not account for possible changes in states' long-term BEV policies. The model instead relies on the assumption that states are entering a period of consistent BEV uptake, which will eventually plateau as BEVs fall in line with the total capacity of vehicles within each state and the country as a whole. It is absolutely possible that states may make significant changes to their incentive policies in the future, which would have a significant impact in changing these projections. However, the model serves as a guide to estimate rough approximations for states' net-zero timelines and required BEV levels.

7. Discussion

Through initial results, it seemed like incentives were working. But were they really?

It was possible that states previously experiencing high demand for BEVs were simply targeting their audience by addressing pre-existing market needs, and not the other way around. California leads all states in BEV uptake, consisting of nearly 39% of all registered BEV units in 2022, but also has multiple affluent cities with high densities of high-income residents, including numerous cities in the Silicon Valley and Los Angeles regions. Other leading states like Hawaii, Washington, and Oregon also host similar communities of increased wealth. In areas such as these, incentives may be distributed at a higher proportion. While the support of such cost-reductive electric vehicle policies is beneficial, it is almost just as important for incentives to be offered equitably, considering the financial restraints of low-to-moderate income (LMI) communities for the universal uptake of clean transportation technology.

7.1 Awareness, Accessibility, and Socioeconomic Factors

Mark Scribner, the Transportation Program Manager for the Massachusetts Offers Rebates for Electric Vehicles (MOR-EV) incentive program, explained that incentive policies are highly dependent on a state's long-term sustainability goals. According to Scribner, states that have chosen to discontinue their incentives do so primarily because of cost barriers and improbable expectations. Georgia, which eliminated its BEV tax credit of $4,000 at the end of 2015, considered its expensive initiatives to outweigh the benefits of increasing sustainable energy in its state, with state policy officials likely considering BEV adoption to support itself. However, many states are advocating for incentives on used BEVs, such as Scribner's MOR-EV program in Massachusetts. Programs like these further indicate that reducing costs, but also the awareness that these cost reductions are possible, are significant factors that are supporting BEV popularity among state residents.

While it is expected that states offering a cost-reducing incentive will have higher registration levels, it is also important to observe factors that sparked irregularly in these growth rates. Specifically, the influence of **awareness**, **accessibility**, and **socioeconomic status** on BEV uptake in state counties.

Using the California Clean Vehicle Rebate Project's (CVRP) outreach maps, I made visual comparisons for the following factors:

Awareness → CVRP Event Outreach (number of events attended by CVRP)

- Awareness is defined as the number of events that the CVRP attended in its records (2014-2021)
- The Event Outreach team works with a range of public events in California, such as auto shows, EV test drive events, environmental events, and conferences, to spread information about clean vehicle incentives and policies.

Accessibility → CVRP Dealership Outreach (number of BEV dealerships in California)

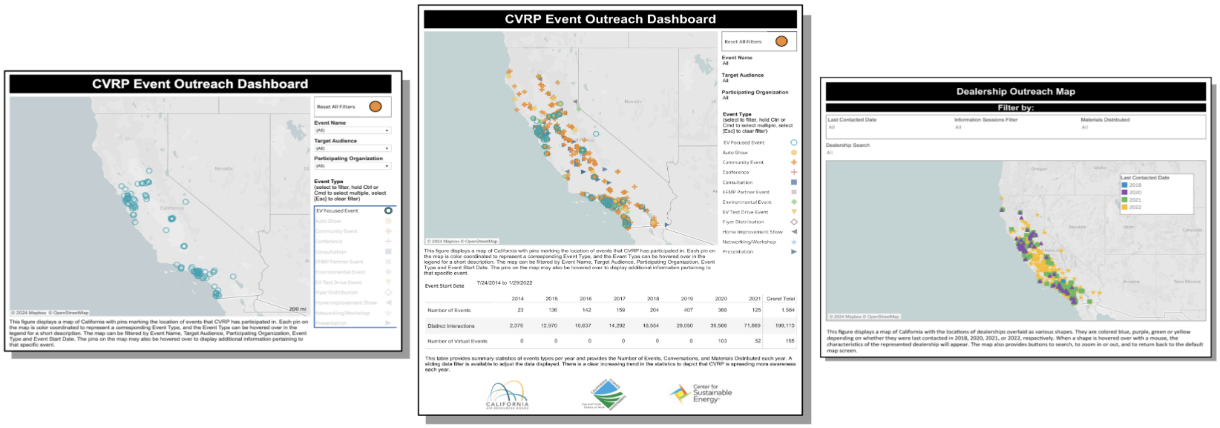
- The Dealership Outreach team engages with sales staff and managers to ensure they have the most up-to-date EV incentive information and resources available to provide electric vehicle (EV) car shoppers with a comprehensive and positive buying experience.

Socioeconomic status → Median individual income (median income per county)

- Socioeconomic status is defined as the average median individual income in each Californian county. This factor is not included in the CVRP dashboard.

These three factors demonstrated close correlations with BEV sales from a visual perspective. From a glance, it appeared that the CVRP attended events in a large range of counties for factors like awareness, as they reached nearly all major cities of California. However, by filtering for the “EV Focused Event” event type, it is more visible that such events primarily occurred in San Francisco and Los Angeles—two coastal, high-income areas that did have high BEV sales, but a significantly wealthier population. Los Angeles residents had an individual median income of $76,000, with significant variance, and $137,000 for San Francisco residents in 2022, which both exceeded the median household income of all California residents of $85,000. After considering these factors, it becomes clearer that electric vehicle information is more widely known, more made available, or more encouraged in areas of greater wealth.

Figure 12-14: *CVRP Event Outreach & Dealership Outreach Dashboards*

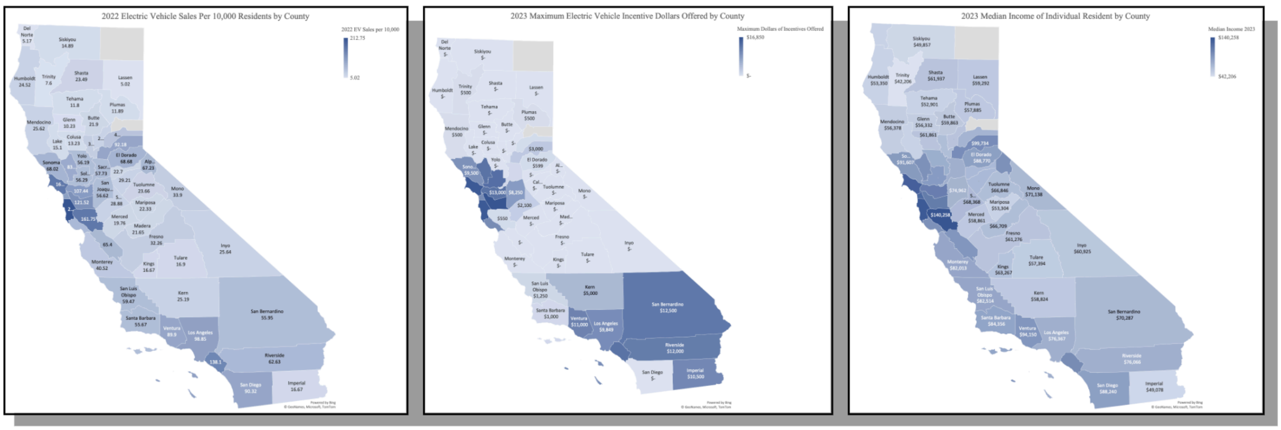


Source: California Vehicle Rebate Program

Similarly, the CVRP showed an increased emphasis on engaging with San Fransisco and Los Angeles community dealerships in their outreach efforts from 2018-2021. According to the description, the CVRP Dealership Outreach team engages with sales staff and managers to uphold accurate BEV incentives and policies to make the purchasing experience more suitable for customers. This engagement includes in-person visits, in-person information sessions, training sessions, and other relevant materials for dealership staff, all of which would be helpful in maximizing the dealership's selling process. The CVRP has documented significant increases to its outreach spread in most of California, but previously only targeted wealthier counties in 2018, 2020, and 2021. While these changes may simply be reporting the most popular destinations, it is noteworthy that the same high-income counties are continuously exposed to new information on battery electric vehicles.

A similar distinction is demonstrated in the following maps, which compare California counties' BEV sales per capita, total incentive dollars offered, and median incomes.

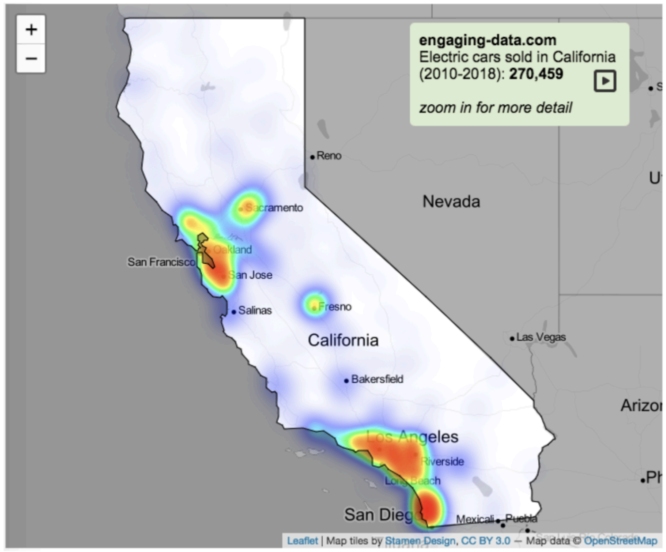
Figure 15-17: *2022 BEV Sales Per Capita, 2023 Maximum BEV Incentive Dollars Offered, 2023 Median Income of Individual Resident by County*



Source: Alternative Fuels Data Center, Kelley Blue Book

In these maps, counties closer to the coast with higher median incomes are more likely to have more regional incentives offered and more BEV sales per capita. These apparent similarities indicate a correlation with coastal proximity, but more likely just areas of high income.

Figure 18: *Heatmap of BEV Sales in California (2010-2018)*



Source: Engaging Data

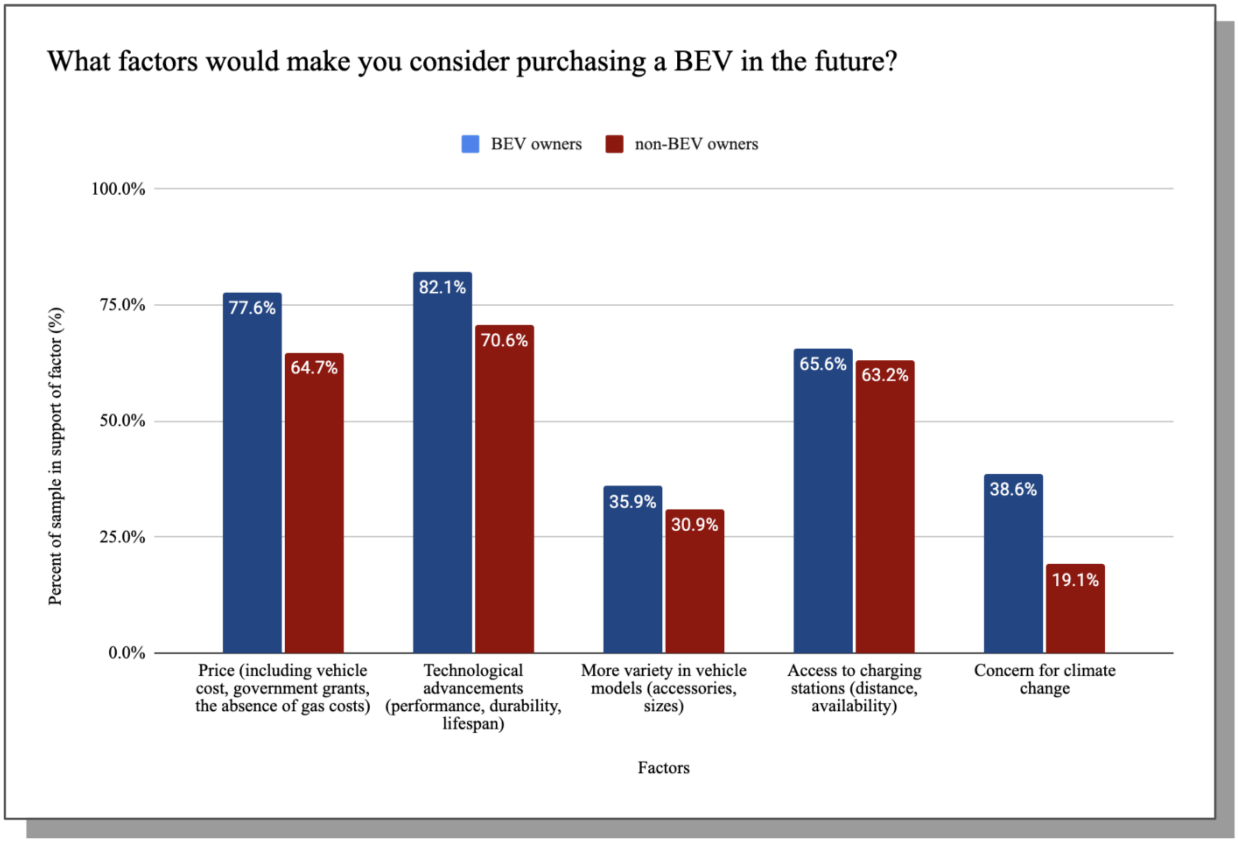
8. Conclusion

Using both an ordinary least squares regression and a differences-in-differences regression to examine the effects of state and county-exclusive incentives on the uptake of BEVs, this research demonstrates that there is a 0.14% increase in BEV registrations and sales when there are at least $1,000 and $500 maximum incentive dollars offered at the state and county levels, respectively.

However, this research does not prove that there is a causal relationship between incentives and BEV uptake. For example, California could simply have more incentives offered because of consumer demand, which may encourage BEV dealerships to target these areas as a result. Through this research, it is clear that incentive effectiveness is closely tied to BEV accessibility, in terms of two factors in specific: the community's long-term sustainability goals and the socioeconomic status of their residents.

Primarily, the latter factor seems to be the controlling factor in BEV adoption. In a self-collected survey sent out to current BEV owners and non-BEV owners, I asked which factors would weigh the most influence in encouraging the purchase of new BEVs.

Figure 19: *Survey, Most Desired Factors for BEV Adoption*



The results showed that the price and technological advancements were the most significant motivators, with both factors receiving over 75% of the total surveyed sample's votes. All factors received higher support from BEV owners than non-BEV owners, with a particular separation in concern for climate change. It stuck out that out of the BEV owners, over 73% reported a household income over $100,000 – a significantly wealthy sample – but yet the sample showed a particular preference for low vehicle costs. This data indicates that regardless of income, vehicle owners are most concerned about how much they have to pay for battery-electric vehicles, and thus BEV registrations will be highest in the regions where costs are most supported. This is a problem that BEV incentives may not solve alone, and instead such support may rely on the cost reduction of electric vehicle models themselves.

Almost in connection with this apprehensive consumer interest, low–cost electric vehicles for the everyday person are becoming a greater reality. BYD's Seagull EV, released in March 2024, combines performance with affordability and will serve as a serious contender in the electric vehicle market, listed at a price of $9,700. The lithium-ion batteries used in the model, supported by China's extensive supply chain, are significantly cheaper than those used by GM and Ford's batteries, which allow BYD to reduce the cost at a rate that many US companies can't match. With the US rumored to prevent sales of the Seagull in domestic dealerships in fear of them taking over the market, United States automakers are pressured to make the cheapest BEV possible to address the majority of American consumers looking for this affordable option.

This study examines the impact of incentives, but also explains how many states are far from reaching their net-zero goals in transportation. States like North Dakota, Kentucky, Alabama, Louisiana, and many more have limited incentive policies in action, which reflects unawareness or distrust in the use of an alternatively fueled vehicle. Many regions may be wary of adopting unproven technologies, especially if there is significant political disapproval from the majority population, and it is important to increase awareness in areas such as these to increase clean energy support, especially in areas with large populations.

However, a state like Hawaii that boasts a high BEV adoption with no direct vehicle cost reductions indicates that clean energy is only accessible to wealthy individuals. This suggests that if the leading adopters don't require incentives, and if incentives are predominantly used by wealthy individuals, it is reasonable to have a healthy suspicion of luxury vehicles designed for the upper class. While incentives may only be a temporary fix while the United States attempts to emulate cost-effective models like the Seagull, they must be spread on a wider level to communities that would benefit most from them.

My findings suggests that incentives are in fact correlated with increased BEV adoption, but may be correlated more with inefficiencies than impact in terms of cost and emission reduction. As the United States seeks to reduce emissions through net-zero goals, incentives will serve only as a partial motivator for prospective BEV owners until they are made more aware to greater communities.

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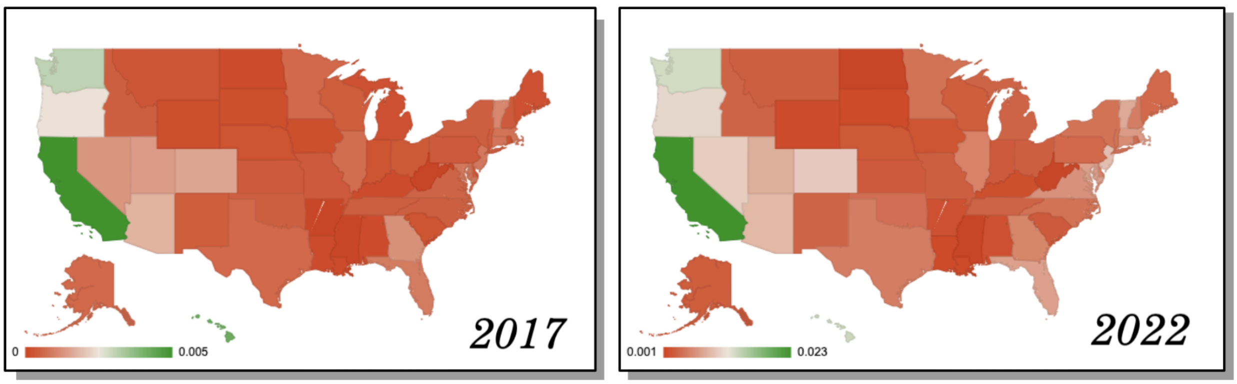
10. Appendix

10.1 BEV Registration by State, Full Dataset: Alternative Fuels Data Center (2017-2022)

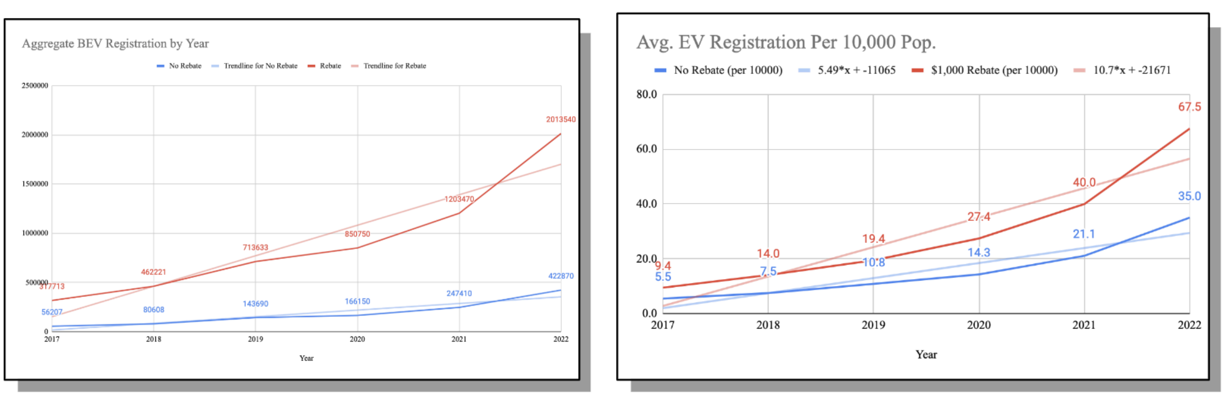
10.2 BEV Sales by California County, Full Dataset: California Energy Commission (2017-2022)

Figure 20-21: *BEV Registrations per capita, by state (2017 vs. 2022)*



Source: Alternative Fuels Data Center

Figure 22-23: *Aggregate BEV Registration & Registration per capita, by incentive offered (2017 vs. 2022)*



Source: Alternative Fuels Data Center

Figure 24: *OLS Regression of BEV per capita on incentives offered, year, income, utility, & political affiliation*

	(1) BEVper10000	(2) BEVper10000	(3) BEVper10000	(4) BEVper10000	(5) BEVper10000	(6) BEVper10000	(7) BEVper10000
PHEVper10000		1.612***	1.351***	1.334***	1.331***	1.322***	1.327***
	(12.54)	(10.36)	(10.55)	(10.53)	(10.91)	(10.80)	
HEVper10000	0.0929***	0.107***	0.0946***	0.0869**	0.123***	0.121***	
	(3.48)	(4.21)	(3.52)	(3.09)	(4.41)	(4.27)	
Incentive	-4.019*	-2.016	-1.665	-1.908	0.312	0.284	
	(-2.44)	(-1.26)	(-1.05)	(-1.18)	(0.19)	(0.18)	
yr2018			0.158	0.335	0.389	0.0787	0.0398
			(0.06)	(0.14)	(0.16)	(0.03)	(0.02)
yr2019			1.988	2.646	2.784	1.561	1.484
			(0.79)	(1.08)	(1.13)	(0.66)	(0.62)
yr2020			4.315	4.133	4.279	2.818	2.782
			(1.71)	(1.69)	(1.74)	(1.19)	(1.17)
yr2021			4.917	5.042*	5.330*	3.314	3.311
			(1.88)	(1.99)	(2.09)	(1.34)	(1.34)
yr2022			14.76***	15.89***	16.43***	13.12***	13.05***
			(5.30)	(5.84)	(5.91)	(4.80)	(4.75)
inc_60_70				-0.345	-0.386	-2.827	-3.458
				(-0.16)	(-0.18)	(-1.34)	(-1.12)
inc_70_80				-5.333*	-5.403*	-4.943*	-6.106
				(-2.29)	(-2.32)	(-2.22)	(-1.30)
inc_80_90				5.114	5.310	8.459**	6.693
				(1.73)	(1.80)	(2.92)	(0.97)
inc_above90				1.516	1.170	5.561	3.211
				(0.42)	(0.33)	(1.57)	(0.35)
Utility					1.660	4.149*	4.162*
					(0.95)	(2.38)	(2.39)
PoliticalAff						11.97***	12.00***
						(5.18)	(5.18)
MedInc~10000							6.18e-09
							(0.28)
_cons	-9.660***	-13.34***	-11.21***	-10.94***	-24.03***	-27.30*	
	(-3.99)	(-4.69)	(-3.74)	(-3.63)	(-6.27)	(-2.24)	
F Statistic		343.5***	147.7***	107.3***	99.11***	102.3***	95.15***
RMSE		13.14	12.47	12.06	12.06	11.55	11.57
Adj. R2		0.775	0.797	0.810	0.810	0.826	0.825

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Source: Alternative Fuels Data Center, Kelley Blue Book