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The impact of Electric Vehicle Charging Stations on Light Duty Electric Vehicle adoption and rebates California.

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Executive Summary

This Study investigates the effect of Electric Vehicle Charging Stations (EVCS) on light-duty Electric Vehicle sales and the Total California rebates. I applied dasymetric model to create a geographic database dividing California state into equal size geographies with community-level attributes. As well as using the difference-in-difference (before-after) design to identify a strategy for estimating the causal effects of these attributes. These attributes include EVCS installations by time, EV sales by time, rebate applications by time, and median income levels. The empirical evidence of this study shows the estimated relationship between public EV charging installation and EV sales overall by community income level, housing density, and other relevant factors. For the investors, policymakers, and other stakeholders, this study provides evidence of a threshold of EVCS on Light Duty Electric Vehicle adoption and rebate in California.

Keywords: Electric Vehicle (EV), Charger, Infrastructure, Energy storage, and Environment.

1 Introduction

Electric vehicles (EVs) have gained traction recently as a preferred substitute to traditional gasoline-powered cars due to their environmental benefits, technological advancements, and low operating costs. However, EV adoption still faces significant challenges, including range anxiety, high upfront costs, and a lack of charging infrastructure. Therefore, governments and private entities have been investing in building EV charging stations to encourage EV adoption. To create pathways to Net-Zero Greenhouse Gas emissions by 2050. The US has committed to reducing net GHG emissions by 50-52% below 2005 levels by 2030 (The WhiteHouse, 2021). According to the United States Environmental Protection Agency, vehicles contribute to the largest carbon emissions in the USA. To decarbonize the USA, the importance of EVs must be emphasized to achieve this goal as important as EV adoption is, and more importantly, the EVCS, which determines the viability of EV adoption. Therefore, Charging Stations' availability is a significant factor in EV adoption.

Rebates are a popular incentive program that governments and organizations around the world have used to encourage the adoption of EVs. Rebates typically provide consumers with a financial incentive to purchase an EV by offering a cash rebate or a tax credit. These incentives help offset the higher upfront cost of purchasing an EV and make them more affordable for consumers.

The Clean Vehicle Rebate Project (CVRP) offers rebates from $1000 to $7000 for purchasing or leasing selected light-duty electric vehicles in California. This rebate helps in reducing the price of EVs for California residents. Therefore, evaluating EV Public Charging Stations' impact on EV adoptions and rebates would help us achieve our goals. This study aims to answer these questions: Are local EV adoption and rebate applications related to installing public EV chargers? If so, what is the quantitative relationship between installation and change in EV sales or rebate application rate? Does the relationship vary based on community features such as commute distance, housing density, or income level? To answer these questions, this study employed differences in different designs to measure the causal estimate of electric vehicle charging stations on EV adoption and rebate in California. First, we split the data into two groups (before-after the installation of EV charging stations), then we calculate the mean of EV adoption for each group and perform a statistical test to determine if there is a significant difference in EV adoption before and after the installation of EV charging stations. This will help answer the research question of how the availability of EVCS impacts the adoption of EVs in California, which will lead to policy implications of the findings.

1.1 Factors that EV adoption.

The factors that affect EV adoption play a critical role in understanding the impact of EVCS on EV adoption. Generally, these factors can be organized into an understanding of three different factors, which are:

1. Manufacturing Factors: These factors affect the EV industry, including incentives and charging infrastructure. (evconnect, 2022).

Table 1: Characteristics of EV Charging Stations

	Level 1	Level 2	DC Fast Charging
Connector Type	J1772 connector	J1772 connector Tesla connector	CCS/SAE connector CHAdeMO connector Tesla connector
Typical Power Output	1 kW	7 kW-19 kW	50-350 kW
Estimated PHEV Charge Time from Empty	5-6 hours	1-2 hours	N/A
Estimated BEV Charge Time from Empty	40-50 hours	4-10 hours	20 minutes-1 hours
Typical Locations	Home	Home, Workplace, and Public	Public

Source: (U.S. Department of Transportation, 2022)

2. The personal/driver factors include the range, charging speed, the awareness and desire of the driver to adopt an EV, cost, and incentives or rebates available for the purchase. One important factor in determining the purchase of an EV is its range, that is, the ability to travel farther on a charge. Over the past decade, battery technology has improved EV ranges. Three electric vehicle charging speeds are currently available in the USA, which are level 1, the slowest, and providing charging through a standard residential 120-volt AC outlet. The level 2 equipment offers charging through 240V or 280V, and the Direct Current Fast Charging (DCFC) has the fastest charging speed. Other variables that affect EV ranges, such as weather, at a temperature below 20^{0} F, can cause EVs to lose around 12% of their range, rising to 41 % if heating is turned on inside the vehicle (Bhutada, 2022). Another important factor is the cost which is represented as the Manufacturer's Suggested Retail Price (MSRP)

Table 2: Personal driving factors for EV adoption

Year	Avg. EV Range	Maximum EV Range	Average MSRP
2010	79 miles (127 km)	N/A	N/A
2011	86 miles (138 km)	94 miles (151 km)	N/A
2012	99 miles (159 km)	265 miles (426 km)	N/A
2013	117 miles (188 km)	265 miles (426 km)	N/A
2014	130 miles (209 km)	265 miles (426 km)	N/A
2015	131 miles (211 km)	270 miles (435 km)	N/A
2016	145 miles (233 km)	315 miles (507 km)	$33,380
2017	151 miles (243 km)	335 miles (539 km)	$58,965
2018	189 miles (304 km)	335 miles (539 km)	$64,300
2019	209 miles (336 km)	370 miles (595 km)	$55,600
2020	210 miles (338 km)	402 miles (647 km)	$54,668
2021	217miles (349 km)	520 miles (837 km)	$64,249
2022	211 miles (341 km)	520 miles (837 km)	$65,291

3. Environmental and External Factors: to establish net-zero emissions by 2050, the need for EV adoption is ever-increasing with the rising gas price.

2 Literature Review

In the related literature on EVs' quantitative and qualitative characteristics, recent studies have been conducted to compare the characteristics of EVs to that of non-EV. (Mandev, Sprei, & Tal, 2022) Studied the impact of household-specific factors, which include frequency of charging, frequency of long-distance trips, and frequency of overlaps between vehicles on electric vehicle miles travelled (eVMT), fuel consumption within two-car households, and utility factor. And found that Plug-in hybrid electric vehicles (PHEVs) with a range of at least 35 miles and some short-range battery electric vehicles (BEVs) can electrify a similar share of total household miles and up to 70% electrification on long-range BEVs. (Pearre, Swan, Burbidge, & Anctil, 2022) stated that EVs depend on public fast charging, especially when traveling outside a single charge range, and therefore a network of fast charging stations is of high importance.

2.1 Qualitative Characteristics

One of EVs' most significant qualitative characteristics is that they emit no tailpipe emissions, making them environmentally friendly and contributing to improved air quality. This characteristic is particularly appealing to environmentally conscious consumers who wish to reduce their carbon footprint. Furthermore, EVs provide a quiet and smooth driving experience, and many models have advanced features, such as regenerative braking, that can improve their performance and efficiency.

Another significant qualitative characteristic of EVs is that they offer a lower total cost of ownership (TCO) than traditional gas-powered vehicles. While EVs have a higher upfront cost but lower operating costs due to their lower fuel and maintenance costs. This makes EVs particularly attractive to consumers interested in long-term savings and a sustainable lifestyle.

EV charging stations also have unique qualitative characteristics. They are typically designed to be compact and unobtrusive, allowing them to blend in with their surroundings. Additionally, many charging stations are equipped with advanced technology, such as mobile applications and smart charging systems, which allow consumers to monitor their charging progress and optimize their charging patterns. These features enhance the convenience and accessibility of EV charging stations, making them more attractive to consumers.

2.2 Quantitative Characteristics

One of the EVs' most significant quantitative characteristics is their range and vehicle type of light-duty EVs. The vehicle type for the light-duty EV is Fuel Cell Electric Vehicle (FCEV), Battery Electric Vehicles (BEV), or Plug-in Hybrid Electric Vehicle (PHEV). EVs have a range that is typically shorter than that of traditional gas-powered vehicles, making them less suitable for long-distance travel. However, advances in battery technology have led to longer ranges, and many newer EV models have ranges that can rival those of traditional gas-powered vehicles. Improvements in charging infrastructure have also led to faster charging times, which can further enhance the convenience and accessibility of EVs.

Another significant quantitative characteristic of EVs is their efficiency. EVs are typically more efficient than traditional gas-powered vehicles, requiring less energy to travel a distance. This efficiency can result in significant cost savings for consumers and contribute to reducing carbon emissions.

EV charging stations also have unique quantitative characteristics. The charging speed of an EV charging station is a critical factor in its appeal to consumers. Faster charging speeds allow consumers to spend less time charging their vehicles and more time driving. Furthermore, the number of charging stations available in each area can significantly impact the convenience and accessibility of EV charging for consumers.

In conclusion, EVs and their charging stations have unique qualitative and quantitative characteristics distinguishing them from traditional gas-powered vehicles and gasoline refueling stations. These characteristics contribute to their appeal to consumers, particularly those who are environmentally conscious and interested in long-term savings. Advances in battery technology and charging infrastructure are continually improving EVs' range, efficiency, charging speed, and charging stations, making them more accessible and convenient for consumers. As these technologies continue to evolve, we can expect to see continued growth in the adoption of electric mobility.

The International Electrotechnical Commission (IEC), CHAdeMO Association, and Society of Automotive Engineering (SCE) are the institutions responsible for standardizing the electric characteristics of EV charging stations (Youssef, Fatima, Najia, & Chakib, 2014). IEC’s recent revision of the International EV charging standards: (International Electrotechnical Commission, 2022) includes some of the following technical changes:

- Changes to the temperature rise test to include additional points of measurement.
- Additional tests for accessories to address thermal stress and stability, mechanical wear and abuse, and exposure to contaminants.
- Additional requirements for contact material and plating

The EV charging stations aim to create reliable support for EV drivers to ensure that affordable and fast charging is available. In California, EV drivers attribute a reliable EV charging station to the following:

- Charging Cable Plug Compatibility: one of the major concerns for EV drivers is the compatibility of the outlet of the charging station to their respective EVs. Unlike gasoline vehicles, which have one universal outlet plug for gasoline, the EV currently has four different outlets for charging. There are two types of AC plugs (type 1 and type 2) and two types of DC plugs (CHAdeMO and CCS)
- Charging Efficiency: the amount of time it takes to charge an EV is important in determining EV adoptions and charging. The situation determines the charging efficiency for an instant. A fast-

charging station of about 15-20 minutes will be required on highways and freeways, but a shop and charge may require 1 to 2 hours for a full charging process of around 22KW. And a home charger may hold up to 3.6KW power and require 6 to 8 hours for a full charging process.

- Diverse Payment Options: paying depends on the charger point operators or network for public charging stations that are not free. Many networks provide subscriptions or memberships that lower the monthly fees, and these payments are usually made through an app, fob, or an RFID card. However, almost all public charging stations have options for card payments.
- Strategic location: a strategic location is a crucial attribute in determining the reliability of an EV charging station. On average rapid chargers will take between 20-30 minutes to provide between 60-200 miles of ranges.

Electric vehicles (EVs) and their charging stations have unique qualitative and quantitative characteristics that distinguish them from traditional gas-powered vehicles and gasoline refueling stations.

2.3 Role of Rebate in EV adoption

In 2021 the US government spending on electric cars tripled to USD 2 billion, which accounts for USD 3,200 per-unit basis. Rebate has accounted for the major government spending on electric vehicles, especially in California (Agency, 2022). Rebates have been shown to be effective in driving the adoption of EVs. A study by the International Council on Clean Transportation found that rebates can increase EV sales by up to three times. Furthermore, a report by the National Renewable Energy Laboratory found that rebates can significantly reduce the payback period for EVs, making them a more attractive option for consumers. In addition to rebates, other incentive programs have been implemented to encourage the adoption of EVs. These programs include free or discounted charging, access to high-occupancy vehicle (HOV) lanes, and reduced tolls. These incentives can help address consumers' concerns about EVs' limitations, such as range anxiety and the lack of charging infrastructure.

Government programs have played a critical role in the adoption of EVs. Governments around the world have implemented a range of incentive programs to promote the adoption of EVs, including rebates, tax credits, and other incentives. These programs have been successful in driving the adoption of EVs in countries such as Norway, where EVs account for over 50% of new car sales.

Rebates and other incentive programs have had a positive impact on the environment. These programs have helped reduce greenhouse gas emissions and improve air quality by encouraging the adoption of low-emission vehicles. A study by the Union of Concerned Scientists found that EVs in the United States could reduce greenhouse gas emissions by up to 30%, depending on the source of electricity used to power the vehicles.

Rebates and other incentive programs have played a critical role in driving the adoption of EVs and other low-emission vehicles. These programs have helped make EVs more affordable and accessible to consumers while also addressing concerns about range anxiety and charging infrastructure. They have also positively impacted the environment and society by reducing greenhouse gas emissions and supporting the development of a more sustainable transportation system. As the EV industry continues to grow, we can expect to see continued investment in rebate and incentive programs to support the adoption of this important technology.

Rebates and other incentive programs have also had a positive impact on society. By promoting the adoption of EVs, these programs have helped reduce dependence on fossil fuels and support the development of a more sustainable transportation system. They have also created new job opportunities in the EV industry, which is expected to grow significantly in the coming years.

The best years to use for the analysis would depend on the availability and reliability of the data for the different variables involved in the analysis. However, to capture the impact of the rebate and incentives available in California for Electric Vehicles and Electric Vehicle Infrastructure, it would be ideal to use the years when the incentives and rebates were most significant and implemented.

Some of the significant incentives and rebates for electric vehicles and infrastructure in California include:

1. California's Zero Emission Vehicle (ZEV) mandate, which was adopted in 1990 and requires automakers to sell a certain number of ZEVs in California each year.

2. The California Clean Vehicle Rebate Project (CVRP) offers rebates for purchasing or leasing new electric vehicles. The program began in 2010 and has undergone several rebate amounts changes.
3. The California Electric Vehicle Infrastructure Project (CALeVIP), which offers incentives for the installation of EV charging stations. The program began in 2015 and has also gone through several changes in incentive amounts over the years.

Based on these incentives and their implementation dates, we will be using the date period from 2010-2022.

3. Data and Methodology

This study aimed to evaluate the impact of electric vehicle charging stations on light-duty electric vehicle adoption and rebates in California, using publicly available data from the years 2010-2022

The post-period of 2019 was chosen for the analysis based on current happenings in California related to the adoption of electric vehicles. In recent years, California has set aggressive targets to reduce greenhouse gas emissions, with a goal of achieving carbon neutrality by 2045. As a result, there has been a significant push to increase the adoption of electric vehicles in the state.

In September 2018, Governor Jerry Brown signed a bill into law that set a target of 5 million zero-emission vehicles (ZEVs) on California's roads by 2030. This includes battery-electric, plug-in hybrid, and fuel cell vehicles. This target is part of California's broader efforts to reduce greenhouse gas emissions, improve air quality, and support innovation in the transportation sector.

Given these recent developments and the push to increase the adoption of electric vehicles in California, the year 2019 was chosen as the post-period for the analysis. This allows for a comparison of EV adoption rates before and after the implementation of policies and programs aimed at increasing the adoption of electric vehicles in California.

Using 2019 as the intervention year is likely justified by some external factors or policy changes in California during that period, which may have affected EV charging station installation and adoption rates. For example, in 2019, California increased its incentives for electric vehicles and announced new regulations requiring ride-hailing companies to gradually transition to zero-emission vehicles. These policy changes may have led to an increase in the installation of EV charging stations and, in turn, a rise in EV adoption rates. Using 2019 as the intervention year, we can compare the changes in EV adoption rates before and after these policy changes took effect. In this case, 2019 was chosen as the intervention year because it was the year when a significant increase in the installation of EV charging stations was observed in California.

4. Results

The result of this study shows the impact EVCS has on EV adoption and the rebate in California.

The mean rebate before installation was 2307.76. This means that, on average, there were 2307.76. electric vehicles in the area before the installation of EV charging stations.

The mean EV adoption count after the installation was 2549.23. This means that, on average, there were 2549.23 electric vehicles in the area after the installation of EV charging stations.

The p-value indicates that the increase in rebate after the installation of EV charging stations is not statistically significant.

Table 3: Impact on Rebates

Methodology	Description
Data Source	California Energy Commission (CEC), California Department of Motor Vehicles, California Air Resources Board (CARB), and U.S. Census Bureau
Period	2010-2022
Treatment	Installation of EV charging stations
Control Group	N/A
Pre-Period	>2019
Post-Period	<2019
Outcome Variable	EV adoption count
t-statistics	nan
Significance Level (p-value)	0.000

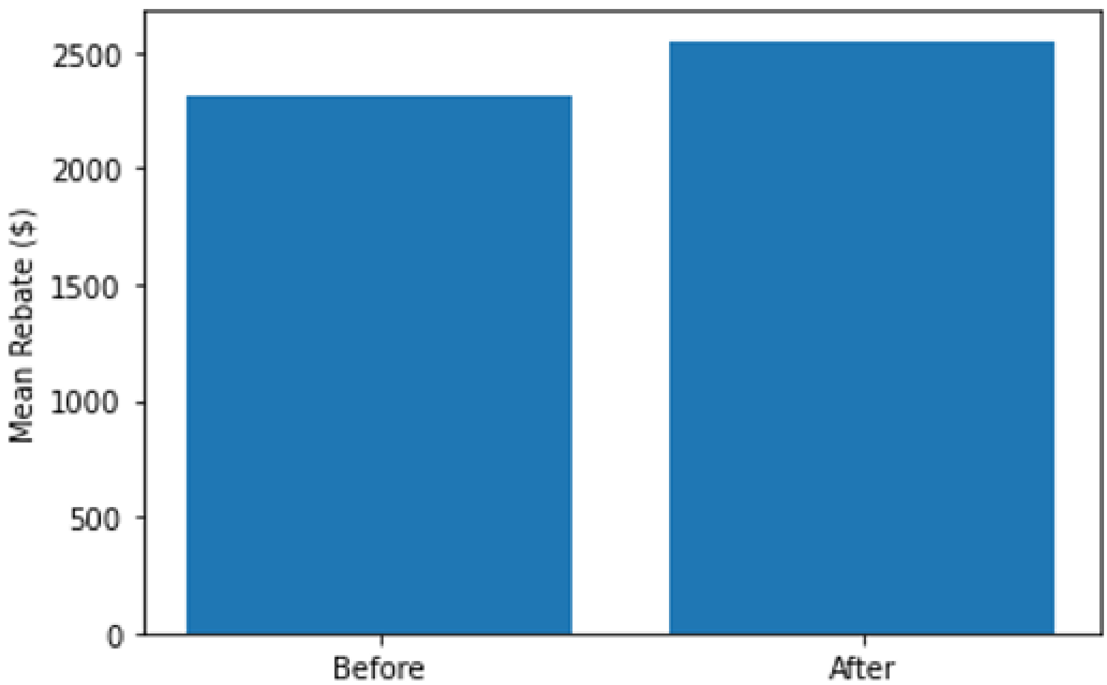


Figure 1: Impact on Rebates

The mean EV adoption count before installation was 283.70. This means that, on average, there were 283.70 electric vehicles in the area before the installation of EV charging stations.

The mean EV adoption count after the installation was 373.02. This means that, on average, there were 370.68 electric vehicles in the area after the installation of EV charging stations.

The p-value of the analysis was less than 0.05, indicating that the increase in EV adoption after the installation of EV charging stations is statistically significant. This suggests that the installation of EV charging stations positively impacted the adoption of electric vehicles in the area.

Therefore, these results support the hypothesis that installing EV charging stations is associated with increased EV adoption, which could be helpful information for policymakers and stakeholders interested in promoting electric vehicle adoption.

Table 4:Impacts on EV adoption.

Methodology	Description
Data Source	California Energy Commission (CEC), California Department of Motor Vehicles, California Air Resources Board (CARB), and U.S. Census Bureau
Period	2010-2022
Treatment	Installation of EV charging stations
Control Group	N/A
Pre-Period	>2019
Post-Period	<2019
Outcome Variable	EV adoption count
t-statistics	-23.89
Significance Level (p-value)	0.000

Figure 2:Impacts on EV adoptions.

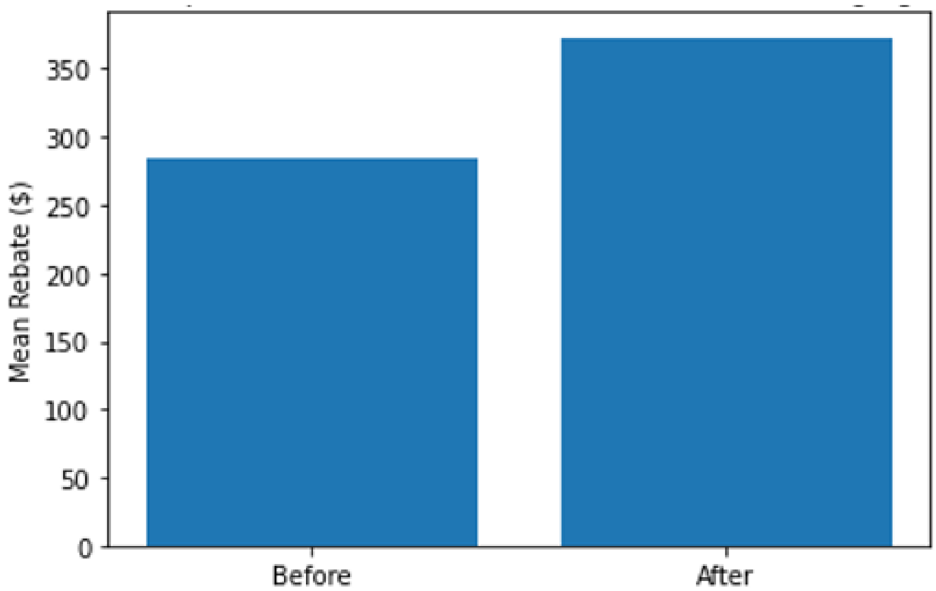
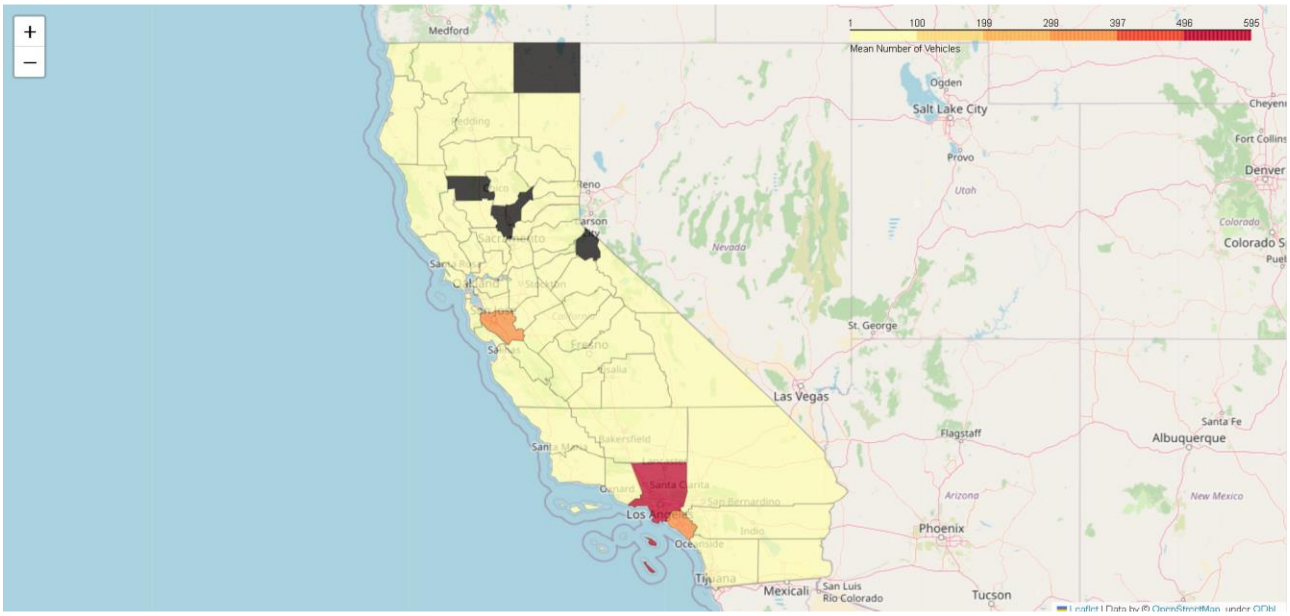


Figure 3: Choropleth map of EV adoption in California



The Choropleth map provides a visualization of the level of electric vehicle (EV) adoption across counties. The colour scheme uses a range of hues to indicate different levels of EV adoption. The black regions on the map signify low levels or no adoption of EVs. The yellow regions represent an average EV adoption rate of approximately 1 to 100 annually, whereas the orange regions reflect an average range of 298-397 annual EV adoptions. The map's red regions represent an average annual EV adoption range of 496-595. This map provides a helpful tool for understanding the variations in EV adoption across different counties in the region.

5. Policy Implications

This study would help inform governments, investors, policymakers, and other stakeholders on how the impact of EVCS on achieving the goal of Net-Zero Greenhouse Gas emissions by 2050. In the paper "The Impact of EV Charging Stations on EV Adoption and Rebate in California," two results were presented. The first result shows no significant difference in the Rebate before and after the installation of EV charging stations. This means EV charging stations did not significantly impact the Rebate in California. The second result shows a statistically significant increase in EV adoption after installing EV charging stations. This means that the presence of EV charging stations had a significant impact on EV adoption in California.

The diffusion of innovation theory can help explain the increase in EV adoption after the installation of EV charging stations. According to this theory, adopting a new technology depends on various factors, including the perceived relative advantage, compatibility, complexity, trialability, and observability of the innovation. In this case, installing EV charging stations can be seen as a relative advantage for EV adoption because it addresses the perceived limitation of range anxiety. EV drivers may be more willing to adopt EVs if they have easy access to charging stations, especially for long-distance travel.

On the other hand, the theory of rational choice can explain the lack of significant differences in rebates before and after the installation of EV charging stations. According to this theory, individuals make decisions based on rational calculations of costs and benefits. In this case, the rebate may not be a significant factor in EV adoption because it represents only a small portion of the total cost of owning an EV. Moreover, the rebate may not be perceived as a significant advantage if not communicated effectively to potential EV buyers.

These findings suggest that installing EV charging stations can be an effective policy to increase EV adoption. At the same time, the impact of rebates may be limited without effective communication and significant financial incentives.

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Presenter Biography

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