Analyzing Appropriate Policy Factors to Stimulate Zero Emission Vehicle (ZEV) Population Growth in California to Achieve the State's Overall Climate and Environmental Goals

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Degree

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ABSTRACT

The objective of this dissertation research is to assess critical policy factors that will need to be adjusted to stimulate significant increases in adoption of Zero-Emission Vehicles (ZEV) in California to support the state's aggressive climate and environmental goals. Currently, California in comparison to the other 49 states has the United States' highest Greenhouse Gas Emissions (GHG) coming from its transportation sector. Also, within the state, transportation is ahead of all other economic sectors, including agriculture, electricity generation, and even industrial pollution in creating poor air quality. California in recent years has set aggressive targets to both decrease GHG's and increase ZEV adoption to combat the climate challenges. Some targets include attaining a ZEV population of at least 5 million by 2030, all light-duty vehicles sold in the state to be 100% ZEV by 2035 and reducing GHG emissions to 40 percent below 1990 levels by 2030. Achieving these aggressive targets through the transportation sector will require shifts in key policies area including multimodal transportation, supportive land-use policies, and even transportation technology. However, the ZEV-related policies adjustments can also be more immediately impactful to the state. Policies and incentives related to offsetting the cost of ZEVs, policies, increasing charging infrastructure, and the cost of fuel are 3 of the most impactful areas that will spur additional sales in the coming years to help California meet its goals. This research provides models to forecast ZEV growth based on the current trends and develops new models based on 3 policies areas adjustments that will help California reach its intended outcomes.

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LIST OF ABBREVIATIONS

List of Key Abbreviations

- EPA – Environmental Protection Agency
- ZEV – Zero Emissions Vehicle
- CEC – California Energy Commission
- SB – Senate Bill
- AB – Assembly Bill
- CARB – California Air Resources Board
- PPE - Personal Protective Equipment
- VMT – Vehicle Miles Traveled
- GHG – Greenhouse Gas Emissions

CHAPTER 1

INTRODUCTION

Air Pollution and GHG Problem in California

The state of California has a tenured history as one of the top public sector leaders on environmental issues in the United States and across the globe. Though much of its environmental work can be dated back to the early 1940's, its emphasis as an environmental strong hold was more formalized in 1970 when the state legislature passed, and the Governor (Ronald Regan) signed into law the California Environmental Quality Act (CEQA) immediately following the United States Congress passage of the National Environmental Policy Act (NEPA) in the same year. At least a dozen states followed California's lead and later adopted state environmental review laws to reduce pollutants impacts on human, air, land, and water ecosystems. In the decades since CEQA, California has continued to heighten its focus on environmental issues. Due to its rapid growth, one of California's long-standing environmental challenges has been poor air quality especially in many of its urban areas.

Much of the air quality challenges the state faces are directly linked to emissions from fossil fuel vehicles. According to the Environmental Protection Agency (EPA), In the United States, greenhouse gas emissions (GHG) caused by human activities increased by 7 percent from 1990 to 2014 (EPA 2020). Across the United States the transportation sector accounts for 29% of GHG (EPA 2020). While in California the transportation sector accounts for a majority of GHG emissions at 41% (California Air Resources Board website 2020). When accounting for fuel production related to consumption by the transportation sector, the 41% calculation rises to nearly 50% according to the California Energy Commission (CEC). In total nearly 80 percent of nitrogen

oxide pollution, and 90 percent of diesel particulate matter pollution in the state comes from the transportation sector (CEC 2021).

A significant amount of the opportunity to reduce GHG emissions and improve air quality in California will undoubtedly come from the transportation sector. Improving multimodal transportation opportunities by getting more people to walk, bike and utilize transit for transportation will be essential but also significant will be increasing the penetration of zero emission vehicles (ZEV's) like electric and hydrogen fuel cell vehicles onto the state's transportation system. California has also led the way in adapting incentives to increase the utilization of ZEV's by improving the affordability of electric vehicles. Electric vehicles while being one of the most environmentally friendly options of transportation, is challenged by the initial purchasing cost that can be a deterrent to increasing its use in the transportation system. This research will further assess the impact of growing state incentives on ZEVs to try and increase its population while trying to achieve climate and environmental goals for the state of California. The research will provide a modeled forecast for future ZEV sales including its supportive infrastructure. It will also analyze 3 of the most significant factors affecting sales of ZEVs in the state and provide policy recommendations to stimulate the needed growth to achieve California's aggressive environmental goals.

Transportation Impacts in American

Poor air quality and GHG emissions challenge in California

Many people living in Southern California and the Los Angeles region during the early 1940's believed the increasingly thickened and unbreathable air they were experiencing was due to possible chemical gas warfare related to World War II (Mcnally 2010). Smog conditions were so

poor that a few minutes outside could lead to extreme irritation of the eyes and ultimately meant lung damage for some. Due to the bad air that people were often warned through public announcements to stay inside. Residents of the region would later find out the extremely poor air they were experiencing was due to a culmination of emissions from more cars being driven through the city and the expansion of manufacturing industries. Other factors like the topography of the Los Angeles basin that helped trap smog and a rapid development pattern that increased the dependence on driving automobiles were also key culprits.

The public demanded more to be done to clean the air and these occurrences helped launch California's foray into becoming a global leader on environmental issues. The push led to Los Angeles adopting smog regulations during World War II. In 1947, nearly two decades before the federal government was able to move forward with substantive environmental laws like the Clean Air Act, the California Legislature and Governor Earl Warren signed into law the Air Pollution Control Act. The law established an Air Pollution Control District in every county of the state to protect local citizens from the harmful effects of air pollution (PBS State of Resolve, energy). In the early 1950' as it became clearer that cars were the main source of poorer air, Dr. Arie Haagen-Smit a Dutch chemist who later became the first Chair of the California Air Resources Board, discovered how smog was created and its photochemical makeup. Dr. Smit took a year leave of absence from his work as a professor at the California Institute of Technology to focus his efforts at the Los Angeles air district laboratory where he discovered how internal combustion engines created smog. His findings on how airborne hydrocarbons from gasoline, and oxides of nitrogen (NOx) produced by internal combustion engines produce poor emissions that lead to smog are part of the foundation of which most air quality regulations where based (CARB – History). The term "smog" was derived from a combination of the words smoke and fog and purportedly coined by

Dr. Des Voeux of London's Coal Smoke Abatement Society (Automobile and the Environment in American History).

The city of Los Angeles population grew from 170,000 in 1900 to 2.8 million in 1940, and over 1.2 million motor vehicles were registered in the county, one vehicle for every 2.3 people (Hanemann 2007). Between 1950 and 1980 California's population grew by another 13 million people. Most of that growth also meant more cars, and freight trucks were driven in the state and for further distances. As the decade before this period the number of cars in L.A. doubled from one to two million (Timeline LA Smog). An estimated 6,000 people attended a community meeting to protest smog levels in Pasadena in 1954 with several protest signs and one that said "It has come to our children's health or oil—so oil must go!". In 1967 Governor Regan signed the Mulford-Carrell Air Resources Act that created the California Air Resources Board (CARB), committing the state to a unified approach to aggressively address the worsening air pollution challenge (CARB – History). The Act also meant a new focus on the automobile industry to create cleaner running vehicles. Despite the industry's push back the state was successful at requiring catalytic converters into all new vehicles. Catalytic converters were designed to remove pollutants from the combustion engine system and help improve air quality. In that period vapor recovery nozzles were also added to gas stations. The nozzles were designed to capture gasoline vapors that escape from automobile tanks when they are being refueled. The captured vapors are returned to the underground gasoline storage tank through special hoses and pipes instead of seeping into the atmosphere and polluting the air. CARB later became the first state environmental organization to set standards for ozone, nitrogen oxide, sulfur oxides, sulfur dioxides, carbon monoxides and particulate matter. Though cars and industries across the state were beginning to pollute less, the smog levels were still high because of the state population

boom and the vehicle miles traveled across the state (CARB History). From the 1980s through the 1990's air quality finally started to see improvement as car engines became cleaner due to higher standards. ARB had been successful at reducing Nitrogen Oxide emissions by 58% compared to 1970 levels and reduced hydrocarbon emissions by 80 percent compared to 1970 levels. (Baltimore Sun, Shinny ZEV 1993). By the early 2000's, California had reduced hydrogen carbon and nitrogen oxide levels by 200,000 tons less than 1990 levels. (ARB—History). Despite the states Vehicle Miles Travelled (VMT) being its highest ever at approximately 40 billion in the year 2000, smog alerts went down from 148 in 1970 to 0 (zero) in the year 2000. Gasoline consumption in California also increased through this period reaching its highest point in 2005 (See Figure 1). As ports and freight movement also grew in the state, diesel emissions became more in focus.

The beginning of the United States emissions challenge

The history of tracking air quality challenges in the United States also mirrors closely with the timeframes in Los Angeles and California. In the 1940's and 1950's as the war wound down and GI's returned to America, the country saw an expansion of homes in suburban outlining areas and the miles automobiles traveled also saw drastic increase. In 1955 President Dwight Eisenhower and Congress enacted the Air Pollution Control Act of 1955. This was the first federal legislation to address air pollution in the US and provided research and technical assistance relating to air pollution control by setting aside funds for research. Though not successful at curbing the air pollution challenges, it served as a catalyst to get the governments attention on the public health dangers that were starting to arise across the country (Ametsoc.org 2020). Nearly 8 years later the first federal law with the words "clean air" was passed with the Clean Air Act of 1963. The Clean Air Act focus was on improving, strengthen, and accelerating programs for the prevention and

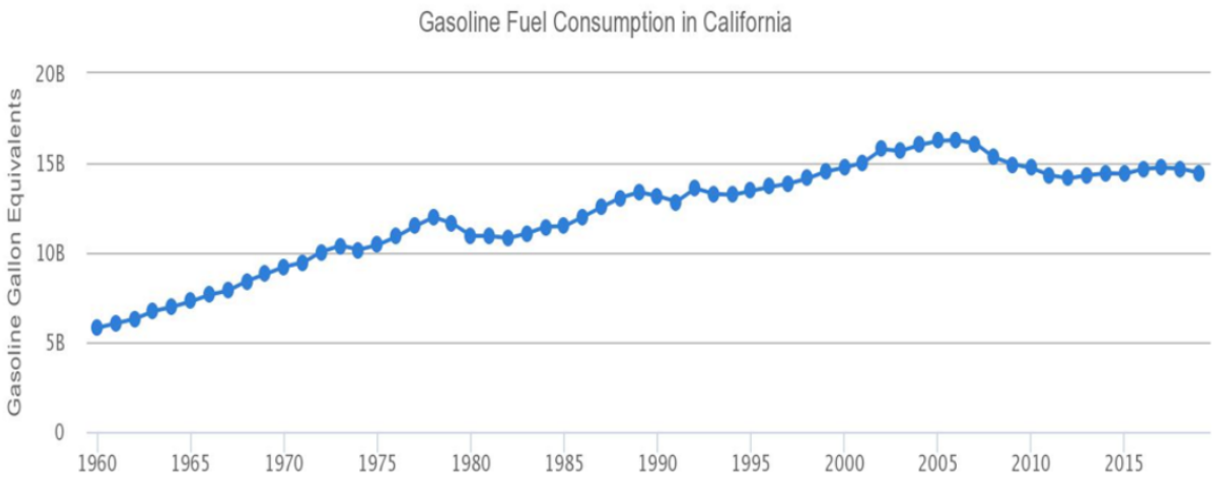

Figure 1. Gasoline consumption for combustion engine vehicles in California nearly doubled between 1960 and early 1970.

abatement of air pollution. It was also the first to begin a focus on the impacts of motor vehicle emissions and set forth a path to develop emission standards. It was followed by the Clean Air Act signed by President Richard Nixon in 1970. This Act ventured to provide for a more effective program to improve the quality of the Nation's air. It was considered an ambitious legislative agenda but was successful at establishing the National Ambient Air Quality Standards (NAAQS) that focused on public health and welfare and also the New Source Performance Standards (NSPS) that focused on regulating new sources of emission that start in an area (Ametsoc.org). It also had a focus on industry emissions and automobile emissions. It also opened the first avenue for people to pursue litigation against anyone or public and private organizations that breach the new emission standards. It took the nation two more decades to enact additional federal legislation to fight the emissions challenges. The Clean Air Act of 1990 increased vehicle emission standards and established a schedule for ongoing reductions. It urged the usage of low-sulfur fuels and other alternative fuels to reduce sulfur dioxide emission in the air (Ametsoc.org). The law also mandated a reduction of Chlorofluorocarbons (CFCs), which are nontoxic, nonflammable chemicals that contain carbon, chlorine, and fluorine. CFC's are still used to manufacture aerosol sprays, blowing agents for foams and packing materials, as solvents, and as refrigerants.

California GHG Reduction Policies, Executive Orders, and Legislation

As California led the way on addressing the Climate Challenge across the country, varying tools have been deployed to tackle the issue. New regulatory and policy adoptions that lead the state towards more attentiveness to the challenge has been chief amongst the tactics. Over the last 20 years California has enacted more than a dozen laws and or executive policies specifically aimed at reducing Green House Gas (GHG) within the state. Under different Governors and differing legislatures the focus on the issue has stayed consistent. In the fall of 2000, Governor Gray Davis

signed into law, after passing at the state legislature—SB 1771. The bill sponsored by state Senator Byron Sher established the California Climate Registry that cataloged early greenhouse gas emission reductions and set reduction goals and standards for measurement and verification. The registry was to serve as a nonprofit corporation focused on emission reductions since 1990 and to adopt a list of approved auditors to verify emission reductions, establish emission reduction goals, maintain a record of all emission baselines and reductions, and recognize, publicize and promote entities that participate in the registry (Hanemann AB 32).

The bill also directed the California Energy Commission (CEC) to update the inventory of all GHG emissions in the state and update the information every 5 years. Other major steps included providing information to all levels of government in the state on feasibility, effectiveness and cost of the tactics deployed to reduce GHG in the state (Hanemann AB 32). In addition to the nonprofit registry that the law established, another organization called the Climate Change Advisory Committee with members from local governments, business and agriculture was to be created. A precursor to SB1771 was SB1941 which was passed by the California legislature 2 years earlier in 1998 but it was vetoed by Governor Pete Wilson. The vetoed legislation had many similar components to 1771 including recommendations to create new committees focused on climate issues and also inventory development requirement for the CEC, which Wilson deemed unnecessary hence his veto of the bill. Successes/Failure?

The next bills that were signed into law to address these issues were SB 527 in 2001 and AB 1493 in 2002. Though only serving as minor adjustments to existing laws, 527 revised the responsibilities of the California Climate Action Registry and required the Registry, in coordination with CEC to adopt third-party verification metrics, developing GHG emissions protocols and qualifying third-party organizations to provide technical assistance and certification

of emissions baselines and inventories (UNT Digital Library). While AB 1493 required the registry to work with the State Air Resources Board, to adopt procedures and protocols for the reporting and certification of reductions in greenhouse gas emissions from mobile sources for use by the board to grant the emission reduction credits. This bill also required the state board to create and implement regulations that achieve the maximum practicable reductions in greenhouse gases emitted by passenger vehicles and light-duty trucks within 2 years.

The same author of AB 1493 Assembly member Fran Pavley authored AB 1007 in 2005. The bill required the CEC to work with other state agencies and prepare a state plan to increase the use of alternative fuels in California (Ca Legislation Information). The plan was required to include evaluations of alternative fuels on a full fuel cycle assessment of emissions of criteria air pollutants, air toxics, greenhouse gases, water pollutants, and other substances that are known to damage human health, impacts on petroleum consumption, and other matters the state board deemed necessary (CA Legislation Information).

Nearly a year later in 2006, one of the most significant legislations to date in the state passed with AB 32—also known as the Global Warming Solutions Act of 2006. Also sponsored by Pavley the law established several key tenants of environmental policy in California today. It requires California's statewide greenhouse gas (GHG) emissions be reduced to the 1990 level by 2020. This goal of an approximately 25% reduction had been previous established in executive order S-3-05 by Governor Arnold Schwarzenegger in 2005, but AB 32 codified the pursuit and required a specific procedure and timetable for implementation (Hanemann 2007). It was the first state law in the country to take a comprehensive, long-term approach to addressing climate change challenges, and did it in a way that aims to improve the environment and natural resources while maintaining economic growth (CARB 2020). The law covered 7 different gases with major

pollution impacts in the state including Carbon dioxide (CO2), Methane (CH4), Nitrous oxide (N2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulfur hexafluoride (SF6) and Nitrogen trifluoride* (NF3).

Based on the current understanding, this is a reduction of about 13%.

- SB 1204 (2014) – establishes a fund that will technology for zero- and near-zero-emission trucks, buses and off-road vehicles. [13]

- SB 1275 (2014) – Establishes a state goal of 1 million zero-emission and near-zero-emission vehicles in service by 2020 – the state fell short of the goals above.

Assembly Bill 32 (AB 32).

The 21st centuries foundational policies California has used to address climate change in the state have been AB 32 (Pavley) which passed in 2006 and SB 32 (Pavley) that passed a decade later in 2016. Both laws charted an explicit course to achieve aggressive GHG reduction targets in the state. AB 32 required that California's statewide greenhouse gas emissions be reduced to where it was in 1990 by the year 2020 (Hanemann2007). This estimated 25% reduction in GHG's was successfully met 4 years early in 2016. But before AB32 passed, it faced several significant hurdles along the way in 2006, including opposition from business groups and fuel production related entities. They argued emissions reductions issues should be controlled from the federal level and that the state did not need to pass a law to achieve such goals (Hanemann 2007). Proponents however contended California role as the 12th largest generator of GHG in the country placed it in leadership role to continue to act on addressing climate related issues.

Once in law—the bill outlined several key steps to achieve several rigorous targets. By June of 2007 CARB had to create an early action measures plan that will detail how emission reductions

will be achieved and by January of 2008 they had to identify what California's actual emissions numbers were in the year 1990 (Hanemann 2007). Another requirement was preparing a plan that addressed utilization of the best and most feasible technologies whilst prioritizing cost effectiveness. This plan was to be made available to the public for comment by January of 2009. Other key timelines in the bill included by January of 2011, CARB had to adopt the regulations that will ensure emission reductions across the varying sectors in the state. All state agencies were also required to consider and implement strategies to reduce their greenhouse gas emissions.

California accomplished the targeted reductions early in 2016 due to a multitude of factors, but transportation as the leading cause of emissions was not one of the areas of success. In the 2018 report announcing the accomplishments, CARB announced greenhouse gas pollution in the state fell below 1990 levels for the first time since emissions peaked in 2004— comparing the achievement to taking roughly 12 million cars off the road or saving 6 billion gallons of gasoline a year. Figure 2 shows the California GHG drop over nearly 2 decades and the state achieving its goal of less than 431 million metric tons of CO2--4 years early by 2016.

The states emission levels in 1990 was 431 million metric tons and the report (*2016 Greenhouse Gas Emissions Inventory Report*) released in 2018 showed California emitted 429 million metric tons of climate pollutants in 2016. This represented a drop of 12 million metric tons (CARB 2021). Key accomplishments in the 2016 inventory report announcement included:

- Carbon pollution dropped 13 percent statewide--since a 2004 peak; during this same period the economy also grew 26 percent.

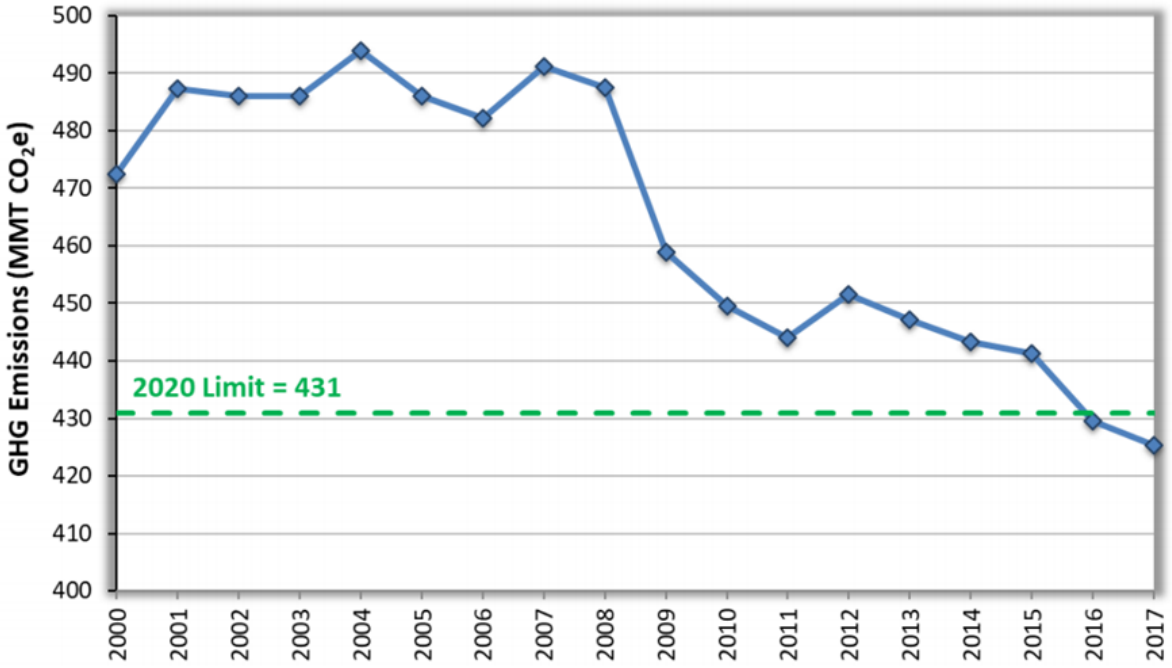

Figure 2. California GHG Emissions Trends. This figure shows the emission trends between 2000 and 2017 as compared to the 2020 statewide GHG limit of 431 $MMTCO_{2e}$.

- Per capita emissions continued to be among the lowest in the country. It fell 23 percent from a peak of 14 metric tons per person (roughly equal to driving 34,000 miles) in 2001 to 10.8 metric tons per person in 2016 (roughly equal to driving 26,000 miles). At the time this was approximately half as much as the national average.

- Carbon pollution dropped 3 percent between 2015 and 2016—roughly equal to taking 2.4 million cars off the road or saving 1.5 billion gallons of gasoline and diesel fuel.

- The "carbon intensity" of California's economy – the amount of carbon pollution emitted per $1 million of gross state product – dropped 38 percent from the 2001 peak and became one-half the national average.

- California produced twice as many goods and services for the same amount of greenhouse gas emissions as the rest of the nation.

Notably transportation or vehicle related emissions were not an area that provided support for the decreased emissions. Transportation emissions saw a 2 percent increase by 2016, this despite the continued growth of electric vehicle (ZEV) utilization across the state. The additional emissions were due to increased fuel consumption by drivers in the state (CARB 2021 https://ww2.arb.ca.gov/news/climate-pollutants-fall-below-1990-levels-first-time). The state however saw a few positive outcomes for transportation in the report due to record breaking biofuel consumption. The biofuels used included mostly ethanol, renewable diesel, and biodiesel fuels. California was able to prevent 14 million metric tons of carbon dioxide from polluting the air by using 1.5 billion gallons of biofuels (CARB 2021). These more environmentally friendly fuels supported the states efforts in comparison to if conventional fossil fuels had been used.

Overall, despite the increased emissions from transportation—2016 and 2017 had the lowest the lowest growth rate over the previous 4 years.

Electricity generation was the industry with the most significant and impactful in generating the needed reductions to meet the goals of AB 32. Electricity generation emissions had fallen by 18 percent when examined in 2016. Solar, wind, and geothermal were the main forms of energy that picked up from the decreased utilization of natural gas. Natural gas usage fell by 15 percent and solar energy mostly through rooftop generation grew by 33 percent (CARB 2021).

One of the most important tools that helped achieve the AB 32 tenants however was CARB's establishment of a statewide Cap-and-Trade program in 2012. The program established policies to limit major sources of GHG emissions throughout the state and incentivizes more environmental friendly practice and technologies across industries. Approximately 80 percent of California GHG's are covered under the cap-and-trade program. (CARB 2021).

Senate Bill 32 (SB 32)

Senate Bill (SB) 32 was signed into law by California Governor Jerry Brown in 2016 exactly a decade after AB 32 was passed. SB 32 took a more aggressive stance and required the state board (CARB) to ensure that statewide greenhouse gas emissions were reduced to 40% below the 1990 level by 2030. Since the law has only been in effect for four years its still early to determine the comprehensive impact of the legislation. Early signs however show emissions possibly trending in the wrong direction. To meet the targeted emission goals for the year 2030 and 2050 the state will have to see more aggressive reductions according to Next 10—a nonprofit based in California that's focused on the intersection between the economy, the environment, and quality of life issues in the state.

In their annual 12th *California Green Innovation Index* for 2018 (the latest year for which conclusive data is available), emissions actually saw an uptick for the first time since 2012. The increase derived from energy use increases in the power and commercial sector. According to the report, to meet the 2030 targets set by SB32—moving forward the state will need to reduce emissions by an average of 4.9 percent each year from 2020 to 2030 (CGI Index 2020). Without extenuating circumstances, the state has never experienced an annual emissions reduction as high as 4.9 percent. In 2009, during the worst economic downturn in nearly 80 years, the Great Recession helped dropped emission pollutants by 6.1 percent in California (Green Car Congress 2020). The highest rate of annual emissions drops in any prior year outside of the recession was 2.6 percent. To reach the 2030 goal California will have to double its prior peaks' annual emission reductions.

GHGs and California's ZEV growth

In California the Air Resources Board (CARB) has the legal responsibility to monitor and regulate seven different Greenhouse Gases (GHG's) to reduce emissions. The seven include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and nitrogen trifluoride (NF3). Carbon dioxides are the main GHGs emitted in California, accounting for 83% of total emissions in 2018. Transportation is the single largest source of carbon dioxide (CO2) emissions in the state (CARB 2018). Now at 47 percent, transportation is significantly ahead of industrial emissions at 23%, various forms of electricity production at 18%, residential emissions also at 7%, commercial activities at 4% and agricultural activities at 1% (CARB 2018). Figure 3 depicts these major economic sectors emissions impact in California as of 2018.

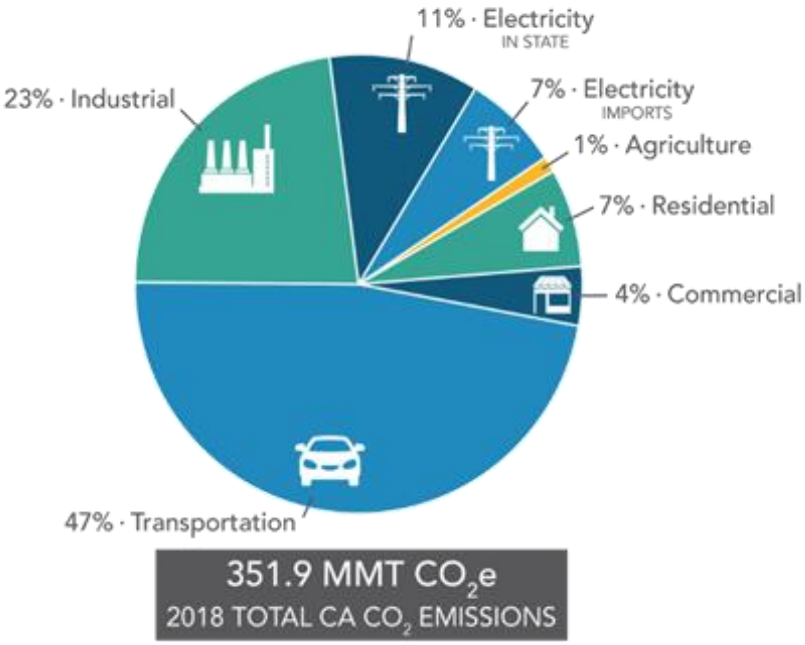

Figure 3. GHG Emissions by Sector with Transportation at nearly 50% (CARB 2018).

Most of the transportation emissions in California are a result of vehicles traveling on roadways. The average passenger vehicle emits about 4.6 metric tons of carbon dioxide per year. This assumes the fuel economy of the average vehicle is about 22 miles per gallon and is driven neatly 12,000 miles a year. Approximately 8,887 grams of carbon dioxide is burned with every gallon of gasoline and emits about 404 grams of CO2 per mile (EPA 2018). Though vehicles prominent emissions are carbon dioxide they also produce smaller amounts of CH4, N20, and HFC's. These smaller gases however still have a higher global warming potential that carbon dioxide (EPA 2018).

From a historical perspective, just a few years earlier in 2016 some of the data for most of California's key economic sectors had lower numbers. Transporation was at 39%, electricty sector was at 16%, while the industrial sector was also lower at 21% of the inventory in both 2015 and 2016 .

For many years California's population growth closely aligned with the increase in vehicle ownership and vehicle miles traveled (VMT). California is the most populous state in the country. Nearly 40 million residents–one out of every eight United States residents lives in California (PPIC 2019). The 20th century turned into a booming period for growth in the state.

While less than 2 million people lived in the state in 1900, by the year 1950 the population stood at 10 million. The state's growth rate was higher than the rest of the country through most of the 20th century until its recent slower pace (PPIC 2019). VMT and VMT per adult have both steadily increased at approximately the same rate as GDP (see Figure 4). But since 2007 vehicle miles traveled per adult nationwide has declined, while California witnessed a similar decline beginning in 2005.

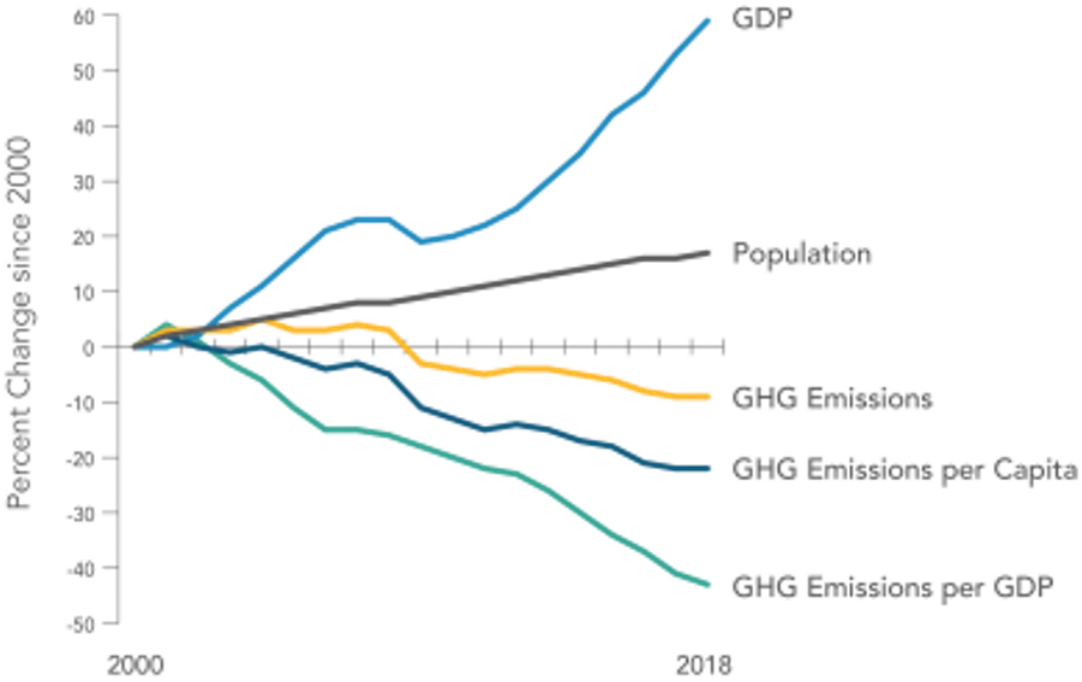

Figure 4. California emissions per capita and GDP have declined over the last 2 decades

CHAPTER 2

LITERATURE REVIEW AND PROBLEM SCOPE

Literature Review

Greenhouse Gas Emissions, Zero Emission Vehicles and topics around the causations and connections of climate change to the transportation sector are increasingly a heavily researched topic. There are several international, national, and local articles and research efforts that address varying components of these issues. Globally transportation accounts for 14% of emissions and has become one of the leading sources of carbon emissions as a major sources of air pollution (UC Berkley Law 2019). China with the largest population in the world however only accounts 9% of its GHG emissions to becoming from the transportation sector (UC Berkeley Law 2019). Two of some its largest cities Beijing and Shenzhen however have GHG transportation rates at 45% and 65% respectively (UC Berkley Law 2019). In the United States, transportation GHG emissions have seen continuous growth over the last several decades. Between 1990 to 2006 alone, transportation GHG emissions increased 27 percent, accounting for almost one-half of the increase in total U.S. GHG emissions for that period (US DOT 2010).

The progressive approaches in policies, regulations, and resources from California over the last 50 years have also directly generated heighted academic analysis on the issue. The difficulty to meet the state aggressive 2030 and 2050 goals have been a common refrain in some publications. Meeting the 2050 will be a challenge unless a portfolio of near-zero carbon transportation solutions is deployed (Cunningham 2010). Two scenarios developed included analysis to see number of ZEVs needed to help achieve 80% reduction in GHG and annual ZEV sales over a 10-year period (2015-2025). A 66% reduction in GHG emissions is achieved by 2050 using an aggressive

assumption that 250,000 ZEVs are sold in the state annually (Cunningham 2010). Using the latest data from the California Energy Commission, over the last 5 years California has averaged nearly 148,000 in annual sales of LDV ZEVS (CEC 2021). To achieve the full 80% reduction in GHG goals, 500,000 ZEVs sales annually by 2025 and biofuels increased to 1.7 billion gallons of gasoline would be needed (Cunningham 2010). A new proposed Automaker Automaker-consumer Model (AUM) was also researched to explore simulating varying designs of a ZEV mandate in Canada's light-duty vehicle sector, that is requiring 30% ZEV sales by 2030 (Bhardwaj 2021). This work compared policy design impacts on ZEV growth, GHG emissions, and auto industry profits. Outcomes showed ZEV mandates effectively increased ZEV adoption and GHG emissions but also led to greater reductions in consumer surplus and automaker profits.

Jenn et al in research titled *Cost Implications for Automaker Compliance of Zero Emissions Vehicle Requirements* investigated the cost implications of enforcing the national Corporate Average Fuel Economy (CAFE) and greenhouse gas (GHG) emissions standards and the Zero Emissions Vehicle (ZEV) requirements concurrently. They developed a new *Cost Optimization Modeling for Efficiency Technologies* (COMET) to outline how vehicle manufacturers implement fuel economy technologies to abide with multiple regulations (Jenn 2018). They considered a variety of scenarios to measure the impact of regulations and how they may lead to changes in technology costs (Jenn 2018). They estimated that by 2025, unit costs reach $1,600 per vehicle on average to comply with CAFE/GHG and increase by 25 percent to $2,000 per vehicle on average to align with both CAFE/GHG and ZEV standards (Jenn 2018). This particular research further outlines the need to continuously reduce the cost of technology and ZEVs to reach California’s adoption and climate goals. In No free ride to zero-emissions: Simulating a region's need to implement its own zero-emissions vehicle (ZEV) mandate to achieve 2050 GHG targets, the

authors make the case that the reductions are not achievable and need additional measures to reach the goals.

An earlier study on the issues in 2007 titled Assessing policies for reducing greenhouse gas emissions from passenger vehicles, Jillian Mallory created a hybrid energy economy model for reducing emissions from passenger vehicles and to increase the adoption of ZEVs. Its of significance to this research project as the model was assessed on a proposed tax on GHG emissions in California, a ZEV mandating policy and a ZEV purchasing subsidy (Mallory 2007). The research suggested at the time a purchase subsidy or incentive-based policy was not cost-effective but did suggest significant reductions in GHG will require full adoption of zero emission vehicles (Mallory 2007).

A component often overlooked in the prior national research was the impact of freight and goods movement on greenhouse gases across communities. Identifying more avenues to make highway driven trucks, shipping of containers and railroads cleaner and or more fuel efficient will be essential for California to achieve its ZEV and GHG goals. In 2015, *Strategies for Transitioning to Low-Carbon Emission Trucks in the United States* developed a new scenario to reach the proposed "80-in-50" target. It explored the feasibility of successfully reaching an 80% reduction in GHG emissions in the United States and California from trucks by the year 2050 (Fulton et al 2015). They concluded even with optimistic increases in ZEV trucks and biofuels, meeting the "80-in-50" target will be very challenging (Fulton 2015). They suggest policies that target the sales of ZEVs to support improved fuel economy standards will be needed to ensure low-carbon hydrogen and diesel replacement biofuels become more readily available on the market.

There are a lot of factors that affect ZEV adoption. We divide the factors into cost-related factors and non-cost-related factors. Cost-related factors include purchasing price, rebates, gasoline

price, electricity price, etc. The non-cost-related factors consist of technology development, driving range, accessibility to charging facility, social impact, environmental impact, governmental policy, etc. There is no consistent conclusion on which factor is the most important. Some of the literature draws opposite conclusions. For example, Lin & Greene (2011), Lin, Greene, Count, & Greene (2015), and Zhang, Qian, Sprei, & Li (2016) hold positive attitudes towards the impact of charging facilities. However, Miele et al. (2020) claim that having more charging facilities does not rise ZEV adoption significantly in Canada. Even the charging facilities reach a universally level, which means that the number of charging stations is no longer a constraint, the ZEV adoption does not rise by more than 1.5% compared with the baseline tendency. Similarly, the impact of gasoline prices is also unclear. Gnann et al. (2015) propose that if the gasoline price increase by 25%, the sales of plug-in electric vehicle (PEV) doubles. However, Zhuge et al. (2020) find that the influence of gas price and electricity price is limited.

Most literature affirms the role of rebates and incentives. Axsen and Wolinetz (2018) present a behaviorally-realistic vehicle adoption model to study the impacts of incentives and mandatory policies on vehicle sales. They find that offering incentives can greatly boost the ZEV sales and help Canada reach the GHG emission goal. Zhuge and Shao (2019) show that vehicle price and usage are the two most important factors among six factors, i.e., vehicle price, vehicle usage, social influence, environmental awareness, and governmental policy. They also find that the importance of the factors is related to personal properties such as education level and income. Zhuge et al. (2019) claim that purchase subsidies play an important role in ZEV adoption while the prices of gasoline and electricity have little effect on ZEV sales. Several other factors are also mentioned. Adnan et al. (2017) point out that the emotion of customers towards the ZEV is an

important factor. Liu and Cirillo (2016) find that increasing gas taxes can reduce GHG emissions.

Al-Alawi and Bradley (2013) point out, in their survey paper, that the agent-based model, discrete choice model, and diffusion model are the three most used methodologies that forecast future market share of ZEV and assess the importance of factors that affect ZEV adoption. Frank M. Bass (1969) presented the first diffusion model. The assumption of the model is that the probability of an initial buying is linearly related to the number of previous buys. The drawback of the diffusion model is that it cannot consider the effect of external factors, such as incentives, sales price, etc. Zhuge et al. (2020) use a multinomial logit model to analyze the impact of six factors. Rahman et al. (2021) present an agent-based simulation model to study the relationship between ZEV adoption and Green House Gases (GHG) emission. In their well-to-wheel (WTW) model, the emission factor is determined by vehicle-specific power (VSP). Although the ZEV does not produce tailpipe emissions, Rahman et al. (2021) point out that increased electricity consumption would also lead to GHG emissions. They find that EV and PHEV are superior to the GV in city driving. In general, PHEV is the best choice in Texas to control GHG emissions.

Gap Analysis

There are significant volumes of publications of reports in the government sector and research developed in academia on GHG emissions and its connections to the transportation sector and ZEVs. Several of the California related reports establish scenarios and models showing the state will fall short of attaining its ZEV and climate goals at the current rate of the related sectors. CALGAPS for example was developed and used to project California's GHG emissions from 2010 to 2050 (Greenblatt 2014). Four scenarios were developed to explore a range of future policy

options and most depicted challenges in reaching the goals. For 2050, all scenarios fell significantly short of the goal and identified additional policies will likely be needed to allow the state to meet its long-term goal (Greenblatt 2014).

A few unique research efforts like *The technology path to deep greenhouse gas emissions cuts by 2050: The pivotal role of electricity*, 2012 research by William et al—did find several of the 2050 GHG goals for California achievable. With assumptions that plausible technological advancements would occur with electrification, they suggest it is possible for California to achieve significant GHG reductions by 2050 with minimal change in lifestyle (Williams 2012).

This research addresses the gap in additional research needed to show how incentives and or the cost of ZEVs can be targeted to reach key demographics in California to increase adoption. It also creates a model outlining how gas prices and ZEV fueling infrastructure will be key to achieving the needed growth in the ZEV market to support the plans to achieve the air quality goals in the state.

Problem Definition

The state of California has over the years set aggressive greenhouse gas (GHG) emissions reduction goals to combat the unwavering impacts of climate change on people and its ecosystems. Most of the ambitious goals have been established through laws and policies targeted at some of the largest culprits of the problem—the transportation sector. Direct emissions from vehicle tailpipes, off-road transportation mobile sources, intrastate aviation, rail, and watercraft accounted for 47 percent of the state's emissions in 2017 (CARB 2020). Replacing petroleum powered vehicles that emit harmful pollutants with cleaner zero emission vehicles (ZEVS) is one of the

main areas of focus for the state. The states key goals for increasing the utilization of ZEVS and directly improving air quality challenges include:

- Attaining 5 million zero-emission vehicles (ZEV's) on the road by 2030
- ZEV's attaining 70% of the light duty market share by 2030.
- All light duty vehicles sold in the state to be 100% ZEV by 2035
- Reduce GHG emissions to 1990 levels by 2020 (achieved in 2016)
- Reduce GHG emissions to 40 percent below 1990 levels by 2030
- Reduce GHG emissions to 80 percent below 1990 levels by 2050

Deciphering the impact of ZEV's in achieving California's climate goals and assessing ZEVs growth trends to determine whether the aforementioned goals are actually practical, achievable and impactful to overall environmental goals for the state is the main focus of this research effort. The research proposes and models 3 critical policy areas (vehicle cost/incentives, charging infrastructure and fuel prices), that will impact ZEV adoption, sales and ownership of the vehicles to achieve the desired emission reduction outcomes.

Evidence of the problem – With transportation accounting for approximately 47% of the poor emission challenges in the state, zero emission vehicles have been identified as one of the main solutions to achieve the high climate goals of the state. California has had a remarkably successful history at being on the forefront of innovative approaches to addressing environmental challenges. For nearly 2 decades it has led the way in transitioning combustion and fuel-based vehicles to more climate friendly automobiles. California has led the United States in electric vehicle sales for the last 20 years and currently accounts for 47% of the annual national market share (CEC 2020). Despite these laudable achievements, the transportation sector has not provided the significant expected reductions in its emissions across the state and the adoption rate of zero emission vehicles

still significantly lags projected goals. At the point of this research California to date had sold approximately 900,000 zero emission vehicles over the 10-year 2010-2020 period (CEC 2021). It has taken more than a decade for the state to reach nearly 20% of its goal and the plan is to grow the remaining 80% over the next 9-year period. This research provides a regression model depicting the shortfall with a status quo approach to growing ZEV adoption in the state. It also further outlines the needed policies, incentives, and strategies for California to achieve the aggressive ZEV sales and ownership goals.

Despite the successes California has experienced at gradually reducing GHG emissions in recent years, like achieving the year-2020 goal of reducing emissions to 1990 levels by 2016 (4- years ahead of schedule), most of the success has not been generated through the transportation sector (CARB 2020). As the largest pollutant, if more gains cannot be achieved through the transportation sector—the 2030, 2035 and 2050 GHG emission goals are likely to fall significantly short. Any major potential gains in improved air quality from the transportation sector will not only be derived from the adoption of more ZEVs onto the transportation system but also through changes in land use development patterns, increased investments in public transit and through creating more walking and biking infrastructure that can serve dual recreational and transportation purposes. However, the most direct and least complicated path to abruptly eliminating emissions in transportation is to reduce the dependence on fossil fuel and combustion engine vehicles that emit carbon monoxide, nitrogen oxides, and hydrocarbons when fuel burns in the engine (NY. Dec 2021).

The consequence of not reaching the proposed ZEV goals means the transportation sector may continue to remain the largest pollutant and the state will not achieve the aggressive air quality goals that have continued to negatively impact the public's health and the environment. A key

upside nonetheless in transportation is the fact that engines and fuels used across the United States have continued to get cleaner largely due to the Clean Air Act emissions standards for new motor vehicles (EPA/clean air act 2021). With the emission reductions national concentrations of air pollutants improved by 77 percent for carbon monoxide, 56 percent for nitrogen dioxide and 22 percent for ozone, between the 1990 to 2017 (EPA air trends 2021). Figure 5 depicts the rising VMT in the United States over this period but a reduction in VOC emissions and projections for similar outcomes until 2030.

GHG Impacts Over the Lat Decade

GHG impacts on Humans

The environments land, air and water are major benefactors of reducing fossil fuel emissions across the planet but the human race is nonetheless significantly aided by fewer tail pipe related pollutants as well. Vehicle related emissions cause damage to lung tissue and can create or exacerbate respiratory diseases like chronic obstructive pulmonary disease (COPD), asthma, and lung cancer (NCBI/NIH 2021). Studies have shown air pollution reductions have accounted for as much as 15% of the overall increase in life expectancy in the analyzed areas (Pope, Ezzati, Dockery, 2009).

The relationship between life expectancy and reductions in pollution, where analyzed through regression models with adjustment for changes in socioeconomic and demographic variables to derive the statistical outcomes (Pope, Ezzati, Dockery, 2009). In a peer review of the Clean Air Act benefits in the United States between 1970 and 1990, concluded reductions in air pollutants generated by the Act prevented 205,000 early deaths and stopped a potential loss of 10.4 million in I.Q points from children in 1990 alone (EPA/clean air act 2021). The California Air Resources

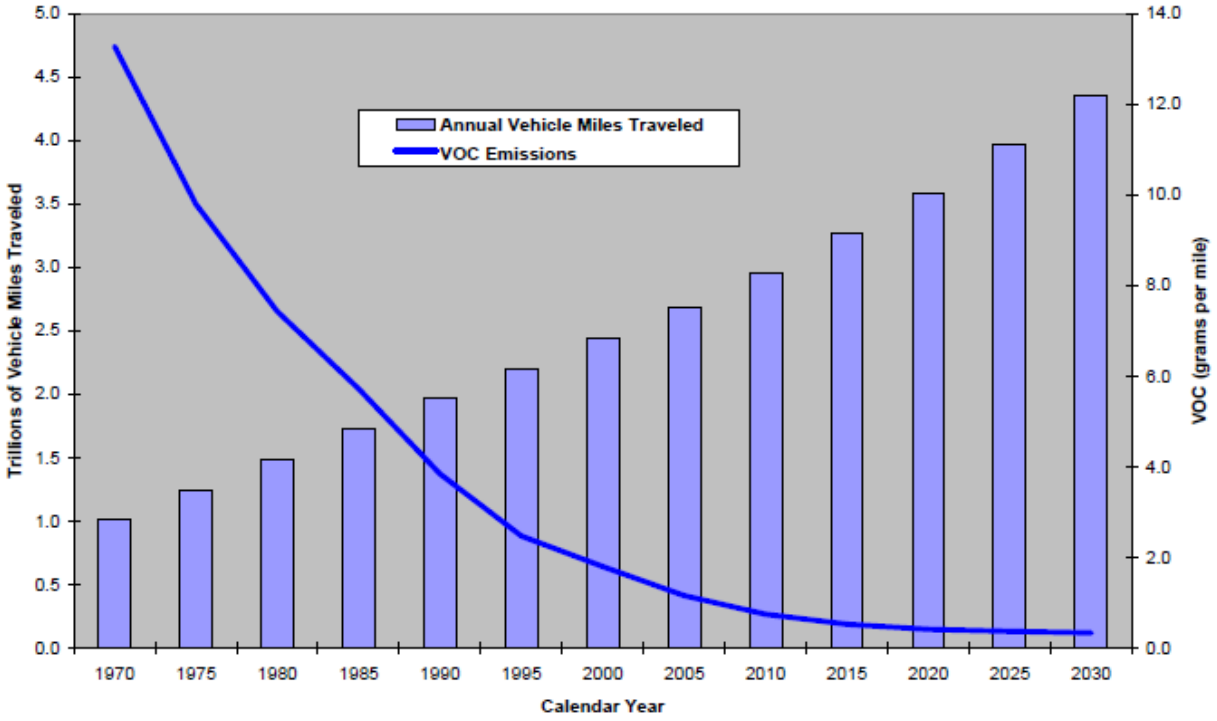

Figure 5. Vehicle Emissions vs. Miles Traveled (US EPA).

Board also estimated air pollutants cause more than 9,000 deaths in California annually (public health/ la 2021).

GHG impacts on Environment

The environmental consequences of not addressing the air quality challenge are also extensive. Some ecosystem impacts include damage to plants and overall forest health, buildup of toxins in food, and damage to fish habitat and other aquatic life (US EPA 2021). Increases in anthropogenic greenhouse gas emissions in the atmosphere are also directly linked to rises in environmental temperature and changes in related processes (Latake 2015). Concentrations of carbon dioxide, methane, and nitrous oxide have been shown to be increasing in recent years and are often created through burning fossil fuels for power generation (Latake 2015).

Climate Changes hastening speed of increase along with habitat fragmentation that's has been created by human activity is combining to create a new "earths landscape" (Cassia et al 2018). It is changing the frequency and intensity of the earth's characteristics like temperature and precipitation. It is also altering the usual seasons and life of earth. (Cassia et al 2018). Greenhouse gases are some of the leading forces creating climate change (Cassia et al 2018).

Identify what is not known about the problem that should be known

California has appropriately identified goals to significantly increase the usage of zero emission vehicles across the state to reduce dependence on fossil fuels, enhance the growth of the emerging clean energy economy and to combat challenges related to climate change and greenhouse gas emissions. For the last decade the California has led the United States in sales and ownership of zero emission vehicles. It is also a leading entity when compared to global partners on the adoption of cleaner vehicles but according to the current trend lines the state is still falling significantly

short of sales and ownership goals that are needed to meet the emission reduction goals of 2030 and 2050.

In 2019, sales of electric cars across the world exceeded 2.1 million, bringing the global stock to more than 7.2 million electric cars (International Energy Agency 2021). In that same year California sold nearly 150,000 electric vehicles accounting for 2.5% of all electric vehicles sold globally, this even though the state only represents .5% of the world's population. In the United States, a review of the top ranked states for zero emission vehicle registrations in 2018, California ranked first followed by Washington, then Florida, while Texas and New York rounded out the top 5 in respective order (afdc 2021). As advancements in technology for the electrification of light duty vehicles, sports utility vehicles and trucks improve, the market penetration of the vehicle continues to show expansion (International Energy Agency 2021). Despite these well recognized and leading positive signs, California is not currently on track to meet the expected goals for zero emission vehicle penetration to achieve the targeted improved air quality outcomes.

Impact of ZEV programs, policies, and incentives on market growth and GHG emission reductions

In California there are clear and direct correlations between the impressive growth of zero emission vehicles like electric cars and the laws, policies, incentives and programs that have been established over the years to support there development. However, the ZEV growth has not had the impact of directly decreasing the amount of GHG emissions in the state. Despite sales increasing from less than 200 ZEVs sold statewide in 2010 to nearly 150,000 sold in 2019 (a nearly 75,000% increase), the market growth has not correlated to air quality improvements in the state (energy.ca 2021). The transportation sectors' emissions in California stayed relatively flat from

2002 to 2007, then saw sharp decreases over the next 5 years from 2008 to 2013 and finally from 2013 to 2018 it was back up with an increase of more than 9.0 MMTCO2e (CARB Inventory 2019). The decreased emissions over the 5-year period were directly connected to fewer people driving during the Great Recession. Vehicle miles traveled (VMT) by drivers in the country dropped as job losses mounted and people traveled less to save money. According to the Federal Highways Administration (FHWA) the national agency charged with maintaining the count of VMT across the country—the annual mileage driving by Americans dropped from 3,032,124 million miles before the recession to 2,956,882 at the end of the recession (FHWA Travel Monitoring 2020). As the VMT dropped across the country so did the GHG emissions. GHG emissions dropped from 1.968.8 million metric tons (MMT CO2 eq.) at the start of the recession in 2017 to 1.750.4 MMT Co2 at the rebound from the recession in 2012. Nationally GHG emissions from the transportation sector has increased from representing 23.7% of all greenhouse gases in 1990 to approximately 50% in 2018. The increase is the largest percentage increase of any sector. The electricity generation and industry sectors where the only areas that dropped in total emissions over the nearly 30-year period (See Table 1 on the next page).

Effective state and national stats, incentives, programs, and laws

Despite the overall drop in VMT being the only significant factor thus far affecting GHG emissions in the transportation sector over the last decade, the continued growth of zero emissions vehicles in the automobile market continues to present a promising future for more improved air quality in the state of California. The growth of the ZEV industry globally and in the state can largely be attributed to a few key factors including, improvements in technology (especially battery technology), incentives for buyers, incentives for manufacturers, and laws or policies pushing for more investments in ZEVs across the board.

Table 1. U.S. Greenhouse Gas Emissions by Economic Sector in MMT CO2 eq. Highlighted are the top emitting economic sectors from each year (US EPA 2020).

U.S. Emissions by Economic Sector, MMT CO2 eq.								
	Transportatio	Electricity	Industry	Agriculture	Commercial	Residential	U.S. territories	Total
1990	1526.622794	1875.705423	1640.708734	600.179282	429.2010775	345.070789	25.162525	6442.651
1991	1480.489044	1871.728211	1613.561094	590.8481	436.4571979	354.68975	25.84773869	6373.621
1992	1540.034504	1886.715101	1649.06042	591.680134	432.1250033	361.222025	25.50664808	6486.344
1993	1577.034801	1962.470913	1620.199787	619.761753	425.5843602	372.612499	26.68577667	6604.35
1994	1631.976758	1987.274097	1645.608862	606.987183	428.8677843	363.260147	27.84799873	6691.823
1995	1667.146555	2003.999184	1662.524796	619.217854	427.9946907	367.523521	27.45364312	6775.86
1996	1723.370543	2077.064892	1691.903156	626.181037	435.6505406	399.454803	27.54040435	6981.165
1997	1749.961462	2143.225639	1691.272865	614.720383	428.1516707	380.828659	28.34736136	7036.508
1998	1792.412211	2229.740835	1661.799988	621.815493	402.9574172	346.873254	27.67006972	7083.269
1999	1863.40094	2243.791992	1609.284251	612.740289	399.4297823	366.684458	30.06731542	7125.399
2000	1913.656839	2349.510725	1598.823879	598.051114	413.738352	387.992539	51.84304496	7313.616
2001	1885.55221	2310.008309	1549.211555	618.927457	402.7437568	378.076884	58.43634226	7202.957
2002	1926.090039	2325.860812	1532.114174	621.906412	404.3104074	375.286669	58.73337557	7244.302
2003	1933.433776	2357.17254	1510.796537	622.357481	420.58694	393.728943	63.28696276	7301.363
2004	1965.962902	2390.210228	1559.489117	635.024013	418.4504266	381.852435	64.48198646	7415.471
2005	1975.58808	2456.258385	1518.818477	629.704181	407.94245	371.015529	63.70392858	7423.031
2006	1975.916846	2399.583772	1550.157824	628.942129	394.4928804	334.3094	61.05999584	7344.463
2007	1974.403171	2466.264685	1541.17254	646.136322	408.4803503	355.254855	57.90410191	7449.616
2008	1870.832363	2412.460981	1481.465809	634.271031	415.7989006	363.906982	45.91291423	7224.649
2009	1796.198799	2196.270145	1326.811606	636.18357	419.562518	354.545147	42.42828557	6772
2010	1802.154809	2311.928875	1418.136083	644.518923	422.0622981	355.539728	36.76562724	6991.106
2011	1769.063259	2209.297928	1421.767309	625.867672	417.8506792	349.089497	34.46607677	6827.402
2012	1749.424799	2071.205645	1415.442997	609.514748	398.9089069	306.938959	34.47171163	6585.908
2013	1751.910826	2089.977324	1466.49365	647.866222	422.2573981	357.735865	28.42782437	6764.669
2014	1785.920221	2090.124498	1450.982944	657.538625	432.6218565	378.29798	29.47058409	6824.957
2015	1794.054456	1950.021956	1441.612574	658.475555	445.4113754	351.502782	30.03336722	6671.112
2016	1829.968791	1857.612566	1402.224053	645.779373	430.1326151	327.840961	26.77948002	6520.338
2017	1847.329197	1778.851683	1423.414702	646.556484	431.8766826	329.90887	25.35371255	6483.291
2018	1878.199037	1798.044517	1483.289677	661.970566	447.3373934	377.251035	25.35717509	6671.449
2019	1875.730588	1648.11147	1504.831223	669.459694	455.3399301	379.51373	25.35854496	6558.345

According to the United States Department of Energy—Alternative Fuels Data Center (AFDC), as of 2019, California leads the country with 117 laws, incentives or program for electric vehicles (AFDC 2021). The next closest states are Colorado with 35, while New York has 28, Oregon and Massachusetts each have 27, and state of Washington has 26 rounding out the top 5.

The most recent account of state-based incentives by the AFDC on California shows 45 state based incentives ranging from the Plug-In Electric Vehicle (PEV) Rebate Program that offers rebates for the purchase or lease of a new all-electric or plug-in hybrid electric vehicle to Emissions Reductions Grants. The state incentives range in value from $7500 to as low $750 and can be in some cases combined with federal incentives. Since the inception of California's Clean Vehicle Rebate Program (CVRP) in 2010, approximately 350,000 vehicles have used the program (CVRP 2020). For fuel cell electric vehicles (FCEVs) the rebate is $4500, for battery electric vehicles (BEVs) its $2000 and for plug-in hybrid electric vehicles (PHEV's) it is $1000. For low-income to moderate income earners the incentives go up to$7000 for FCEVs, $4500 for EVs and $3500 for PHEVs (CVRP 2020). With nearly 75 percent of all zero emission vehicles sold in California making use of the program it has been a critical part of the ZEV industry growth. Table 2 summarizes the 5 major areas that utilized the CVRP subsidy over the initial 10 years of the program with a majority of the funding going to PHEVs.

Achieving the major state targets

The state of California in its ambitious greenhouse gas reduction plans to reduce the harmful impacts of Climate Change has outlined several major targets, some of the most important of which are:

- Reduce greenhouse gas emissions to 1990 levels by 2020 (achieved in 2016),
- Reduce greenhouse gas emissions to 40 percent below 1990 levels by 2030,

Table 2. California ZEV Rebate Summary (CVRP 2021).

Rebates Issue/Approved to Date	Vehicle Type	Number of Rebates	Percentage of Total Rebates	Rebate Amount
Plug-in Hybrid Vehicle (PHEV)	Highway-capable, four-wheeled, plug-in hybrid electric vehicle (electricity & gasoline)	138,245	34.4%	$222,584,738
Battery Electric Vehicle (BEV)	Highway-capable, four-wheeled, all-battery electric vehicle	254,944	63.40%	$654,949,875
Fuel-cell Electric Vehicle (FCEV)	Fuel-cell electric vehicle (hydrogen)	7,610	1.9%	$38,870,168
Other	Non-highway BEVs, highway-capable zero-emission motorcycles, and city & commercial zero-emission vehicles	1,143	0.30%	$1,991,990
Total		401,942	100%	$918,396,771

- Reduce greenhouse gas emissions to 80 percent below 1990 levels by 2050
- All light duty cars or vehicles sold in the state to be 100 percent zero emission (ZEV) by 2035
- Achieving 100 percent carbon-free electricity by 2045 and economy-wide carbon neutrality

For the state to achieve the desired outcomes of continued air quality improvements by reducing GHG, a multipronged approach that addresses the highest polluters in the state will have to continue to be used. The highest emitters in the state by economic sector are Transportation 47%, Industrial 23%, Electricity 9%, Agriculture 9%, and Residential rounding out the top five at 7% (CARB 2021). Continuing to target the transportation sector will yield the most results for reduced GHG in the state considering the continued growth of Vehicle Miles Travelled (VMT) to near pre-recession levels (figure xx). Despite the 7.5% growth in VMT from 329 billion in 2005 to 354 billion in 2017, the states per capita energy use is the third lowest in the nation (Caltrans-Energy 2021). Gasoline sales in 2016 where less than in 2002 and overall consumption decreased by 2.2% between 2005 and 2017 (Caltrans-Energy 2021). These positive signs of reducing the dependence on fuel (ultimately reducing emissions by cutting back fuel production), can largely be attributed to the growing market of fuel-efficient vehicles.

Despite being a catalyst to some important initial victories for the climate, fuel-efficient vehicles will not create a panacea for air quality challenges across the state. In addition to growing the fuel efficient and ZEV market, connecting transportation modes and land uses will be essential to achieving sustained reductions in VMT and GHG.

CHAPTER 3

ACHIEVING THE ADVANDED GHG REDUCTION TARGETS

Correlation between ZEV population and GHG reduction

Internal Combustion Engine vehicles also know in the energy and transportation space as ICE vehicles have been around since Henry Ford's assembly line rolled out the model T's in the 1930's. After the end of World War II and the "G.I.'s" returned to the US with a need for more housing—it spurred suburbanization and increased the demand for more personal vehicles. As a record braking depression also dissipated more transit and passenger rail entities started to close their operations as vehicle use increased. The increased vehicle use played a critical role in expanding the nation's transportation system but also in the air quality challenges the country started to face throughout the 20th Century. As the fuel efficiency of vehicles improved over the decades, air quality as well improved due to the fewer emissions. The fuel economy of the average new vehicle improved from 13 miles per gallon of gas (mpg) in 1975 to approximately 25 mpg today (EPA 2021). This drastic efficiency over a 40-year period means today's average car can go twice as far on one tank of gas than it could in 1975. Even more, the trucks on the roads today are 98 percent to 99 percent cleaner than they were in the late 1960s for smog related pollutants (EPA 2021).

A major part of why vehicles fuel efficiency and emissions have improved over the last 4 decades can be directly tied to the Clean Air Act (CAA) of the 1970 and its associated regulations on emission standards. Those regulations have allowed the EPA to on multiple occasions update and lower the aggregate of pollution that vehicles can emit. The updates have been grouped into "tiers" with the first emission standard for light trucks and cars being Tier 1

covers the older generation of vehicles that are the year 2003 and prior. While Tier 2 and Tier 3 covers emission standards for newer vehicles (EPA 2021). Another key measure signifying the improvements to air quality impacts from vehicle emissions are the outcomes on Nitrogen Oxide (NOx). NOx emission standards for light duty vehicles in 2025 are expected to be a 98% improvement from where they were in 1975 (EPA 2021). In 1975, the average light duty vehicle was emitting 3.1 grams per mile of nitrogen oxide. By 1994 that average was down to 0.6 grams per mile, while in 2004 it was 0.07 grams per mile, and its expected to be at 0.03 grams per mile in the year 2025.

Recent data from the EPA also shows despite continued rises in vehicle miles traveled from the CAA timeframe in 1970, the Volatile Organic Compounds (VOC) emissions have seen just as significant a decline due to impacts of the environmental policies. Between 1970 and 2017, there was a 73 percent decline of the aggregate national emissions of the six most common pollutants. In this same period the national gross domestic product (GDP) also grew by 324 percent (Truesdale 2020). These six key pollutants regularly tracked by the EPA are labeled as criteria air pollutants. The criteria air pollutants are particles, ozone, lead, carbon monoxide, nitrogen dioxide and sulfur dioxide. Over a nearly 30-year period (1990-2017), all 6 pollutants with many connections to vehicles related emissions have seen major declines. The percent of lead related air pollutants dropped by 80 percent, 77 percent decline for carbon monoxide, 88 percent for sulfur dioxide (1-hour), 56 percent for nitrogen dioxide (annual), and 22 percent for ozone. Fine particle concentrations (24-hour) lowered 40 percent and coarse particle concentrations (24-hour) dropped by 34 percent (EPA 2021).

Relationship between costs and ZEV sales

Lifetime cost

The average cost of a new fuel-based car in the Summer of 2019 was approximately $36,600 (Coren 2019). That cost represented a 2% increase from the year before in 2018 (Coren 2019). However, the inverse has occurred with electric vehicles with, the average cost decreasing from $64,300 to $55,600--a 13.4% decrease over the same period (Coren 2019). Despite the higher upfront cost for ZEVs, recent analysis shows that when total ownership cost with factors such as price, fueling cost and maintenance are considered, ZEVs have a lower lifetime cost especially in the more affordable ranges (Preston 2020). A 2020 Consumer Reports analysis found through the first seven years of ZEV ownership a fuel savings of $4700 could be identified and a lifetime savings of $6,000 to $10,000 could be actualized (Harto 2020). Table 3 shows the BEV savings per mile with PHEVs generating the most savings over a lifetime. The savings often depended on the range of vehicle purchased, with the lower priced model vehicles yielding larger margins over the estimated 200,000-mile life of ownership (Preston 2020).

In a 2017 study that compared life cycle cost of earlier generation models of electric vehicles and internal combustion engines, similar outcomes where identified. Lifecycle cost on 16 selected vehicles to determine the total vehicle ownership costs over 5-, 10-, and 15-year periods.

The higher costing vehicles showed a better life cycle cost than lower priced models (Raustad 2017). Research results also showed the battery electric vehicles (BEVs) are cost competitive with their ICE counterparts (Raustad 2017). Two popular BEVs ultimately showed better life cycle cost than low-cost ICE conventional models. Plug in Electric Hybrid vehicles were also shown to be competitively priced in comparison to standard ICE models (Raustad 2017).

Table 3. Estimated Per-Mile Repair and Maintenance Costs by Powertrain (Harto 2020)

Powertrain Type	0-50K Miles	50k-100k Miles	100k-200k Miles	Lifetime Avg
BEV	$0.012	$0.028	$0.043	$0.031
PHEV	$0.021	$0.031	$0.033	$0.030
ICE	$0.028	$0.060	$0.079	$0.061

The higher costing vehicles showed a better life cycle cost than lower priced models (Raustad 2017). Research results also showed the battery electric vehicles (BEVs) are cost competitive with their ICE counterparts (Raustad 2017). Two popular BEVs ultimately showed better life cycle cost than low-cost ICE conventional models. Plug in Electric Hybrid vehicles were also shown to be competitively priced in comparison to standard ICE models (Raustad 2017). In the direct comparison of an electric vehicle (Nissan Leaf) versus an internal combustion vehicle (Hyundai Elantra), the annual operating cost for the Leaf was $5,360 and the Elantra was at $7,076 (Raustad 2017). This accounts to a nearly $2,000 annual cost savings for Nissan Leaf (ZEV) purchaser.

A recent Consumer Reports analysis of its 2019 to 2020 reliability survey data for thousands of electric and gas-powered vehicles found that drivers of electric vehicles saved an average of 50% (see Table 4) on maintenance and repair over the lifetime of a vehicle compared to owners of gas-powered vehicles (CR White Paper 2020). As consumer awareness of the maintenance and overall lifetime cost saving increase—there should be continued shifts in growth for the ZEV market.

Initial/upfront cost of ZEVs

Though Consumer Reports states the typical total ownership savings over the lifetime of most EVs ranges from $6,000 to $10,000, a more immediate influencer of ZEV's purchases is the upfront cost of the vehicles. Purchasing prices for ZEVs can be significantly higher than fuel-based vehicles but recent years have seen the cost become more competitive. Due to the gradual decreasing electric vehicle battery cost the purchasing price of ZEVS have seen a recent decline. Since their commercial introduction in 1991, the price of lithium-ion cell batteries have fallen by 97% (Ritchie 2021). In 1991 a battery with a one-kilowatt per hour capacity cost approximately $7500, while 27 years later in 2018 it cost 41 times less at $181 (Ritchie 2021). The two examples below put in perspective the drastic reductions in cost:

Table 4. Lifetime Maintenance Costs by Powertrain (Harto 2020)

Powertrain Type	Lifetime Maintenance and Repair Cost	Lifetime Savings vs. ICE
ICE	$9,200	$4,600
BEV	$4,600	$4,600
PHEV	$4,600	$4,600

- The popular Nissan Leaf electric car – which is also one of the most affordable models – has a 40-kWh battery. At the 2018 price, the battery costs around $7,300. Trying to purchase the same model in 1991: the battery alone would cost $300,000 (Ritchie 2021).
- Another example is Tesla Model S which has a 75 kWh battery. In 2018 the battery costs around $13,600; in 1991 it would have been $564,000. More than half a million dollars for car battery alone (Ritchie 2021).

Incentives and policies

Much of the recent successful growth of the ZEV market in California can be attributed to policies and robust financial incentives implemented at the local, state and federal levels. As the incentives have picked up so have the sale numbers. Recent research has been consistent with results showing incentives are effective at increasing the market share of ZEVs including HEVs, PHEVs, and BEVs (Hardeman et all 2017). As much as a 2.6% increase in sales has been identified for every $1000 offered as a rebate or tax credit incentive (Jenn et al 2018). The efficiencies in the United States are as high as $10,000. Existing literature however has also shown deficiencies with the incentives and ways that they can be made more effective at drawing consumer interest (Hardeman et al 2017).

Across the international ZEV market there are generally 4 main types of incentives that work towards reducing ZEV cost for consumers (Hardeman et all 2017). Some of the incentives are applied at the point of purchase and others are in the form of a rebate post the purchase. The 4 types of incentive include:

1). Point of Sale Incentives – focuses on reducing the purchase price at the time of purchase. These incentives are typically in the form of government purchase discounts or grants.

2). Purchase Tax Exemptions – generally allows purchasers of ZEVs to pay lower or no purchasing tax. It is also applied at the point of purchase

3). Post purchase rebate – are incentives provided to consumers after they have purchased the ZEV. Typically the vehicle seller provide a monetary payment in the form of a check to buyer.

4). Income Tax Credits - though not the most popular form of incentives, these allow purchasers of ZEVs to pay a reduced income taxes at the end of the financial year. The tax credit is limited to amount of tax liability owed.

Other incentives like sticker passes for utilization of high-occupancy-vehicle (HOV) lanes have also been found to be effective in increasing interest in purchasing ZEVs.

States and localities also offer ZEV owners other incentives beyond the list above to also

include:

1. Access to HOV lanes regardless of occupancy in the vehicle,
2. Access to free charging stations,
3. Free workplace charging, particularly for federal and state employees,
4. Preferred parking locations at airports and garages, and
5. Some states (Hawaii) offer free meter parking.

A national analysis of incentives and programs to encourage purchases of ZEVs clearly shows California leads in most of the important categories. California's combined ZEV incentive initiatives outnumber the total programs provided by the United States federal government. The state has 19 grant programs, 43 rebate programs, 5 exemption programs, 4 loans and lease programs and 3 tax incentive programs (US DOE 2021). Their exemption programs provides opportunities from restrictions and requirements such as roadway weight limitations, parking fees, high-occupancy vehicle (HOV) lane access, and vehicle inspections. Their rebate incentive

program covers the purchases of vehicles, sale of fuel, and the alike. California's incentive program is managed by the Clean Vehicle Rebate Program (CVRP) an arm of the Air Resources Board. During the first 5 years of the CVRP program (2010-2015), more than 75 percent of ZEV's purchased in the state took advantage of an incentive program (CRVP 2021). More than 81 percent of battery electric vehicles (BEVs) sold participated in the incentive program, while 67 percent of all plug-in hybrid electric vehicles (PHEV) utilized it (CRVP 2021).

In addition to the significant discrepancy between battery and plug vehicle participation, there are also major variations in participation amongst vehicle brands. The eligible brand of vehicles with the most participation in the rebate program between 2010 and 2015 was Nissan at 86 percent and Tesla at 80 percent. The lower end of participation came from Toyota at 64 percent and Ford at 59 percent (CRVP 2021). The counties with the highest overall ZEV participation in the incentive program over the study period were Fresno County 85%, Kern County 82%, Placer County 78%, Alameda County 78% and San Diego County at 77%. The lowest participation came from Mendocino County 56%, Napa County 60%, Humbolt County 60%, Monterey County 63% and Merced County also at 63% (CRVP 2021).

In analyzing possible causations for the lower percentages of participation in some counties, data shows most entities with lower participating rates also rank on the lower end of economic outcomes in the state. The CRVP report analysis also identified lower levels of awareness and understanding of the rebate programs by consumers and or dealers as a possible factor and the greater ability and desire to purchase or lease without using the rebate. The latter reasoning likely applies more to counties like Napa and Solano with higher income levels but yet lower involvement in the rebate program.

Incentive for lower income

Quite a bit of analysis has gone into analyzing who benefits the most from the California and national rebate incentive programs. California recently (2019) changed its rebate program to be more focused on individuals with middle to lower incomes than the more affluent, though these updates were not necessarily described as such. Statistical data from the IRS in 2014 showed 78.7 percent of the federal consumer tax credits were paid to households with adjusted gross incomes of $100,000 or more (Winegarden 2018). In additional, 20.5 percent of the tax credits went to households with an adjusted gross income between $50,000 and $100,000 (Winegarden 2018). This essentially means 99.2 percent of these tax incentives went to households with incomes above $50,000. Though these are national numbers from the IRS, California's data is likely analogous as the state represents more than 50 percent of market share of ZEV for the entire country.

California offered a $2500 tax credit to any qualified purchaser of a ZEV and in addition offered eligible lower income families an additional $2000. This meant lower income families could receive a total tax credit of $4500, but with the higher cost of most ZEVS compared to fuel powered vehicles—purchasing leaned towards the more financially affluent. To address the disparities in purchasing and utilization of the tax incentives, CARB in 2019 made changes to the program. The updated policies reduced the amount middle-to-higher income families can receive from $2500 to $2000, while leaving the lower income family incentive at a maximum of $4500. The lower family income bracket will be critical to achieving the goals of getting to 5 million or more ZEV sales in 9 years in the state, as the estimated median adjusted growth income in the state stands at $47,031 in 2018 (Saint Louis Federal Reserve 2021), while the average cost of a new electric car is $55,600 (Coren 2019). Despite the federal, state and local subsidies to buy

ZEVs, the vehicles are generally still cost prohibitive to most lower income families. With the passage of SB 1275 of in September of 2014 not only did among other things, establish a goal to place in service at least 1,000,000 zero-emission and near-zero-emission vehicles by January 1, 2023, it also established the creation of the Charge Ahead California Initiative (CACI). The initiatives focus is to increase access for disadvantaged, low-income, and moderate-income communities to ZEVs. It is also focused on ensuring all Californians, especially lower-income households that are negatively impacted by air pollution, benefit from zero tailpipe emissions.

Over the lifetime of the incentive program, the state is to be credited for making frequent adjustment as inequities were discovered through implementation. In 2016, the program was amended to not allow eligibility for gross annual incomes above the thresholds of single filers making $150,000, for head–of–household filers making $204,000 and $300,000 for joint filers. The median income of used vehicle buyers in California for ZEV's is $150,000 in comparison to gasoline powered vehicle at $90,000 (Turrentine et al., 2018). The Telsa automobile brand continues to dominate sales and the market share of ZEVs in the United States and across the world. In the latest 2020 report from EV Sales Blogspot a website created to track electric car sales across the world, Tesla included two of the top 5 best-selling electric vehicles in the world. Despite the novel Coronavirus (COVID-19) pandemic that plagued the world's health and economy through 2020, Tesla's Model 3 had more sales than it has ever had in its history with 365,240 vehicles sold worldwide (Electrek 2021). The Tesla Model 3 represented 12% of the global market share of all electric vehicles sales in 2020 (Electrek 2021). The second Tesla brand vehicle in the global top 5 sales for 2020 was the Tesla Model Y with 79,734 vehicles sold and 3% of the global market share (Electrek 2021). Both the Model 3 and Model Y's retail MSRP is at nearly $40,000, while the average cost of a medium sized new sedan vehicle in America is

$25,000 (Kelly Blue Book, 2021). The $15,000 cost difference can be a significant barrier with median household incomes at roughly $47,000 in the state.

Relationship between charging infrastructure and ZEV sales

To support reaching the targeted goals for ZEV population growth in the state, a recent 2021 California Energy Commission report, outlined California needs 1.2 million ZEV charges across the state within the next 8 years (by 2030). The number of public charging units available from 2013-2020, garnered through data received from https://www.energy.ca.gov/data-reports/energy-insights/zero-emission-vehicle-and-charger-statistics, is plotted in the next figure below (red bars), along with a second-order quadratic regression (red dashed line) to estimate the number of chargers available by 2030.

In 2013, when charging infrastructure data was starting to get tracked more appropriately in California there were approximately 5,200 charges across the state and that number has since seen significant growth to nearly 31,000 chargers in 2020. These numbers are substantially higher than other states with the state of New York having approximately 6,500 chargers, Florida 5,500, and Texas 4,900 (Inside EVs 2021).

Based on the existing trend and data the quadratic analysis predicts there will be approximately 101,454 charges in the state by 2030 (see Figure 6), this would be significantly short of the 1.2 million estimated goal for chargers needed in the state at the time. This 2030 estimated chargers' growth assumes there are no major policy changes or financial incentives to boost charger infrastructure deployment across the state.

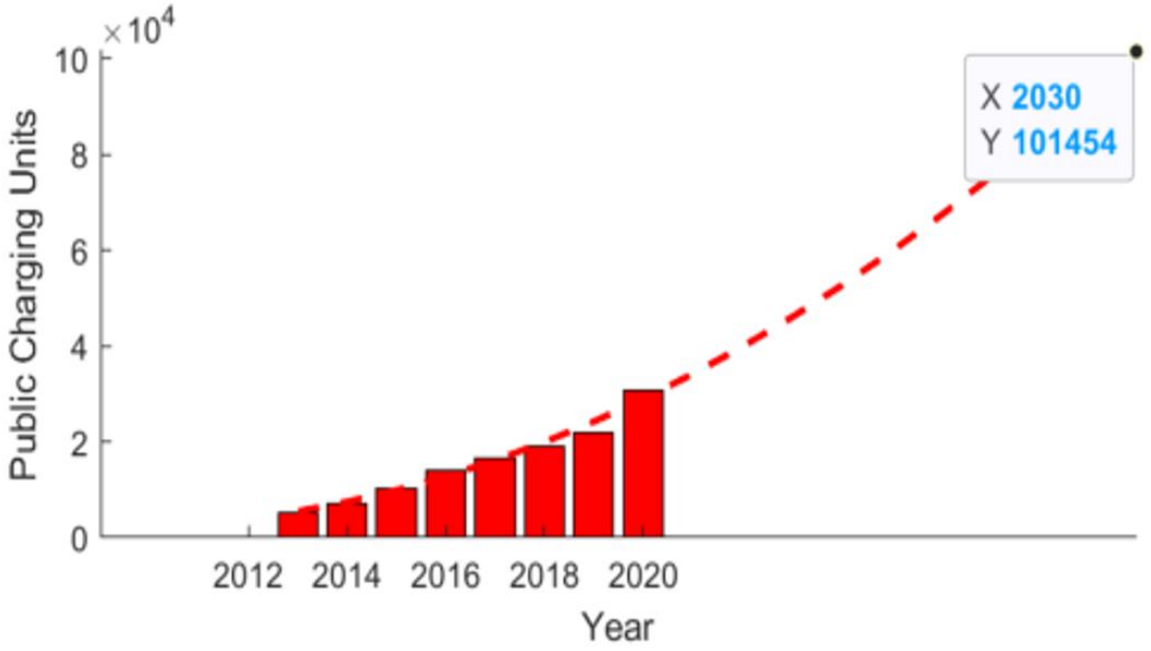

Figure 6. ZEV charging growth over 7 years in California and the projected growth to 2030.

Also plotted below is the ZEV population relative to the number of public charging units, as shown below (red circles). We can apply a first order linear regression to get an estimate of how the ZEV population is predicted by the number of charging stations. Using the estimate of the number of charging stations in 2030 from the prior graph of 101,454, the population of ZEVs predicted in 2030 is approximately 2,485,740. This estimate is well in line with 2,623,965 ZEV population predicted from the quadratic model based upon the current trend in ZEV populations. This alignment gives more validity to the overall prediction.

To achieve the target population of 5 million ZEVS, the above data suggests that there would need to be at least 202,212 charging units across the state (note that how these units are distributed county by county may also affect the population). According to current trends (quadratic model fit to the bar graph), 202,212 public charging units would not be reached until mid-August 2038. This timeline prediction is consistent with the August 2037 predicted from the ZEV sales in the time quadratic regression.

However, the roughly 31,000 public chargers that exist across the state today are not considered adequate to meet the growing ZEV market and frequent concerns about range anxiety. As of 2019, California had approximately 36.5 million total vehicles registered in the state and 10,500 retail fueling stations, a ratio of nearly 3600 vehicles to each station (Statista 2021). A better ratio for the EV market will be needed for the success on California transportation system. Figure 7 further outlines the public charging growth in the state over an 8-year period. Multiple California government-based reports have outlined the need to have 1-million chargers in the state by 2035 to support the overall ZEV growth plan but the boost in infrastructure will also have to come from private charging facilities.

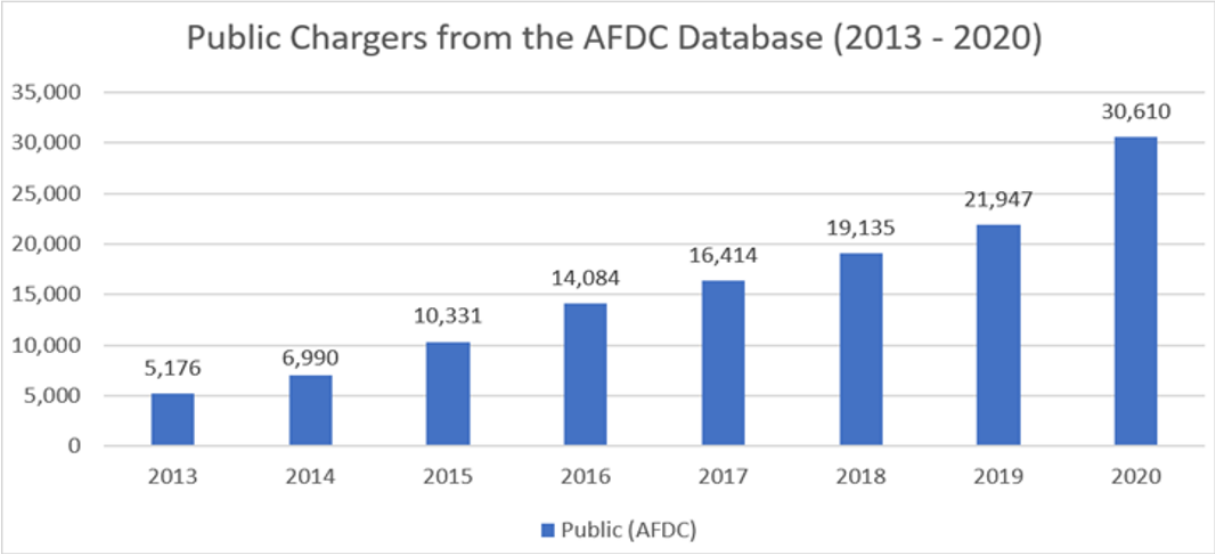

Figure 7. ZEV charging growth over 7 years in California and the projected growth to 2030

The current charging infrastructure while the largest of any state in the nation we still need policies that require new private developments to add charging infrastructure to create a proliferation across the state. Ensuring low to middle income communities also attain access to charging infrastructure will be key to increasing ZEV adoption in the state. Figure 7 shows the progression of public ZEV charging in California over an 8-year period. While Figure 8 shows a regression analysis of the relationship between ZEV charging infrastructure and ZEV growth. The significant lead of ZEV charging infrastructure California has on the rest of the nation is mapped in Figure 9 in the appendix.

Relationship between gas prices and ZEV sales

The third factor this research considers as having a significant correlating impact on ZEV sales is the cost of gas to consumers. A few recent research efforts have explored the connection between fuel cost and ZEV sales with some showing a more direct connection and others showing a limited indirect impact. Geo-political conflicts across the globe over the last decade have impacted the supply, demand, and cost of goods. These impacts have also be felt in the transportation sector when the conflict involves oil producing nations. Recent conflicts in the Middle-East near Libya, Egypt, and in South America near Venezuela have all led to increases in petroleum prices which lead to more demand for alternative transportation modes that do not depend on fuel. Including ZEVs and public transit. With most ZEV purchases being made by middle to higher income earners, this demographic is generally deemed to be not as responsive to fluctuations in gas prices like moderate- or lower-income earners (CARB 2017). Despite this caveat, electric vehicle sales do appear to stop increasing around the same time gas prices begin to decrease *(CARB* 2017). As a key highlight of this, the 2017 Air Resources Board Report showed signs that in 2015 plug in hybrid electric vehicle sales fell dramatically in concert with gas prices also seeing a decline. In

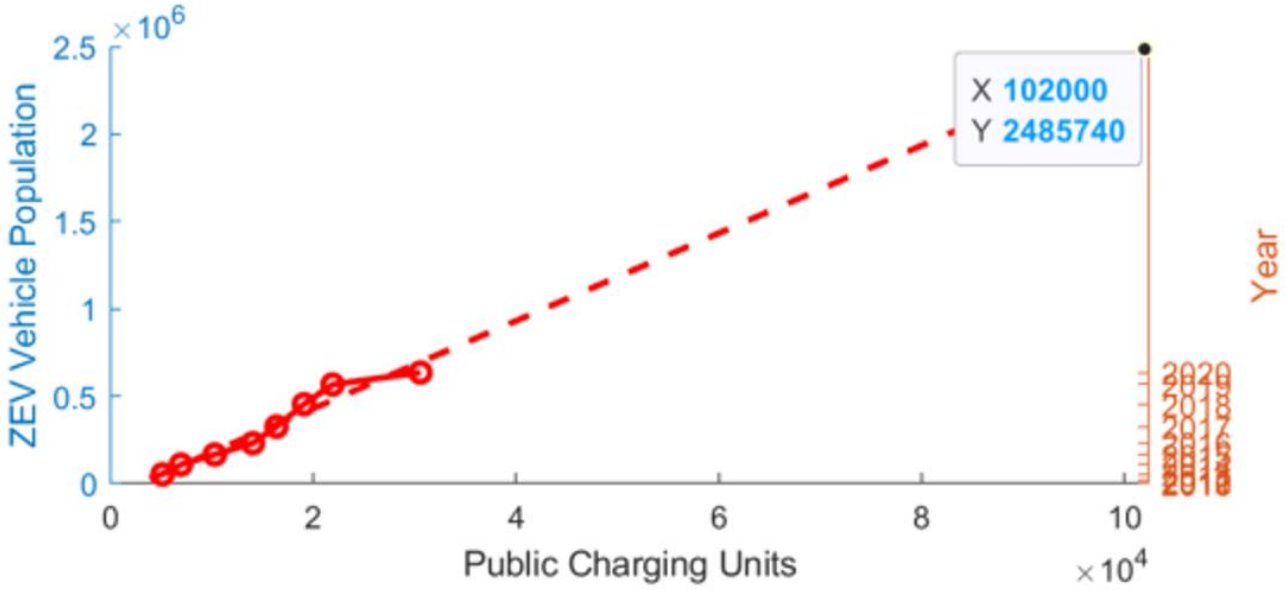

Figure 8. Relationship between public charging units and ZEV population

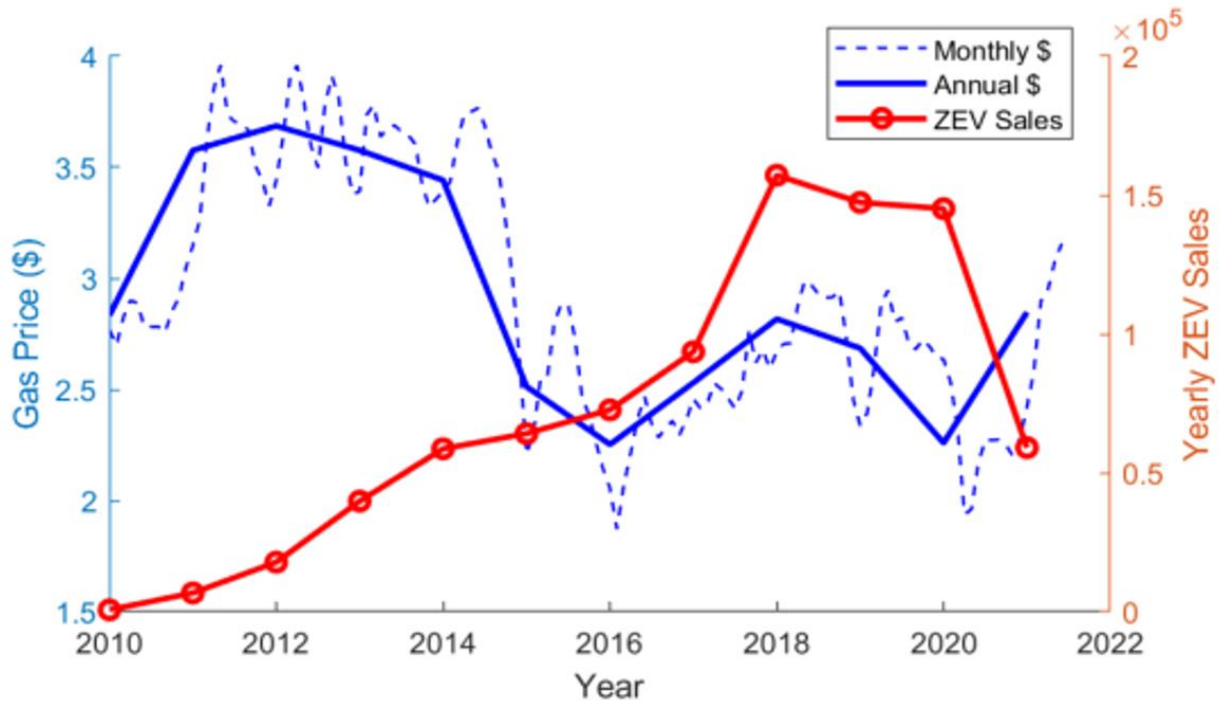

Figure 9. Changes in gas price and yearly ZEV sales over year 2010 to 2021

CARB's model to analyze the connections between gas prices and ZEV sales, a one dollar per gallon increase in gas price is associated with 366 higher monthly ZEV purchases if all other hybrid electric vehicle sales fell dramatically in concert with gas prices also seeing a decline. In CARB's model to analyze the connections between gas prices and ZEV sales, a one dollar per gallon increase in gas price is associated with 366 higher monthly ZEV purchases if all other factors remained at a status quo. It concludes there is suggestive evidence that increased gas prices lead to increased ZEV purchases. The following regression plot shows monthly and annual gas data (blue plots, left y-axis) for the time period 2010-2021. The data is taken from https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=emm_epm0_pte_nus_dpg&f=aO verlayed are the annual ZEV sales (red line, red y-axis) for the same time period.

Over the last 2 decades gas prices have closely aligned with the growth of ZEV (See Figure 10). The details in the graphic on Figure 11 also show a scatter plot of the yearly ZEV sales against the annual average gas prices. Each blue dot represents the average gas price and ZEV sale for a given year. Circles outlined in red are for years 2015-2020.

These circles are intentionally isolated in these years through the subsequent analysis because

1. the ZEV sales data for year 2021 (green circle) is not yet complete
2. there seems to be a shift in the data trend from the early years 2010-2014. Note that there is typically an adoption curve that is associated with new technology. Note that ZEV sales likely would be increasing regardless of the gas price, because of the adoption curve.

A linear fit to the data from years 2015-2020 (red dashed line) suggests that as gas prices increased, so did ZEV sales. There is a caveat that the data here is limited so any conclusions

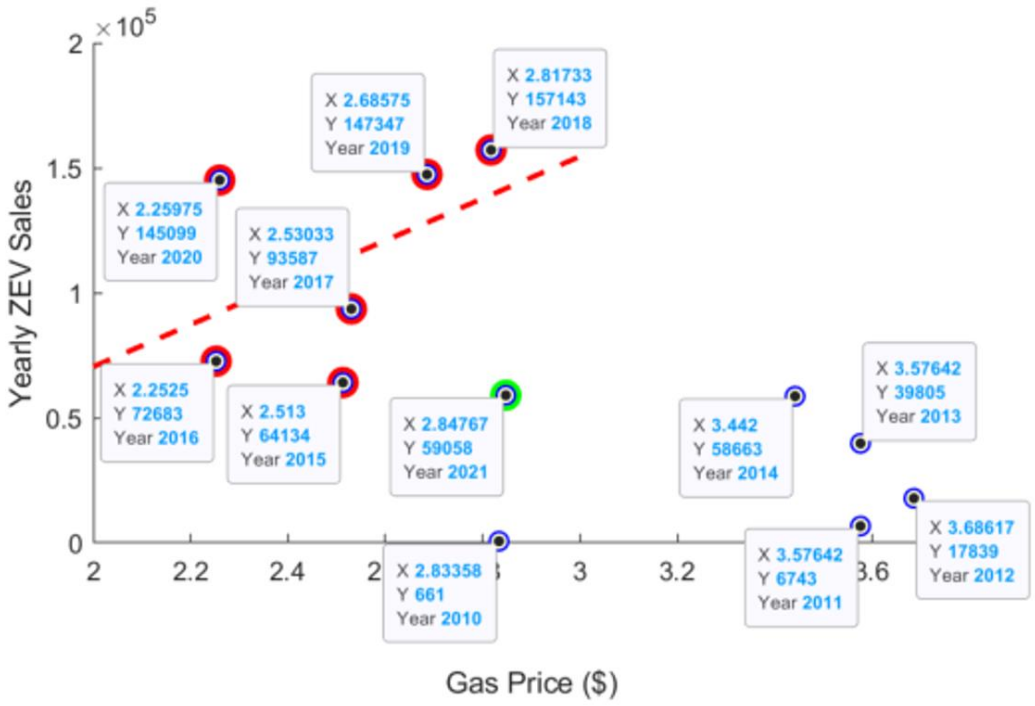

Figure 10. Relationship between gas price and yearly ZEV sales

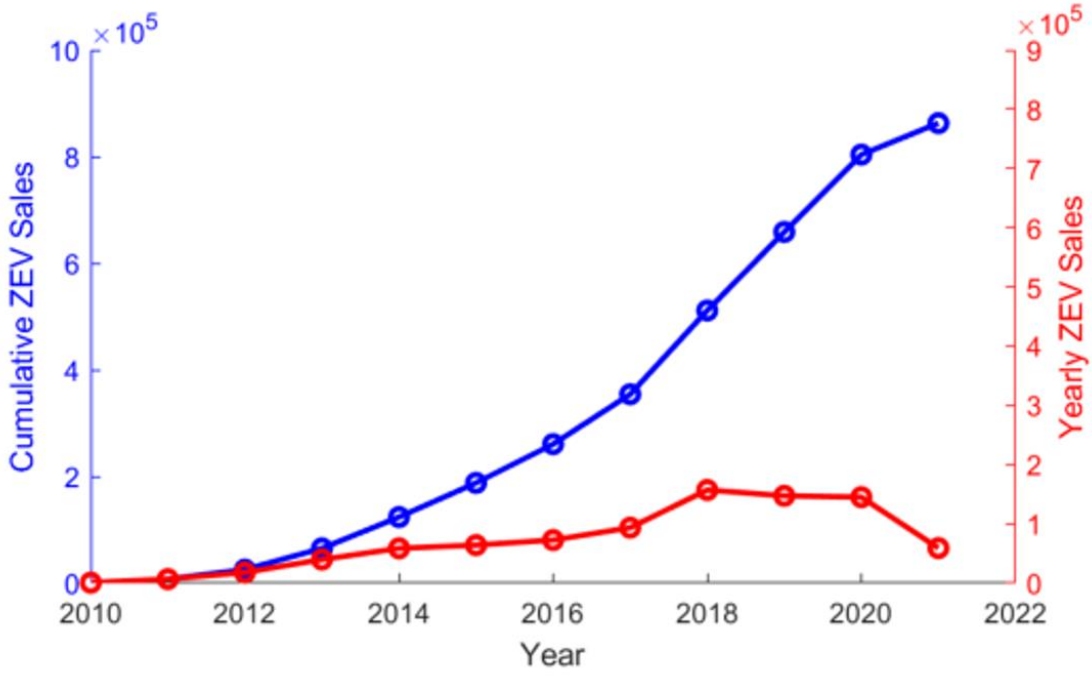

Figure 11. Cumulative ZEV sales and yearly ZEV sales

must be drawn cautiously. However, there does seem to be a moderate correlation (r = 0.46) between gas price and yearly ZEV sales from 2015-2020. ZEV sales generally increase as gas price increases. A subsequent analysis based upon the monthly gas prices and monthly ZEV sales may better elucidate this trend.

Current trends in ZEV sales and projected shortfall to attain ZEV goals

The following graph shows the yearly (red line, right y-axis) and cumulative ZEV sales (blue line, left y-axis) in the state of California over the time period 2010-2021, based upon data derived from https://www.energy.ca.gov/files/zev-and-infrastructure-stats-data (V New ZEV Sales Last updated 04-30-2021.xlsx). The total ZEV population (Cumulative ZEV Sales) in California has grown from a mere 768 vehicles in 2010 to more than 635,000 in 2021—a nearly 83,000 percent increase over the 11-year period. Overall annual sales have also seen significant growth over the period from 661 vehicles sold in 2010 to 147,000 sold in calendar year 2020.

The next modeled graph depicts the recorded population of Zero Emission Vehicles (ZEVs) over the time period 2010-2020 and shows projections to the key goal year of 2030. The data is taken from https://www.energy.ca.gov/files/zev-and-infrastructure-stats-data (Vehicle Population Last updated 04-30-2021.xlsx). These projections show the continued growth of ZEV populations using either a first-order linear (dotted red line) or second-order quadratic (dotted blue-line) regression, with the second-order regression (r = 0.998) more precisely fitting the data than the first order regression (r = 0.964).

Linear Model: $\text{ZEV Population} = -135222542 + 67223.7 * \text{Year}$

Quadratic Model: $\text{ZEV Population} = 25969205775 - 25842942.6 * \text{Year} + 6429.3 * \text{Year}^2$

Projections out to the year 2030 show ZEV population predictions of 1,241,661 and 2,623,970 for the first- and second-order models, respectively (figure shows numbers rounded to nearest 10). Note that these numbers assume that history is a direct predictor of future trends assuming no changes in policies and or consumer behavior.

Based on these model projections (Figure 12), the state of California's ZEV target population of 5 million by the year 2030 would not be reached until the January 2086 (first order linear regression model) or August 2037 (second order quadratic regression model). These projects assume current trends will hold and no policy changes are implemented through the years. There are approximately 635,000 total ZEVs in California today and the most analogous model (quadratic) is predicting approximately 220,000 ZEVs will be added to the state fleet annually over the next 9 years to reach a total of 2,623,970.

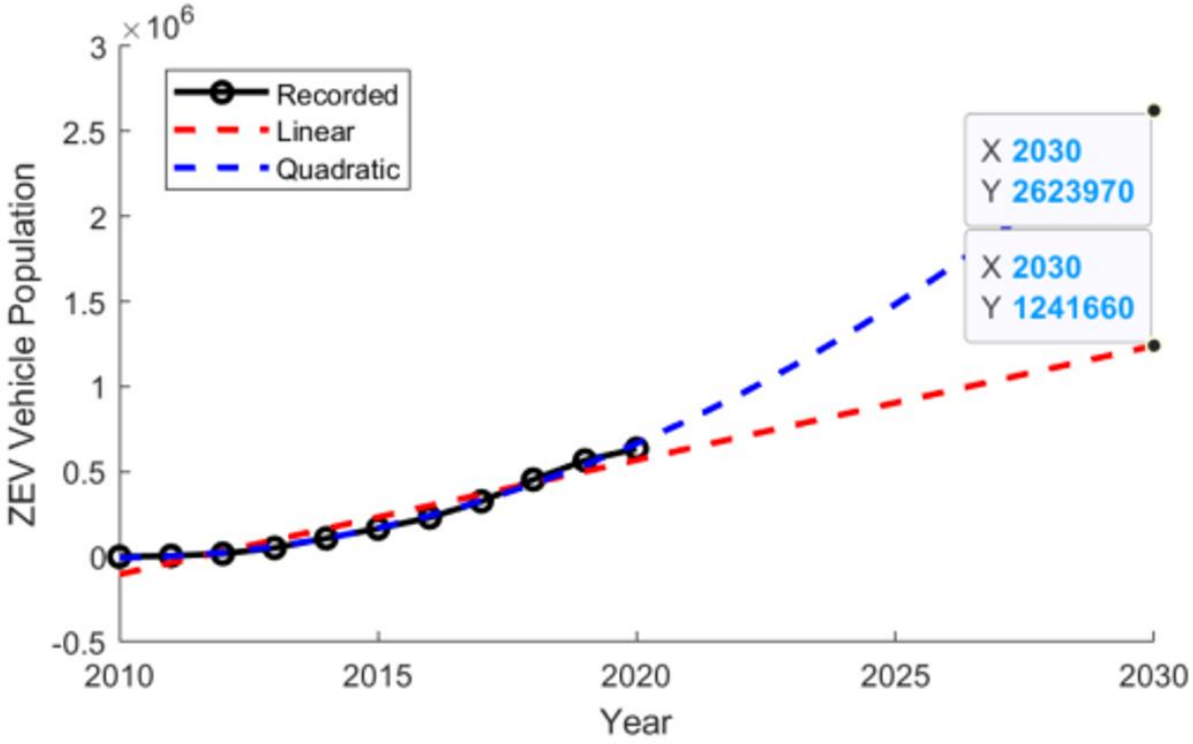

Figure 12. Prediction of ZEV population using linear and quadratic regression

CHAPTER 4

THE ADVANCED ZEV PREDICTION MODEL

Key factors influencing ZEV sales in California

Beyond the incentives program described in the immediate prior chapter, there are a few other critical factors that continue to show the most direct and indirect influence on the sales and market share growth of ZEVs in California and other parts of the world. Prominent on the factors list include issues like the socio-economic status of consumers, total upfront cost of the ZEVs, ZEV charging infrastructure, and fuel or gasoline cost. This research further explores these three key influencers with models and recommends adjustments in funding and policies to reach the targeted vehicle adoption rates and environmental outcomes for the state.

Despite the recent years of experiencing sharp increases in sales, ZEVs still only represent less than 2.5 percent of the total vehicle population in California and only 9.3 percent of overall annual vehicle sales in the state (CEC 2021). To reach the levels of the planned goals for sales and total ZEV population, varying policy adjustments will be needed along the way. Understanding the key factors that have had the most impact on growth will be essential as policy adjustments are considered. In a 2017 report commissioned by the California Air Resources Board (CARB) and the California EPA, research unveiled electric vehicle sales are not evenly spread across communities in the state. Corroborating other similar findings, the research showed communities ranked in the top 25 percent of socio-economic standings purchased 10 times more ZEVs than communities in the bottom 25 percent (CARB, CalEPA 2017). In addition to household income, the clean air vehicle decals sticker program that allows drivers of single occupancy ZEVs to access carpool or High Occupancy Vehicle (HOV) lanes was shown to have a positive correlation to

increased sales in regions with such designated lanes (CARB, CalEPA 2017). Also refueling needs associated with households preferring longer battery ranges and access to residential, public and workspace charging were other factors impacting ZEV adoption.

Rebates and incentives

The upfront cost of ZEVs has historically been and will continue to be a leading factor in the future growth and adoption of the vehicles. The incentives and rebates offered at the federal and state levels will also be a key influencer to reach the desired milestone population goals in California at 2030 and 2035. The upfront cost of zero emission vehicles is currently higher than comparable internal combustion engine vehicles, though costs have dropped rapidly in recent years (Perry 2018). Estimates are showing that by 2025 electric vehicles will fall to the point of being more cost-competitive with internal combustion engine counterparts (Perry 2018).

Using preset formulas from the Alternative Fuels Data Center website (with Annual Driving Distance of 11926 miles), I compared the total cost of ownership and emissions for two of California's top selling ZEVs (Tesla Model 3 and Chevrolet Bolt) to a top selling hybrid and regular gasoline vehicle and the results showed at this time, the overall total cost (excluding incentives and rebates) will be higher for ZEVs long term. This highlights the importance of increasing incentives opportunities and making consumers more aware of the opportunities to reduce cost.

The graph above shows the cumulative cost of ownership by year for each vehicle, including fuel, tires, maintenance, registration, license, insurance, and loan payment. The tool assumes a five-year loan with a 10% down payment. Year one on the graph represents the 10 percent down payment plus the first year's total operating costs.

The data in Table 14 is historical data of rebates in California. The total number of rebates are increased but the amount per rebate is quite stable from the year 2013 till now. Higher-income groups are not eligible for claiming the rebates. The lower-income groups can claim an increased amount of rebates. The current model does not consider different income groups.

Table 15 shows the average gas price in each month from January 2010 to December 2020. The gas price fluctuates during the 10 years, but the gas price of the year 2010 is about the same as that of the year 2020. Along with the inflation, we witnessed a surge in gas prices this year. However, data for the year 2021 is not considered in this study as we still do not have completed data for November and December.

Charging infrastructure

Table 5 shows the information on public charging facilities in California. Private stations are not count the number of private stations as they may not affect consumers' decisions. There are mainly three types of charging ports, level 1 chargers, level 2 chargers, and DC fast chargers. Level 1 chargers use electricity at 120 volts and provide about 5 miles range per hour of charging. Level 2 chargers use electricity at 208 to 240 volts. It provides 14 to 35 miles of range per hour of charging. Level 2 chargers are the main ports of most public charging stations, accounting for 78.25%. The DC fast charging ports are more advanced than the other two counterparts. They work at 480 volts and can recharge a BEV to 80 percent capacity in about half an hour.

The New SPRE-CA Model

Through this research a new SPRE-CA model has been developed to predict the ZEV sales in the state of California. As was shown in Figure 13, the inputs of the model are incentives and rebates, gas price, charger accessibility, and total sales prediction. Relevant data for the first three inputs is

Table 5. Historical data of the number of public charging stations through the year 2010 to the year 2020

Year	Number of stations	Number of ports	level1 ports	level2 ports	dc fast ports
2010	86	308	24	281	3
2011	183	658	77	538	43
2012	288	1020	92	859	69
2013	427	1597	110	1272	215
2014	550	1981	130	1567	284
2015	868	3030	135	2349	546
2016	1178	4134	143	3311	680
2017	1426	5104	144	4228	732
2018	1842	7249	158	5599	1492
2019	2395	9813	171	7327	2315
2020	6155	19559	217	15304	4038

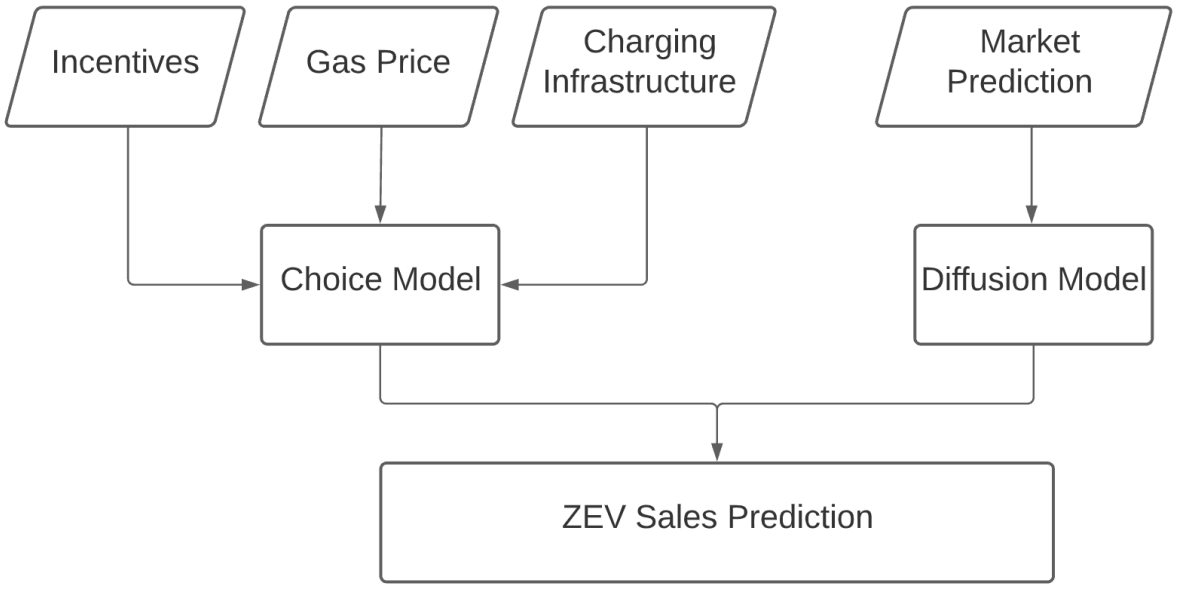

Figure 13. Overview of the Sales Prediction Model for California (SPRE-CA)

outlined in the attached appendix. There are two sub-models in the SPRE-CA model, namely the choice model and the familiarity model. The choice model is used to estimate the probability that a driver chooses ZEV rather than non-ZEV.

We assume that there are two groups of people, one is the ZEV-neutral group and the others are conventional vehicle enthusiasts. The ZEV-neutral group does not have any preference between ZEV and non-ZEV. Therefore, the probability calculated by the choice model can be applied to them. Conventional vehicle enthusiasts never consider ZEV because they do not know ZEV well or for other reasons. The market diffusion model is used to determine the population that belongs to the ZEV-neutral group. The notations used in the choice model and diffusion model are defined as follows.

Notations

P_t	Represent the probability of purchasing a ZEV
U_t	Represent the utility of purchasing a ZEV
β_1	Represent the coefficient associated with the average amount per rebate
β_2	Represent the coefficient associated with the average yearly gas price
β_3	Represent the coefficient associated with the number of charging facilities
α	Represent the intercept of the multi-linear regression
RB_t	Represent the average amount per rebate in year t
GP_t	Represent the average gas price in year t

CF_t	Represent the number of charging facilities in year t
DF_t	Represent the diffusion factor in year t
y_t	Represent a number that is used to calculate the diffusion factor in year t

Choice model

The choice model outlined in Figure 18, is used to calculate the probabilities that a customer purchase ZEV. As shown in Equation (1), the probabilities are calculated based on the utility of purchasing a ZEV. If the value of U_t is zero, the probability of choosing ZEV and non-ZEV are equal, which is one half for both of them. If the value of U_t is greater than zero, the probability of choosing ZEV is greater than that of choosing non-ZEV. In contrast, if the value of U_t is less than zero, the probability of choosing non-ZEV is larger. Note that the choice model is applied to customers who are ZEV neutral, which means they do not have a preference over the type of internal combustion engine.

$$P_t = \frac{e^{U_t}}{1 + e^{U_t}} \tag{1}$$

U_t refers to the utility, which is also the benefit, of choosing ZEV in year t. Its value is calculated as shown in Equation (2). In order to calculate the utilities, there are four important parameters to be determined, i.e., β_1, β_2, β_3, and α. The other variables such as RB_t, GP_t, and DF_t are given. RB_t is the average amount per rebate in year t. GP_t is the average gas price in California in year t. CF_t is the number of charging facilities in year t. Based on the historical sales data, the values of U_t can be determined by Equation (3),

$$U_t = \beta_1 \cdot RB_t + \beta_2 \cdot GP_t - \beta_3 \cdot CF_t + \alpha \quad (2)$$

$$U_t = \ln(\frac{P_t}{1 - P_t}) \quad (3)$$

Historical data for incentives, gas price, and the number of charging stations are shown in Table 6. The values of U_t are calculated and listed in

Table 7. With the data of U_t, RB_t, GP_t, and CF_t, the parameters β_1, β_2, β_3, and α can be estimated using multiple linear regression. This is done by using the machine learning tool scikit-learn. The estimated parameters are shown in Table 8. In order to compare the importance of the three factors, we normalize the input data and run the calculations. The parameters after normalization are $\beta_1 = 1.1033$, $\beta_2 = 0.3182$, and $\beta_3 = 0.7775$. The results show that the incentive have the greatest impact on ZEV sales among the three factors. The second important factor is the number of charging facilities. The gasoline prices are the least important.

Diffusion model

Diffusion factor DF_t measures the ZEV acceptance by the market. Its practical meaning is the percentage of people that is ZEV-neutral. It takes time for an innovation to be accepted by the market. The chance that a ZEV is chosen is very low at the beginning as the market has little knowledge of it. The consumers may have concerns related to safety issues, ranges, incremental price, etc. As the adoption of ZEV increased, people get familiar with ZEV, and its advantages and disadvantages (see Figure 14). The probability of choosing ZEV is increased, especially if ZEV is recommended by a friend or a native. We assume the diffusion of ZEV follows a sigmoid

Table 6. Historical data of rebates, gas price, and the number of charging stations.

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
RB_t	1800	2021	2062	2173	2278	2404	2368	2476	2195
GP_t	4.091	3.934	3.800	3.210	2.786	3.085	3.554	3.674	3.133
CF_t	288	427	550	868	1178	1426	1842	2395	6155

Table 7. Historical data of utilities of ZEV

Ye.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
P_t	0.000	0.004	0.011	0.024	0.036	0.039	0.044	0.057	0.096	0.090	0.089
U_t	-7.812	-5.486	-4.506	-3.690	-3.290	-3.197	-3.067	-2.801	-2.240	-2.311	-2.328

Table 8. Estimation of the parameters

$\widehat{\beta_1}$	$\widehat{\beta_2}$	$\widehat{\beta_3}$	$\hat{\alpha}$
0.0016305	0.24379	4.19402	-6.21998

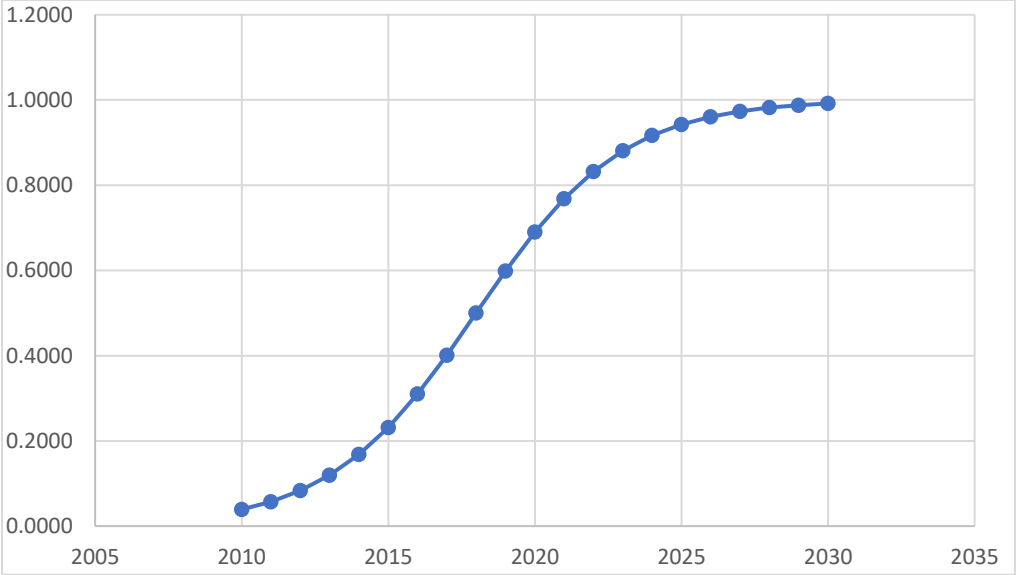

Figure 14. Diffusion factors through the year 2008 to 2050

function as follows.

$$DF_t = \frac{1}{1 + e^{-y_t}} \tag{4}$$

DF_t is the percentage of consumers that are ZEV-neutral. They do not have a preference over ZEV or non-ZEV. They make fair decisions based on the choice model.

$$y_t = -4 + \frac{4 - (-4)}{2028 - 2008}(t - 2008) \tag{5}$$

We assume that only 2% of people (where $y_t = -4$) know ZEV by the year 2008, which is the year that the first commercial Tesla was released. We assume it takes 20 years that 98% of people (where $y_t = 4$) become ZEV-neutral by the year 2028.

Model evaluation

Figure 15 shows the sales prediction using the SPRE-CA model. The results are compared with the true ZEV sales through the year 2010 to 2020. The blue line is the real sales, and the orange line is our prediction. From the figure, we notice that our prediction fits the real sales well. There is a sales drop during the year 2017 to 2018. Our prediction also reveals the trend but with one-year delay.

In the year 2019, the incentive of EV for regular community is reduced from $2500 to $2000. The decreased incentive could be one of the contributors that caused the sales drop. Other factors may include the outbreak of the epidemic, which is not considered in this dissertation.

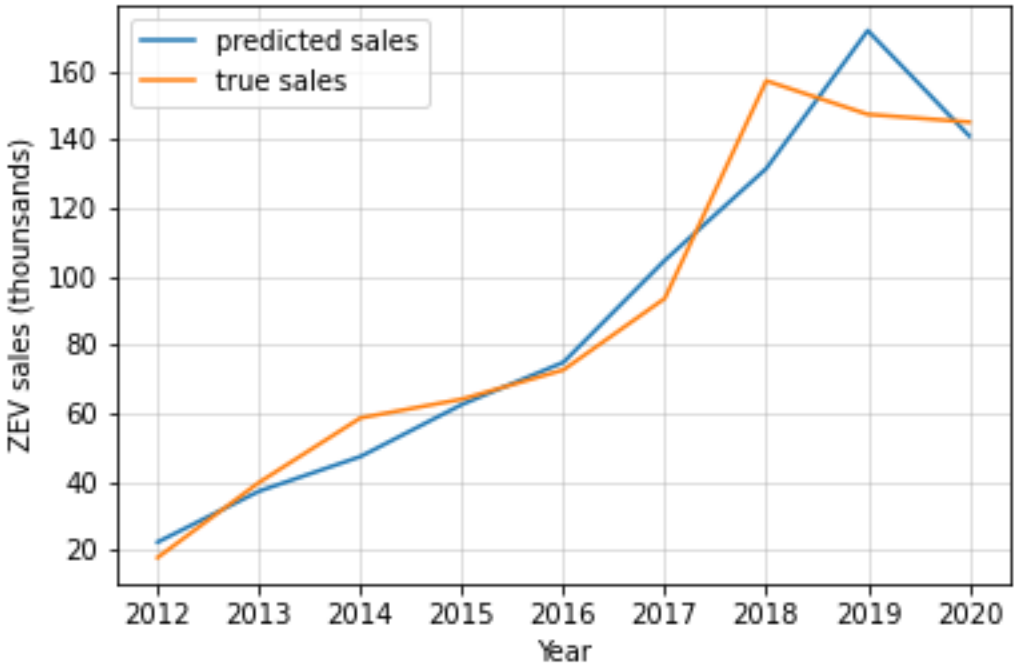

Figure 15. Prediction using the SPRE-CA model and the historical new ZEV sales.

CHAPTER 5

COMPUTATIONAL EXPERIMENTS AND BUSINESS INSIGHTS

Impacts of the three key factors based on the SPRE-CA model

Rebates and incentives

Figure 16 shows predictions for new ZEV sales during the year 2020 to 2035 if the policy on rebates and incentives is changed. Four situations are considered in the experiments. Specifically, the incentive amount is reduced by 25% and 50%, and the cases that incentive amount increases by 25% and 50%. The results show that the incentive amount has a significant impact on new ZEV sales. Based on the SPRE-CA model, the new ZEV sales in year 2035 would reach 1.04 million if the incentive amount is increased by 25%. If the incentive amount is increased by 50%, the new ZEV sales in year 2035 would reach 1.53 million. This number of sales is about 10 times the sales in year 2020. By comparison, the blue line shows the situation that all the factors maintain the same, i.e., the incentive, gas price, and the number of charging stations do not change from the year 2020 to the year 2035. In this baseline case, the predicted new ZEV sales in year 2035 would be 0.58 million, which is about one-third the situation where incentive is increased by 50%. The new ZEV sales would be suppressed if the amount of incentive is decreased. For instance, the new ZEV sales in year 3035 would drop to 0.28 million and 0.12 million if the incentive amount is decreased by 25% and 50%, respectively.

Gas price--generating ZEV demand

Global conflict such as wars in nations with significant oil reserves or in major oil producing countries often generates spikes in gas prices. The Russia and Ukraine conflict in early 2022 has

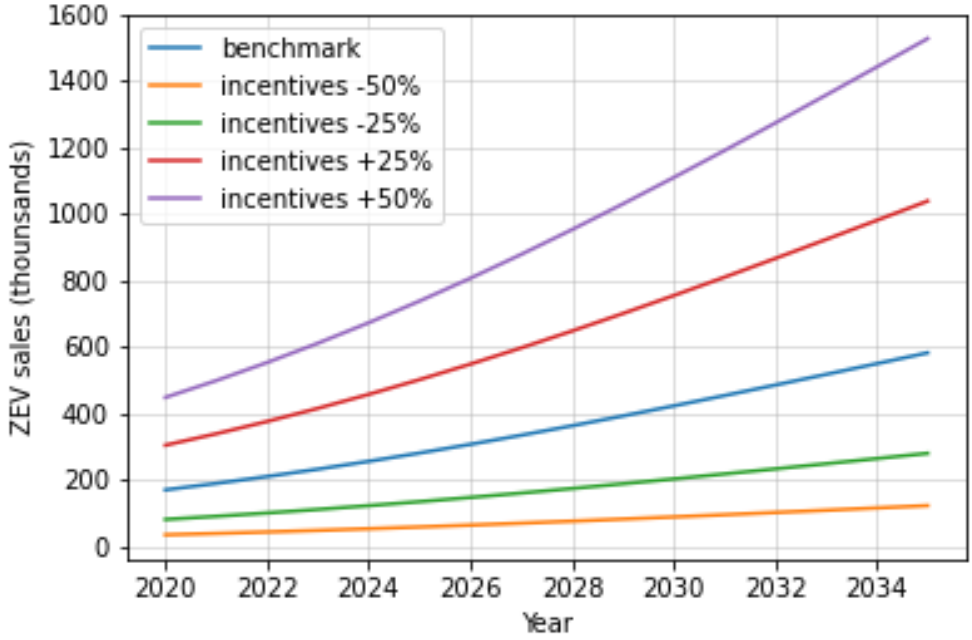

Figure 16. ZEV sales prediction using the SPRE-CA model regarding incentives policy change

driven up fuel prices across the United States and the world as Russia represents nearly 10 percent of global petroleum production (Dallasfed 2022). Similar spikes in petroleum cost were seen in the early 1990's after Iraq's invasion of Kuwait and the eventual Gulf War led by the U.S forces (DallasFed 2022). Though the United States has less than 5% of the world's population--it is the largest consumer of oil in the world (see Figure 17). The fluctuations in gas prices directly impact the United States and California more specifically with more registered vehicles (30 million) than any other state. The increased gas prices make ZEVs a more attractive option due to potential savings on operation cost. Despite the increased demand and expected spike in ZEV sales, challenges related to the supply chain backlog of 2021 have hampered many segments of the automotive industry. As the supply chain challenges improve at the major ports across the country, its expected that ZEV sale numbers will also see improvement.

Figure 18**Error! Reference source not found.** predicts the new ZEV sales during year 2020 and year 2035 when the gas price is increased while the other two factors maintain the same. The results show that the impact of gas price is lower than the impact of incentives amount. However, the percentage increase in gasoline price may easily exceed the percentage increase in the incentive amount. In our experiments, the benchmark gasoline price is $3.13 per gallon, which is also the average gas price in California in the year 2020. If the gas price maintains unchanged through year 2020 to year 2035, the predicted new ZEV sales in year 3035 is 0.58 million.

However, keeping the gas price unchanged seems impossible in practice. The gas price is more likely to increase than to go down. At the time of writing, the average gas price in California already reaches $5.86 per gallon due to the impact of Ukraine War. If the gas price continues to

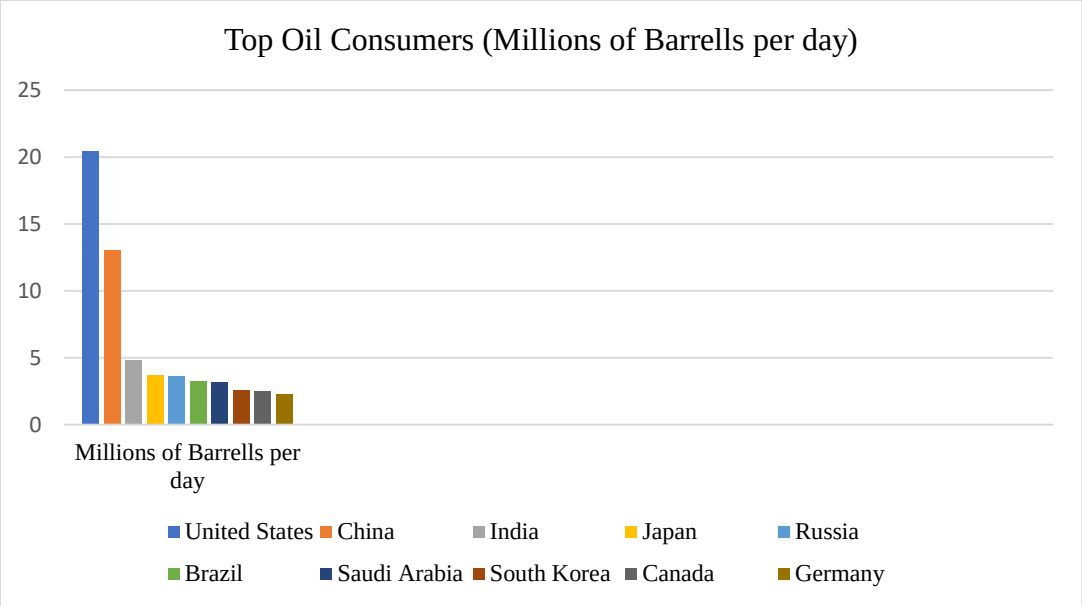

Figure 17. Top oil consumers globally in millions of barrels daily.

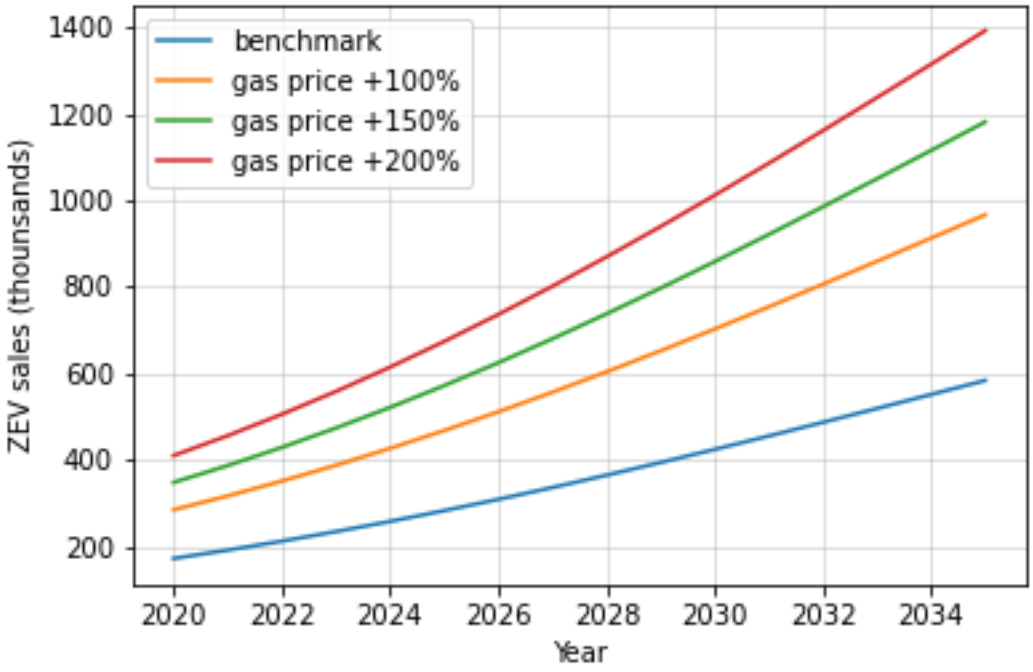

Figure 18. ZEV sales prediction using the SPRE-CA model regarding increased gas price

increase to $6.26 per gallon, double the average price in year 2020, the ZEV sale in year 2035 would reach 0.97 million. If the gas price further increases to $7.83 per gallon, a 150% improvement compared with the price in year 2020, the predicted ZEV sale is 1.18 million. Furthermore, the predicted ZEV sale reaches 1.39 million if the gas price increases to $9.40 per gallon.

Charging facilities

Figure 19 forecasts the new ZEV sales during year 2020 to year 2035 as the number of charging facilities increases to various levels. The number of public charging stations is 6,155 while the number of public charging ports are 19,559 in California in year 2020. The factor used in the model is the number of public charging ports. We consider four situations where the ports are increased by 25%, 50%, 75%, and 100%, respectively. As is shown, the predicted new ZEV sales in year 2035 are 0.68 million, 0.78 million, 0.89 million, and 1.00 million, respectively.

Sensitive analysis

Figure 20 provides a sensitive analysis in terms of the three factors affecting the future new ZEV sales. The effects of the factors are evaluated by increasing and decreasing them by 10% and 20%, respectively. The results show that the influence of increasing the factors are greater than that of decreasing the factors. For example, increasing the rebate amount by 10% can stimulate the new ZEV sales by 28.74%, while decreasing the rebates by 10% will only reduce the new

ZEV sales by 24.20%. However, it is true that the number of charging facilities may not decrease in practice. Similarly, the gasoline price is unlikely to drop. By the time of writing, the average gas price in California already increased by 87.22% compared with the gas price in year 2020.

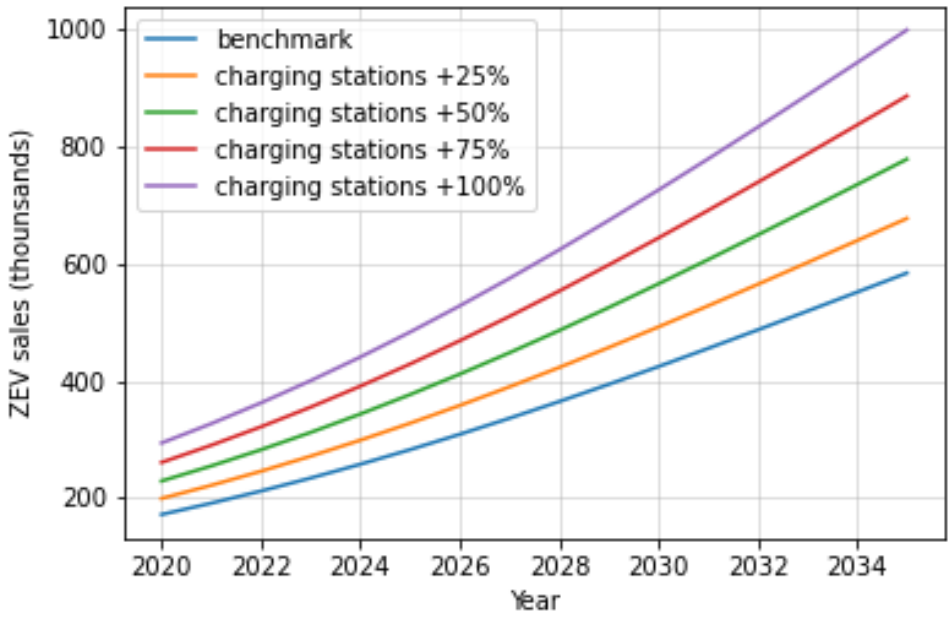

Figure 19. SPRE-CA projections of charging infrastructure adjustment impacts.

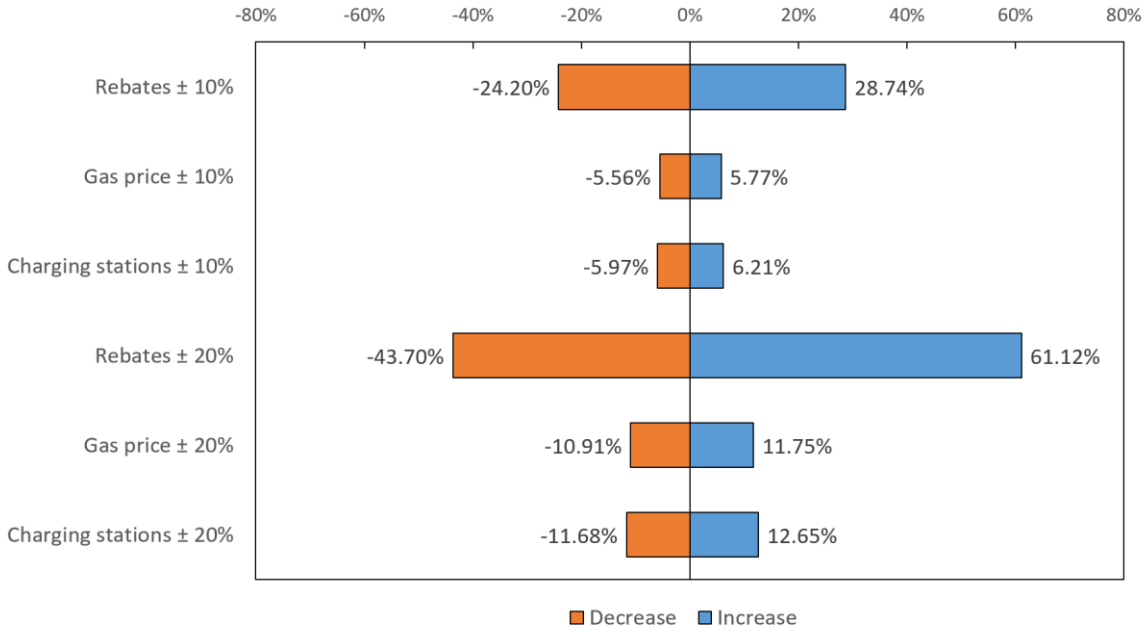

Figure 20. SPRE-CA model sensitive analysis regarding the three factors

The computational results also indicate that the incentive amount has the greatest impact among the three factors. The impact of gas price and the number of charging facility on new ZEV sales is about the same. Specifically, the impact of incentive amount is about five times larger than the impact of gas price and the number of charging stations.

Forecasts of ZEV market share based on realistic, optimistic, and pessimistic scenarios

In this section, a forecast of the ZEV market share from 2020 to 2050 is developed based on a realistic scenario, optimistic scenario, and pessimistic scenario. In a realistic scenario, an assumption is made that the average incentive amount per rebate in California remains at the current level through 2050. The gas price and the number of public charging ports also follow current growth trends. According to the historical data over the past 20 years (from year 2002 to 2021), the average gas price in California fluctuated between $1.56 per gallon and $4.09 per gallon as shown in Figure 27. By using a linear regression model, the predicted gas price in 2050 is $5.28 per gallon. Note that the forecast does not consider special factors, such as the recent Ukraine War that caused a significant increase in gasoline prices in March 2022. The number of public charging ports will reach 48,308 in 2050 by the historical data over the last 10 years (from year 2012 to year 2021). In 2021 the public charging network stood at approximately 30,000.

The optimistic scenario refers to the situation that the factors are changed in favor of ZEV sales. In our experiments, we assume a 50% increase in the incentive amount per rebate. In addition, we assume that the gasoline price and the number of public charging ports will be 50% higher than the realistic scenario. Under the optimistic assumption, the average incentive amount, the gas price, and the number of public charging ports in California by 2050 is $3292 per rebate, $7.92 per gallon, and 72,462, respectively.

In contrast, the pessimistic scenario refers to a situation in which the three factors change in a direction that negatively infects ZEV sales. Specifically, we assume that the average incentive amount is decreased by 20% from the current level. In addition, the gas price and the number of public charging ports are 10% less than the realistic estimation. The average incentive amount, gas price, and public charging ports under the three scenarios are summarized in Table 9.

The market share of ZEVs from year 2020 to 2050 under realistic scenario, optimistic scenario, and pessimistic scenario is depicted in Figure 21. The initial market share of ZEV in 2020 is 8%. As is shown, ZEV market share grows linearly under realistic scenario and pessimistic scenario. By the year 2050, the ZEV share will reach 59% and 37% under realistic scenario and pessimistic scenario, respectively. Under the optimistic scenario, ZEV's market share increases linearly from 2020 to 2040. The increasement gets slower after year 2040 because the ZEV share is getting close to saturation. Based on the results obtained from the SPRE-CA model, it is difficult to achieve the goal that all light duty cars or vehicles sold in California to be 100 percent zero emission by 2035.

Reducing ZEV purchasing cost to increase sales

To improve the penetration of ZEVs and help California reach one its key goals in the climate change battle to reach 5 million vehicles in the state by 2030, the average price of a non-luxury clean vehicle will need to fall by 15 to 20% over the next few years. Based on latest data in Table 10 from Edmund (an online resource for automotive inventory and information), the average non-luxury EV from the best sellers on the market, cost approximately $34,000. These relatively low cost EV's however only have an average battery range of 172 miles. The cheapest luxury end EVs that are the best sellers had a significantly higher average cost at nearly $50,000, while yielding almost 245 miles on their battery range. The difference between both EV ranges netting $16,000

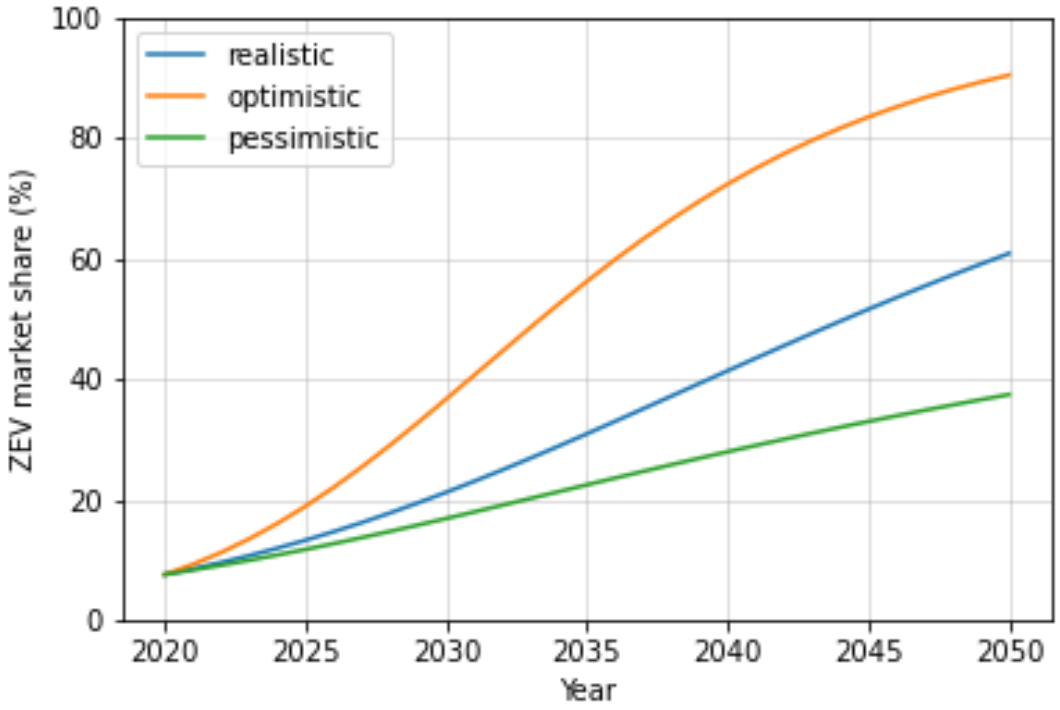

Figure 21. Forecasts of ZEV share under realistic, optimistic, and pessimistic scenarios

Table 9. Estimation of three factors by 2050 under realistic, optimistic, and pessimistic scenario

Scenario	**Average Amount of Incentive Per Rebate**	**Average Gas Price**	**Number of Public Charging Ports**
Baseline	$2,195 (Year 2020)	$3.133 per gallon (Year 2020)	19,559 (Year 2020)
Realistic	$2,195 (Year 2020)	$5.28 per gallon (Linear regression)	48,308 (Linear regression)
Optimistic	$3,292 (+50% Realistic)	$7.92 per gallon (+50% Realistic)	72,462 (+50% Realistic)
Pessimistic	$1,756 (-20% Realistic)	$4.75 per gallon (-10 % Realistic)	43,477 (-10% Realistic)

Table 10. 2021 Cost of EV's in various ranges -- higher mileages result in higher cost (Edmunds 2021).

Electric Vehicle Type	Cost	Battery Range
2021 Mini Cooper SE	$30,750	110 miles
2021 Nissan Leaf	$32,620	149 miles
2021 Hyundai Ioniq Electric	$34,250	170 miles
2021 Chevrolet Bolt EV	$37,495	259 miles
Cheapest Luxury Electric Cars		
2021 Tesla Model 3	$41,190	263 miles
2021 Ford Mustang Mach-E	$43,995	230 miles
2021 Tesla Model Y	$53,190	244 miles
2021 Polestar 2	$61,200	233 miles
Cheapest Plug-In Hybrids		
2021 Hyundai Ioniq Plug-In Hybrid	$27,705	29 miles
2021 Toyota Prius Prime	$29,195	25 miles
2021 Kia Niro Plug-In Hybrid	$30,765	26 miles
2021 Honda Clarity Plug-In Hybrid	$34,395	48 miles

in cost and more than 70 miles in battery range. The delta between both ranges of EVs is the optimum point of growth for new ZEVs sales in California over the 5 years.

The outlook for this optimum point of growth is because the median income of used vehicle buyers in California for ZEV's is $150,000 in comparison to gasoline powered vehicle at $90,000 (Turrentine et al., 2018). Also, the median annual household income in the state is approximately $76,000 which post taxes and other financial deductions yields a net take home pay of about $5,000 monthly. Several nationally regarded financial advisors and experts on income, salary and expenses recommend approximately 10 to 15 percent of take-home salary (net monthly pay) to go to expenses related to owning or leasing a car. Ten percent of the monthly net pay for the median income earner in the state is $500 which is also the approximate monthly payment for $25,000 vehicle financed over 5 years - $420 (this excludes insurance and other maintenance or operational cost). Driving the ZEV cost down to make it more affordable for the general public or average median income earner in the state will be a key catalyst for growth in California. As the vehicle cost go down, the battery range should not be sacrificed—as this will also be an important factor in reducing "range anxiety" concerns in efforts. An clear example of how important charging infrastructure and cost is to future ZEV growth in the state--is the city of Los Angeles (see Figure 22). It currently has the highest number of electric vehicle drivers in the state at more than 17,000 (Charge Point 2022), but based on mapping created during this research, most of the ZEV charging network is not located in lower income areas of the city and the highest density of ZEVs are also located in higher income areas.

Summary of SPRE-CA Model outcomes vs. California's goals

California has been successful at setting aggressive goals to increase sales of zero emission vehicle

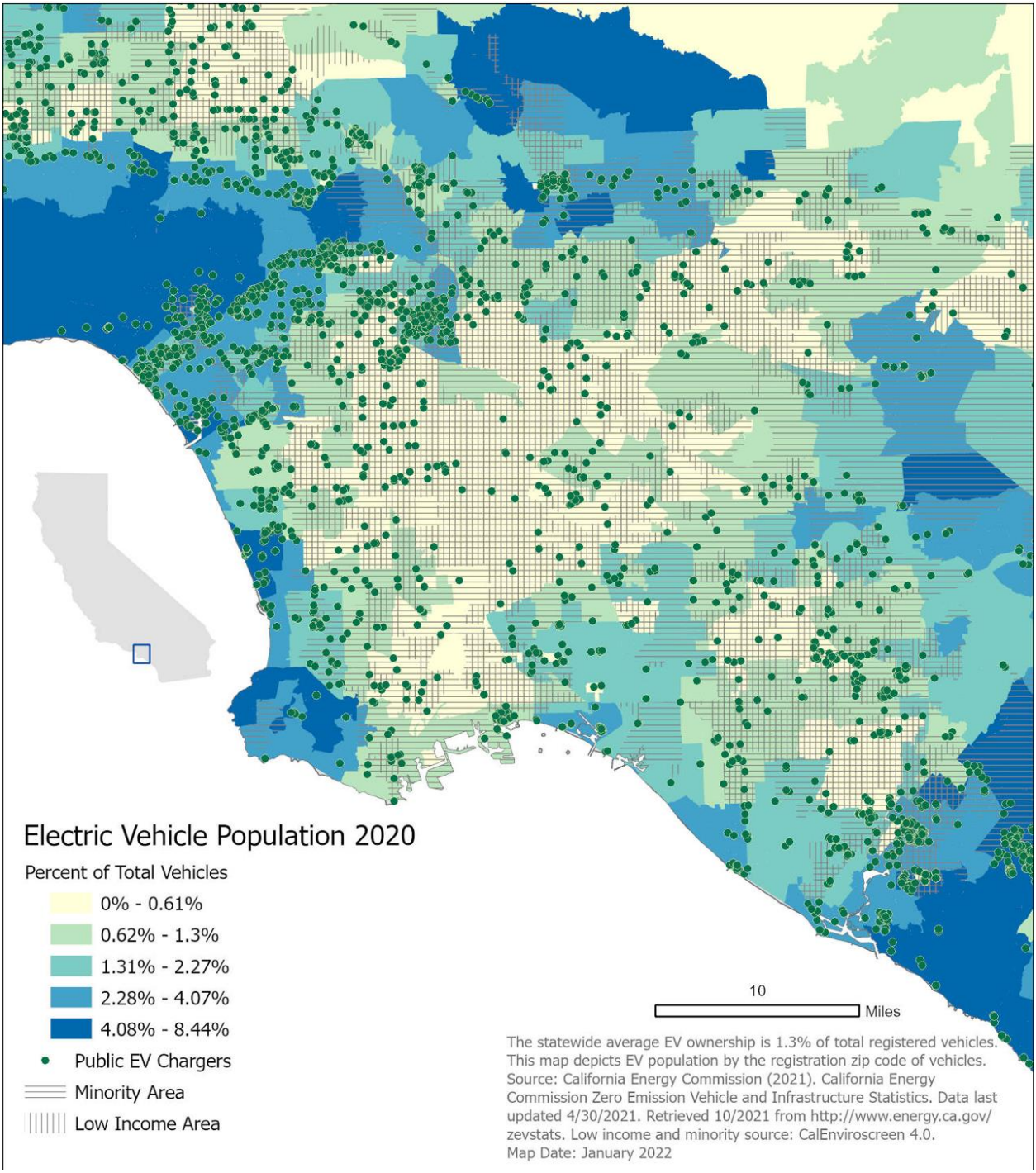

Figure 22. Graphic depicts the density of both the ZEV population and public charging network in Los Angeles in 2020, The data is overlayed on minority and lower income communities (Caltrans District 5 and 11, 2021).

through policies, regulations, and major funding support. Many of the specific goals around sales increases for California have been proposed by the California Air Resources Board in the updates to the 2021 California Code of Regulations. The Table 11 outlines the percent requirement goal for ZEVs based on model year. With a key milestone of reaching 61% of ZEVs sold in the state to be ZEV by the year 2030 and 100% by the year 2035. The new forecast model developed through this research shows even through optimistic scenarios the 2030 and 2035 goals will likely not be reached. Even more aggressive incentives and cost reduction efforts will need to be pursued to attain the goals.

Table 11. The new SPRE-CA model forecasting realistic, pessimistic, and optimistic scenarios for ZEV growth in California. Milestone years 2030, 2035 and 2050 are highlighted.

Year	Market Share - Realistic	Market Share - Optimistic	Market Share - Pessimistic	Total Market Volume	ZEV Sales - Realistic	ZEV Sales - Optimistic	ZEV Sales - Pessimistic
2020	7.57%	7.57%	7.57%	2,268,815	171,678	171,678	171,678
2021	8.52%	9.26%	8.31%	2,338,385	199,266	216,429	194,221
2022	9.57%	11.22%	9.09%	2,407,955	230,328	270,225	218,934
2023	10.70%	13.48%	9.92%	2,477,525	265,113	333,998	245,894
2024	11.93%	16.04%	10.80%	2,547,095	303,848	408,508	275,156
2025	13.25%	18.89%	11.72%	2,616,665	346,740	494,271	306,756
2026	14.67%	22.02%	12.68%	2,686,235	393,966	591,495	340,706
2027	16.17%	25.40%	13.68%	2,755,805	445,664	700,044	376,994
2028	17.77%	29.00%	14.71%	2,825,375	501,938	819,425	415,587
2029	19.44%	32.77%	15.77%	2,894,945	562,844	948,803	456,424
2030	21.20%	36.67%	16.85%	2,964,515	628,397	1,087,049	499,427
2031	23.02%	40.63%	17.95%	3,034,085	698,563	1,232,810	544,495
2032	24.91%	44.61%	19.06%	3,103,655	773,266	1,384,589	591,515
2033	26.86%	48.56%	20.18%	3,173,225	852,387	1,540,830	640,356
2034	28.86%	52.42%	21.31%	3,242,795	935,766	1,699,995	690,883
2035	30.89%	56.17%	22.43%	3,312,365	1,023,212	1,860,633	742,953
2036	32.95%	59.77%	23.55%	3,381,935	1,114,502	2,021,423	796,421
2037	35.04%	63.20%	24.66%	3,451,505	1,209,391	2,181,216	851,146
2038	37.14%	66.43%	25.76%	3,521,075	1,307,617	2,339,038	906,991
2039	39.24%	69.46%	26.84%	3,590,645	1,408,903	2,494,105	963,827
2040	41.34%	72.29%	27.91%	3,660,215	1,512,968	2,645,806	1,021,535
2041	43.42%	74.90%	28.96%	3,729,785	1,619,530	2,793,695	1,080,006
2042	45.49%	77.31%	29.98%	3,799,355	1,728,306	2,937,467	1,139,145
2043	47.53%	79.53%	30.99%	3,868,925	1,839,022	3,076,944	1,198,866
2044	49.55%	81.56%	31.97%	3,938,495	1,951,412	3,212,049	1,259,101
2045	51.53%	83.40%	32.93%	4,008,065	2,065,220	3,342,790	1,319,789
2046	53.47%	85.08%	33.86%	4,077,635	2,180,207	3,469,241	1,380,883
2047	55.37%	86.60%	34.78%	4,147,205	2,296,142	3,591,527	1,442,347
2048	57.22%	87.98%	35.67%	4,216,775	2,412,813	3,709,810	1,504,154
2049	59.03%	89.22%	36.54%	4,286,345	2,530,022	3,824,278	1,566,286
2050	60.78%	90.34%	37.39%	4,355,915	2,647,586	3,935,138	1,628,732

CHAPTER 6

CONCLUSION

Despite California's lengthy history of being on the forefront of progressive environmental policies, it today remains on the frontlines of a significant battle against climate change. To combat this challenge, one of the top priority areas will have to continue to be the transportation sector with nearly 50 percent of greenhouse gas emissions from this sector impacting the state. Changing land use patterns to encourage denser development, increasing the managed lanes systems (HOV/HOT lanes) and increasing investments in multimodal transportation will continue to be essential policy levers to adjust but more immediate impacts on air quality can be accomplished through an immediate heightened adoption of zero emission vehicles across the state.

This research confirms 3 policy areas are major factors in impacting ZEV adoption in California. Gas prices, ZEV charging infrastructure and overall vehicle cost when considering the impact of rebates, subsidies, or incentives. These major market influencers varied in level of impact—with overall cost being the most significant influencer for policy makers to continue to address to grow overall sales. The average price of a moderate luxury electric vehicle at the time of this research was $50,000, while the basic or lower range electric vehicle was $34,000 (Edmunds 2022). To reach the states goal of 5 million ZEVs sold by 2030, more shifts in policy to incentives middle to lower income families purchasing ZEVs as they enter the market will be needed. Based on the most optimistic scenarios developed through the modeling in this research, California can reach its goal of more than 1 million ZEVs sold annually by 2030 which will put it over the 5 million goal. Combined with an equitably distributed charging network to support this ZEV growth, many of the goals to reduce emissions across California can be achieved.

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APPENDIX

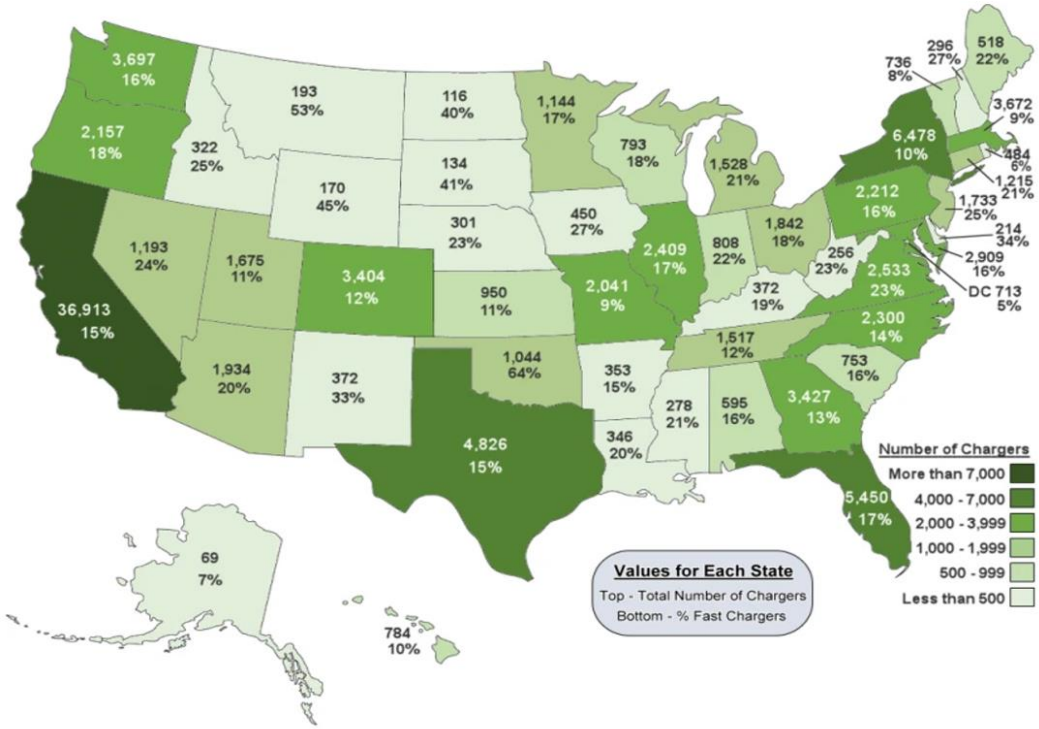

Figure 23. Total number of level 2 & fast charging units per state with share of fast charging units (March 2021-AFDB).

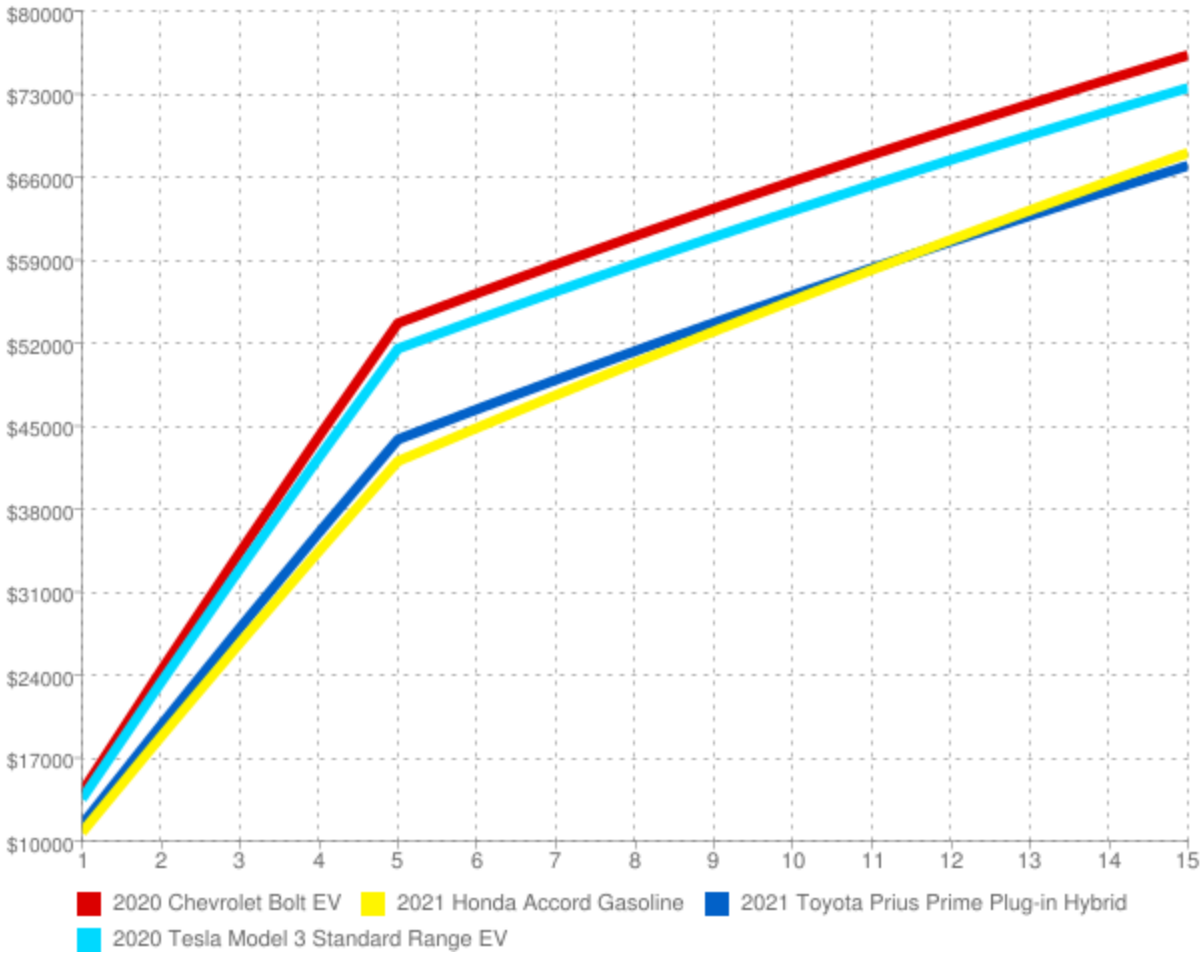

Figure 24. Cumulative total cost of ownership by year (Dollars)

Table 12. Analyzing cost of California's best-selling ZEVs to a Hybrid and Gasoline vehicle

Vehicle Type and Year	Annual Fuel Use	Annual Electricity Use	Upfront Cost	Annual Fuel/Elec Cost	Annual Operating Cost	Cost Per Mile	Annual Emissions (lbs CO2)
2021 Toyota Prius Prime Plug-in Hybrid	95 gal	1,712 kWh	$27,600	$572	$2,829	$0.24	3,269
2020 Tesla Model 3 Standard Range EV	0 gal	3,100 kWh	$35,000	$636	$2,741	$0.23	1,788
2020 Chevrolet Bolt EV	0 gal	3,479 kWh	$36,600	$714	$2,818	$0.24	2,006
2021 Honda Accord Gasoline	351 gal	0 kWh	$24,700	$814	$3,072	$0.26	8,425

Table 13. Vehicle Cost and Incentives in California (Bay Area Air Quality Management District 2018).

Rebate Programs	New EV	Used EV	EV Charging	Stackable with Clean Cars for All?
CVRP	$1,500-$7,000	No	No	Yes
CVAP	$2,500-$5,000	$2,500-$5,000	up to $2,000	No*
DCAP	$2,500-$5,000	$2,500-$5,000	up to $2,000	No**
Federal Tax Credit	up to $7,500	No	No	Yes
MCEv	$3,500	No	No	Yes
Used EV Rebate Program	No	$2,000	No	Yes
California Clean Fuel Reward	Up to $1,500	No	No	Yes

*Incentives are not stackable but low interest loans may be available.
**Incentives are not stackable but low interest loans may be available.

Table 14. Historical data of rebates through the year 2010 to the year 2020

Year	Number of ZEV sales	Number of Rebates	Total Amount	Amount Per Rebate
2010	661	135	628,050	4,652
2011	6,743	4,521	16,024,688	3,545
2012	17,839	11,219	20,191,580	1,800
2013	39,805	29,152	58,908,955	2,021
2014	58,663	43,702	90,107,319	2,062
2015	64,134	46,543	101,152,717	2,173
2016	72,683	44,455	101,265,528	2,278
2017	93,587	47,757	114,785,939	2,404
2018	157,143	73,392	173,768,338	2,368
2019	147,347	71,124	176,125,855	2,476
2020	145,099	43,628	95,760,643	2,195

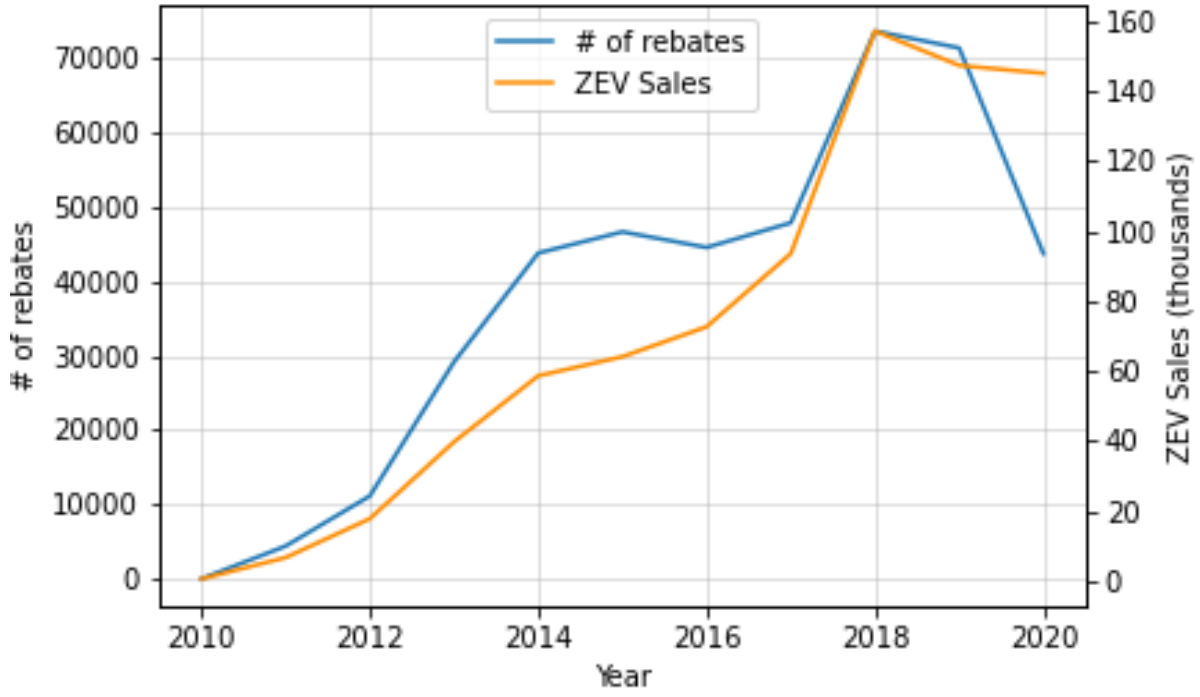

Figure 25. Relationship between the number of rebates and the yearly ZEV sales

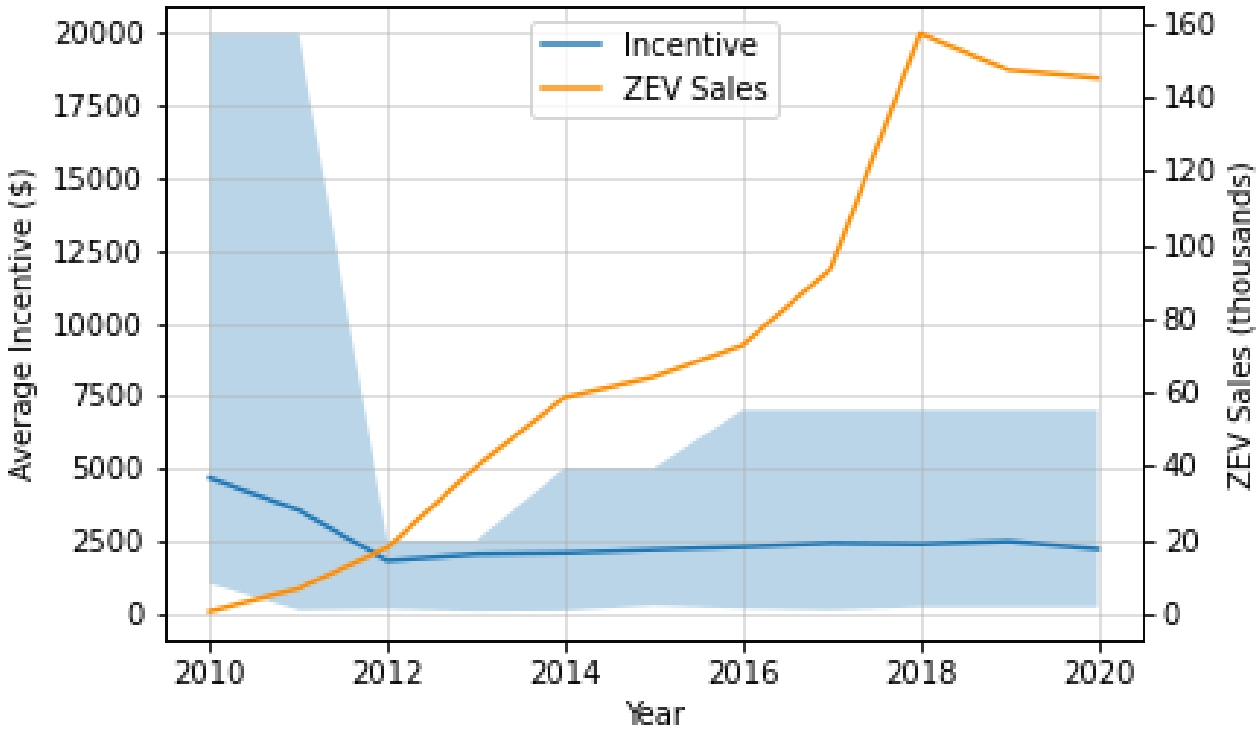

Figure 26. The relationship between the average incentives and the yearly ZEV sales

Table 15. Historical data of gas price through the year 2010 to the year 2020

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	avg
2010	3.07	2.99	3.10	3.14	3.14	3.13	3.17	3.19	3.06	3.15	3.21	3.30	3.14
2011	3.39	3.58	4.00	4.21	4.23	3.97	3.84	3.82	3.97	3.89	3.85	3.65	3.87
2012	3.75	4.03	4.41	4.29	4.35	4.13	3.82	4.11	4.21	4.46	3.89	3.63	4.09
2013	3.68	4.13	4.19	4.03	4.05	4.05	4.06	3.92	3.99	3.83	3.64	3.64	3.93
2014	3.67	3.73	3.98	4.21	4.22	4.16	4.11	3.96	3.82	3.59	3.23	2.92	3.80
2015	2.60	2.76	3.39	3.26	3.80	3.60	3.81	3.59	3.18	2.95	2.82	2.78	3.21
2016	2.82	2.48	2.68	2.82	2.86	2.93	2.91	2.75	2.80	2.86	2.79	2.74	2.79
2017	2.85	2.95	3.06	3.07	3.10	3.08	3.01	3.07	3.22	3.14	3.29	3.19	3.08
2018	3.27	3.42	3.48	3.62	3.69	3.67	3.61	3.56	3.59	3.76	3.63	3.37	3.55
2019	3.23	3.24	3.34	3.89	4.02	3.79	3.67	3.56	3.69	4.12	3.94	3.61	3.67
2020	3.49	3.45	3.26	2.83	2.77	2.97	3.10	3.16	3.17	3.14	3.12	3.14	3.13

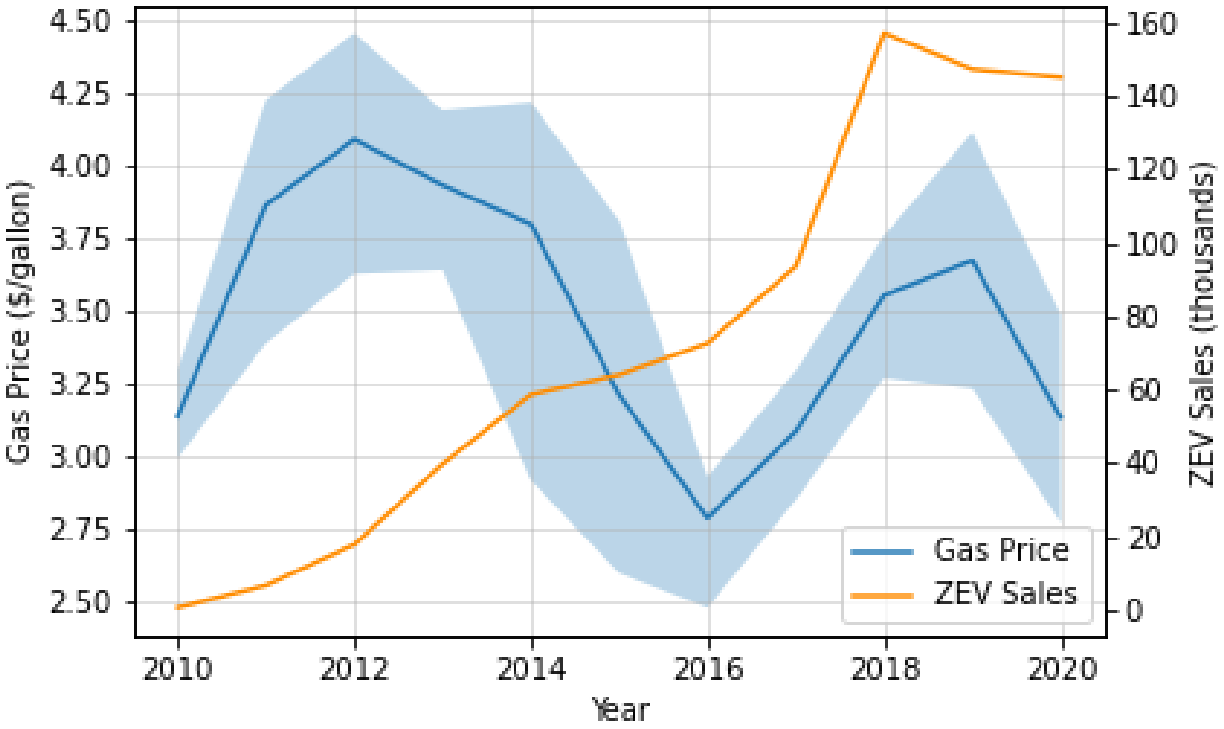

Figure 27. The relationship between the gas price and the yearly ZEV sales

Table 16. CVRP rebates issues to consumers in low-income communities from March 2010 to November 2019 (Nguyen 2020).

Year	Total CVRP Rebates Issued	CVRP Rebates Issued to Consumers in Low Income Communities	Percentage of Total CVRP Rebates Issued
2010	135	23	17.04%
2011	4,521	856	18.93%
2012	11,219	1645	14.66%
2013	29,152	4175	14.32%
2014	43,702	7121	16.29%
2015	46,543	7461	16.03%
2016	44,455	7785	17.51%
2017	47,758	9488	19.87%
2018	73,380	14426	19.66%
2019	65,009	13889	21.34%
Total	365,964	66869	Average: 18.3%

Table 17. The percentage goals to be used in the calculation of the Annual ZEV Requirement for the applicable model year (California Code of Regulations 2021).

Model Year	CA Percent ZEV requirement
2026	26%
2027	34%
2028	43%
2029	51%
2030	61%
2031	76%
2032	82%
2033	88%
2034	94%
2035	100%

VITA

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