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Accelerating California's Transition toward an Electric Transportation Sector

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Accelerating California's Transition toward an Electric Transportation Sector

submitted to
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Abstract

As the need to reduce carbon emissions becomes more urgent, electric vehicles are becoming an increasingly popular solution. Last year, California, a leader in climate policy, mandated that 100 percent of new vehicle sales must be zero emission vehicles (ZEVs) by 2035. ZEVs will rule the freeways of California eventually, but uncertainty remains in terms of when and how this shift will occur. This thesis delves into the barriers still at hand in order to accelerate and promote an equitable and effective transition to ZEVs, primarily looking at total cost of ownership (TCO), lack of adequate charging infrastructure, and slow vehicle turnover. Creating a model to estimate TCO, this thesis finds that electric vehicles (EVs) and internal combustion engine vehicles (ICEVs) will reach cost parity this year for some models. Used vehicles are expected to achieve price parity between EVs and ICEVs by 2029, while it is anticipated that price parity for new vehicles will be reached after 2030. Finally, it evaluates and recommends policy options for California, concluding that charging infrastructure investment should be a top priority.

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1. Introduction

Overwhelming evidence exists that the planet is warming, largely due to human activity, specifically the burning of fossil fuels. Global surface temperature has increased faster since 1970 than in any other 50-year period over the last 2,000 years. Carbon dioxide concentrations in the atmosphere today are higher than at any point in human history, and global carbon dioxide emissions increased by over 50 percent in the last 30 years (IPCC 2022).

Anthropogenic climate change has likely driven the increase of many weather and climate extremes, including heat waves, floods, heavy precipitation, droughts, and tropical cyclones. These events are damaging to both nature and people. The continued consequences from human emissions are potentially catastrophic, including further environmental destruction, loss of biodiversity, displacement of communities, and increased threats to food and water security. With every increment of warming, these risks increase. Further complicating the issue of climate change is the fact that it disproportionately affects communities that contribute the least to the problem.

In order to best mitigate the consequences of global climate change, warming should be limited to two degrees Celsius (IPCC 2022). In order to reach this goal, a state of net zero carbon emissions must be reached. This requires immediate carbon dioxide emission reductions in all sectors.

As of 2020, the transportation sector contributed the most to total US greenhouse gas emissions, accounting for 27 percent of all emissions. In California, that number is even higher, nearly 50 percent of the state’s greenhouse gas emissions are accounted for by the transportation sector (CEC n.d.).[1] Within transportation, 57 percent of emissions are attributed to light-duty or passenger vehicles (EPA 2022).

Nationally and globally, California has positioned itself as a leader in climate policy in the past decades. The state has the largest economy in the US and the fifth largest in the world (Wrinkler 2022), and with a strong tech and innovation sector, it has the ability to create demand for clean technologies. California has a history of leadership in terms of progressive climate standards and policies: the state banned leaded gasoline in 1985 and passed the Global Warming Solutions Act in 2006. As of 2016, California has successfully decoupled greenhouse gas emissions and economic growth (Saha and Muro 2016). While it only contributes to one percent of total global carbon emissions (Lopez 2022), California is poised in terms of its soft power and influence to develop and promote climate policy that will have broad-reaching impact. How California's transportation sector moves away from reliance on gasoline will affect policy in other states and nations.

California, and especially the Los Angeles area, is distinctive in terms of transportation. A vast majority of Los Angelenos use private vehicles to get around: 78 percent of people commuting to work are driving alone, while only six percent use public transit (Our County 2018).[2] Public transportation on average makes a commuter's trip to and from work twice as long. This reliance on driving can be attributed to Los Angeles' development in the 1960s, which was built around the automobile. Freeways replaced the streetcars; then they facilitated the growth of suburbs and encouraged additional low-density development. Urban sprawl, low-

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[1] This is higher than US average because it accounts for the carbon emissions coming from electricity sources. Also, California has more clean energy overall than other states so less carbon emissions from other sectors and more from driving in comparison.

[2] This percentage has decreased during the COVID-19 pandemic and struggled to regain riders since (Goldberg 2021).

density development, and a lack of centralization became a reinforcing feedback loop. Although the city attempts to improve public transportation,[3] it is not a realistic or viable option for many. Thus, the culture of personal vehicle use is maintained. Policy can be enacted to reduce incentives for driving and incentivize biking, public transport, and other forms of micro-mobility, but Los Angeles is unlikely to become a mass transit dominated city, such as New York. The geography and existing structure remain a barrier. With roughly half of its population living in the Los Angeles area (US Census Bureau),[4] California's strategy to reduce transportation emissions in the state will have to effectively target this region in order to be successful.

In 2022, around 20 percent of all new cars sold in California were "zero-emission vehicles" (ZEVs), which include battery-electric (BEVs or EVs), plug-in hybrid, and fuel-cell electric vehicles.[5] The market has grown considerably, from around 8 percent in 2019. California leads the nation in terms of sales: around 40 percent of all US new ZEV sales were made in the state, and ZEVs are already California's second-largest global export market (Veloz 2023). The state has high ambitions; it aims to phase out sales of all new internal combustion engine passenger cars by 2035. Governor Gavin Newsom outlined this goal in September 2020 with an executive order that requires sales of all new passenger vehicles to be zero-emission by 2035. These are the most aggressive transportation regulations in the US.

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[3] Los Angeles invests more in public transportation than any other city in the country (Goldberg 2021).

[4] This includes Orange County, Riverside County, San Bernadino County, and Ventura County as well as Los Angeles County.

[5] It is important to note that this term does not technically mean these vehicles release zero carbon dioxide emissions throughout their lifetimes. Plug-in hybrid vehicles use both gasoline and electricity as fuel sources. Producing the electricity needed to charge an EV can also contribute to carbon emissions.

Shortly after Newsom’s executive order, California’s Air Resources Board passed the Advanced Clean Cars II rule that amended California’s Zero-emission Vehicle Regulation. The new regulations require an increasing number of ZEV sales starting in 2026, and guide the state to 100 percent of new car sales being ZEV in 2035.

California’s Air Resources Board, or CARB, is the state agency responsible for implementing and enforcing air pollution control and public health protection programs. Established in 1967, CARB is one of the oldest and most comprehensive state air quality agencies in the country. CARB's mission is to promote and protect public health, welfare, and ecological resources through the effective and efficient reduction of air pollutants while recognizing and considering effects on the economy. To achieve this mission, CARB has the authority to adopt and enforce regulations that control various sources of air pollution, such as transportation. They introduced the ZEV mandate in the 1990s, when a regulation was enacted that required automakers to start phasing them in, and mandated that ZEVs make up 10 percent of automakers’ overall sales by 2003. Strongly opposed by the automobile and oil industries, the regulation was weakened after a few years. However, support has grown considerably since then; in 2012, with lower battery costs, increased awareness of climate change, and the success of early EV models like Tesla's Model S, a stricter mandate was adopted.

The current mandate outlined has built upon iterations since then. All ZEVs will count toward the percentage of EV sales required of the manufacturer. However, plug-in hybrids (PHEVs) can only make up 20 percent of the automaker’s sales, given that these are partially gas-fueled vehicles. The regulation exempts small manufacturers until 2036 since these manufacturers account for only two percent of sales combined. All EVs must be made to have a minimum range of 150 miles before they have to recharge, in order to count for a credit. PHEVs must have an electric range of 50 miles by 2029. The mandate also simplifies the credit market allowed in the ZEV requirement. The credit market has previously permitted manufacturers to buy, sell, or bank (for future years) their credits in order to meet their requirements. Formerly, different ranges or considerations of vehicles would qualify them for different numbers of credits. Now, all ZEVs receive one credit. However, automakers can earn extra credits if they target low-income households. If they sell a ZEV at a 25 percent discount to a community-based carsharing program, sell low-cost (under $40,000) ZEVs at any discount, or sell a ZEV that is baseline less than $20,275, they can receive from 0.1 up to 0.5 extra credits. Only five percent of the requirement can be met with these extra credits. Although, the credit options and market will all phase out after 2035.

Figure 1 below shows the proposed ZEV market share requirements and an estimate of these requirements adjusted for flexibility in carryover credits and environmental justice, as calculated by Tal and Davis for the Institute of Transportation Studies at UC Davis (2022).

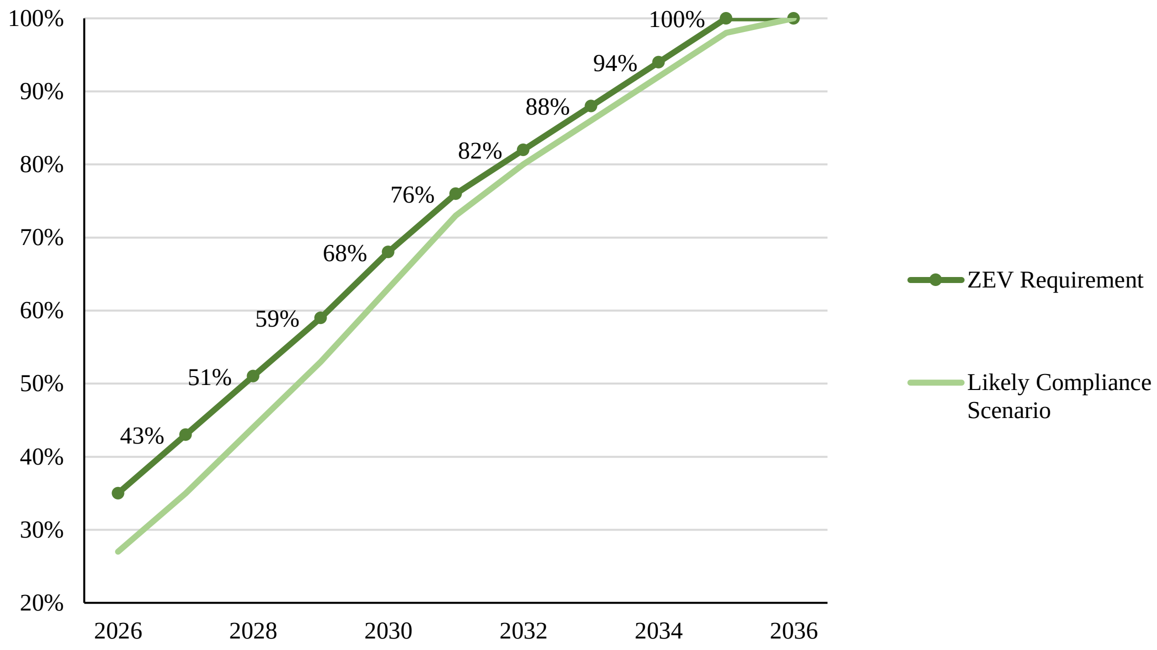

Figure 1. CARB ZEV mandate requirements up to 2036 and adjusted estimate (Tal and Davis 2022).

Other states may end up adopting this mandate for themselves. Since 1977, the US Clean Air Act allowed other states to follow California's emission standards instead of the US EPA standards. Fourteen states have adopted previous versions of California's ZEV regulations from 2012. With this new regulation extending beyond the state of California, the impacts could be immense.

This thesis will analyze and promote California's transition to an electric-powered transportation sector. It will discuss the barriers to the success of the above mandate and adoption of EVs, mainly the high cost, lack of infrastructure, and slow overall fleet turnover. Next, the thesis will delve deeper into the cost barrier of EVs in order to explore how and when they can be adopted in mass numbers. A model is developed in order to estimate when EVs will reach both cost and price parity with their ICEV counterparts, with a particular focus given to analyzing the used vehicle market. The resulting implications and need to accelerate the adoption will lead the thesis to its final section, discussing policy aimed at promoting the adoption of EVs. The thesis will conclude by providing policy recommendations for California and offering a perspective on the implications for the EV transition in other states and at the national level.

Overall, the thesis takes a comprehensive approach to the transition to electric passenger cars, focusing on the questions of when and how this transition can occur in a more equitable and effective manner, rather than whether it will happen. The remarkable improvements in electric vehicle technology since California's first ZEV mandate suggest that it is only a matter of time before these vehicles become the dominant mode of transportation. However, there are still uncertainties regarding the timing, equity, and strategies for accelerating the transition, which are the primary focus of this thesis.

2. Barriers to Adoption

The transition to electric vehicles is inevitable (Sperling 2018). The questions remain: how fast and equitable will this transition be? How might it be accelerated? Even with a ZEV mandate in place, California’s shift to entirely electric passenger cars does not follow a straightforward path.

In 2035, when California mandates all new vehicle sales are electric or zero-emission vehicles, the majority of vehicles on the freeways in Los Angeles will still run on gasoline. A full transition to all electric vehicles will take years to materialize, as older ICEVs will still be on the road well past 2030. Furthermore, if other states or the national government do not follow California’s example, other states with manufacturers still selling ICEVs may diminsh the success of the mandate, as those unwilling to purchase an EV can just hop across the state border to buy an ICEV.

Slow Fleet Turnover

Fleet turnover lags new car sales considerably. An analysis of fleet turnover shows that if new vehicle sales are 100 percent electric by 2035, by 2050, 95 percent of vehicles on the road will be electric (Plumer, Popovich, and Migliozzi 2021).[6]

This lag period is large because conventional gasoline-powered cars last a long time on the road – and are only lasting longer with advances in technology. The average age of a passenger car or light-duty truck in the US is now over 12 years, up from 9.6 years in 2002 (Parekh 2022).[7] Low-income households with an annual income below $25,000on average have cars that are four years older than households making over $150,000 a year (Bauer, Hsu, and Lutsey 2021). A new ICEV sold in 2034 may be in commission and emitting carbon into the atmosphere well into the 2050s.

Most cars are purchased used. Used car sales totaled almost three times more than the sales of new vehicles in the past ten years (Experian 2022). Only 33 percent of low-income households’ vehicle purchases and 50 percent of high-income households’ vehicle purchases are new vehicles (Bauer, Hsu, and Lutsey 2021). EVs have yet to catch up with ICEVs in the used market. 89 percent of 2016-2020 model year EVs are still registered by their first owner, as compared to 68 percent of gasoline vehicles for those same model years (IHS Markit 2021).

Cost of Electric Vehicles

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[6] However, this model did not allow hybrids or other types of ZEVs besides EVs in their hypothetical mandate, which California has.

[7] This average has also grown in recent years due to supply chain and inventory issues arising from the COVID-19 pandemic.

Today, many are open buying an EV. Around 35 percent of Americans state they plan on or are “seriously considering” buying an EV. An additional 35 percent “might consider” switching to an electric vehicle. The 28 percent that does not plan on going electric cite a lack of charging infrastructure, range anxiety, and cost as their objections (Tucker 2022). These concerns hinder widespread adoption.

The most cited barrier to adoption is the cost of EVs. EVs still have a much higher sticker price than most ICEVs. In 2022, the average price of an electric vehicle was $61,488 compared to $49,507 for all passenger cars (St. John 2023). However, this is mainly because luxury cars make up a large portion of the EV market – such as Tesla’s luxury models, Ford’s electric version of the F-150, and Rivian’s $73,000 R1T. Almost 80 percent of EV sales are at luxury prices while on average only 17 percent of the gas combustion car sales are luxury purchases (St. John 2023). Prices are getting comparable, but even the cheaper EVs – like last year’s $27,400 Nissan Leaf - are more expensive than the ICEVs; Nissan’s Altima was priced about $3,000 less. Used EVs also tend to be more expensive than their gas counterparts. This price point makes EVs out of touch for many lower-income drivers, as households with incomes below $75,000 spend on average 20 to 50 percent of their total income on owning a car.

Arguably, EVs are said to save enough money in operating costs, such as gas and maintenance, that make the total cost of ownership cheaper for EVs than ICEVs. But many estimates of the total cost of ownership show different results and uncertainty. Even if this was the case, a higher purchase price point for both used and new cars make EVs out of touch for many lower-income consumers, who cannot financially afford large upfront costs.

Subsidies are often used to incentivize and promote the adoption of electric vehicles. However, if these subsidies do not have income caps in place, they can be distributed unevenly and potentially benefit high-income individuals who were already planning to purchase an expensive EV even without the subsidy.

California and the federal government both have subsidy programs in place to help promote EV adoption. Consumers can receive up to $7,500 from a federal tax credit and California offers $7,000 to those with an income under $135,000. Used vehicles are also now eligible for a portion of the federal subsidy. California's rebate is only offered to new vehicles. California also only now offers a subsidy to vehicles under a purchase price of $55,000.

Lack of Charging Infrastructure

Insufficient charging infrastructure is a concern for consumers and a significant obstacle to achieving higher levels of EV adoption. Considerable investment is necessary to both promote and support EV adoption levels. California has outlined a goal to complete a 6,600-mile statewide charging network and deploy 1.2 million chargers by 2030. It invested $2.9 billion last year for the cause, 30 times what it previously invested in 2019. California additionally will be spending federal infrastructure funding on electric charging infrastructure. California's Deployment Plan for the National Electric Vehicle Infrastructure or NEVI Program, approved by the U.S. Office of Energy and Transportation in September of 2022, will receive $56 million in funding for infrastructure, through the Federal Infrastructure Investment and Jobs Act of 2021. Yet, the issue of funding for public charging stations in California is not resolved. Sustained and equitable funding is needed. Recently, a proposition to generate between $3.5 and $5 billion every year to help with charging stations by taxing those making over $2 million, was stopped. [8]

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[8] The California ballot proposition 30 would have raised the income tax on Californians making over $2 million, in order to pay for EV rebates, charging stations, and wildfire prevention. It would have raised between $3.5 billion and $5 billion every year. Around 80 percent of the money would have been

The amount of funding and investment needed to support existing EVs is one of the main obstacles that must be overcome for a successful transition to EVs.

Energy Demands

The energy grid in California needs to be ramped up. Ironically, only six days after CARB finalized their ZEV regulations last August before it ultimately passed in November, there was a massive heat wave, causing an unprecedented, 10-day emergency alert that warned residents to cut electricity use or face outages. Almost 15 times more electric cars are expected on California's roads by 2035. With the additional electricity needed, power capacity will need to increase by three times what it is today. Renewable energy provided only 36 percent of the state's power supply so far this year. The state plans to expand that – to 100 percent clean energy by 2045. An analysis shown by CARB models the clean energy demand and showed that a high pace of construction is needed - six gigawatts (GWs) annually for the next 25 years (Gill 2021). If California does successfully transition to EVs without upgrading its grid to clean and renewable energy, the benefits and possible decrease in carbon emissions would be negated because EVs would simply generate carbon emissions when electricity is produced at the power plant level.

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spent on incentives for individuals buying zero-emission cars and building more charging stations. Half of this funding would have been directed toward low- and middle-income residents. The proposition had majority support until Governor Gavin Newson unexpectedly made a sharp opposition to it. The proposition in November failed to pass, with 59 percent voting no. Lyft was a huge supporter of the proposition because under new California state law, is required to have 90 percent electric vehicles. Governor Gavin Newson capitalized on this and made ads calling Prop 30 "a cynical scheme to grab a huge taxpayer-funded subsidy" for a plan "developed by a single company to funnel state income taxes to benefit their company" (Mitchell 2022).

There are many potential roadblocks to a successful transition to an electric-powered transportation sector. The rest of this thesis will look specifically at the barriers of cost, lack of infrastructure, and slow fleet turnover, through estimation and policy evaluation.

3. Model of Total Cost of Ownership

In order to look at one of the main barriers to EV adoption among consumers, this thesis develops an economic model to estimate and compare the total cost of ownership between an EV and an ICEV, specifically for those purchasing a used vehicle. As stated above, fleet turnover will be tied to the used vehicle market and thus, it is extremely important to assess the total cost of ownership for those buying used vehicles as well as new ones.

Numerous studies have attempted to estimate the total cost of ownership (TCO) for EVs in comparison to ICEVs. However, this has proven to be challenging due to the various assumptions that are involved, including projections on future battery costs, increases in gas prices, electricity prices, and estimated depreciation values. Despite the typically higher purchase price of new EVs compared to ICEVs, some studies have shown that operating costs, especially in states like California where gas prices are high and maintenance costs are expensive, are significantly lower for EVs (Harto 2020). As battery prices decrease and manufacturers benefit from economies of scale and learning by doing, the purchase price of EVs is expected to decline, while operating costs will continue to remain lower than ICEVs. CARB analysis indicates that EVs are likely to reach cost parity with conventional vehicles by 2030 and that by 2035, consumers are likely to save up to $7,900 in operating costs over the first 10 years of ownership. They claim owners will also see 10-year savings from 2026 model-year battery-electric vehicles, though not quite as much (CARB, 2022).

The question this model attempts to examine is when and how cost parity will be achieved between the two. Several studies suggest that EVs will reach cost parity with ICEVs anytime between now and 2030 (Chakraborty et al. 2022, Harto 2020, Bauer et al. 2021).

3.1 Literature Review

Bauer et al. (2021) examined when lower-income households will benefit from transitioning to electric vehicles. They found cost parity for low-income households achieved by 2025. By 2029, EVs reach upfront price parity with the average vehicle purchased by a low-income household, less than two years after the average vehicle purchased by a high-income household. However, Chakraborty et al.'s (2022) study of California's transition to electric vehicles does not achieve cost parity for most households until 2030. An additional study (Parker et al. 2021) considered the difference in TCO calculations based on variations in electricity rates and other dissimilarities. It can vary by a factor of 1.2. They find that median costs of ownership are usually higher for EVs but buying an EV will save money for approximately 17 percent of households. Finally, an overarching view on the forecasting of TCO explores the many different implicit assumptions behind models (Velzen et al. 2019). They outline that the frequently overlooked profit margin is a significant factor. Many EVs are produced at a loss right now for the manufacturer, and when automakers attempt to scale back up and make more of a profit, prices of EVs may not decrease as much is otherwise shown. They state sometimes this means that TCO is not lower for EVs. Chakraborty et al.'s study does include this assumption in their model.

The Chakraborty et al. study and the Bauer et al. study both provide valuable insights for the following model, with the former focusing specifically on TCOs in California and the latter examining TCO projections with used vehicle prices.

This model presented in this thesis aims to predict TCOs for EVs and ICEVs, for those purchasing a used vehicle, for 2023, 2025, and 2030, in order to understand the transition for consumers to EVs, and further, when EV sales will reach the used car market. The second part of Chakraborty et al.'s study attempts to estimate the distribution of TCOs among different income levels. However, the model only accounts for new car purchases, which may not be a realistic assumption, since many lower-income individuals tend to purchase used vehicles and pay in cash or other non-loan forms of payment (Pierce et al. 2020).[9] This analysis is not an accurate representation of these households and individuals. On the other hand, Bauer's study only considers a 2020 model vehicle for years up to 2030, which may also be problematic for estimates of a total cost of ownership, when they assume a ten-year car is purchased. Ten years is not the average age of a car purchased for any income group. The model below uses a car age of five years, as Chakraborty et al. (2022) does, to easily compare results and to be consistent with the purchase behavior of low-income groups. On average, those with a household income under $75,000 purchase a vehicle that is 5.5 years old (Bauer et al. 2021).

TCO estimates are still very uncertain. To address this uncertainty, it is crucial to continue building models and conducting research to assess how projections are shaping up and to make necessary adjustments to the models.

3.2 Model framework

In this section, a model framework for TCO is outlined. These equations follow, for the most part, from the TCO model framework from Chakraborty et al. (2022), and Lutsey et al. (2021). They are adjusted slightly for different assumptions mentioned above. The reasons for this are 1)

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[9] Adequate loan programs or loans in general prove difficult to obtain for this demographic.

these were the most updated and relevant models available and 2) this makes the results more comparable.

Two different powertrain technologies are analyzed: battery electric vehicles (BEVs) and internal combustion engine vehicles (ICEVs). Three classes of EVs, short, medium, and long range are analyzed.[10] Compact and mid-size ICEVs are assesed.

The overall total cost of ownership of a vehicle with powertrain technology, p, and class, c, is calculated using the following equation;

$$TCO_{p,c} = CC_{p,c} + OC_{p,c} \tag{1}$$

Where;

$CC_{p,c}$ = capital costs of a used five-year-old vehicle. This is the main difference in assumption from the model presented by Chakraborty et al. The total cost of ownership calculated in this equation for all the vehicles assumes owners purchase a five-year-old vehicle. The cost of a charger installation is also combined to develop overall capital costs. Registration is not included because the used vehicle registration costs are minimal and relatively similar across powertrain technologies.

$OC_{p,c}$ = operating or recurring annual costs.

The operating or recurring costs are calculated by the following equation;

$$OC_{p,c} = \sum_{n=1}^{N} \frac{FC_{p,c} + MT_{p,c,m}}{(1+r)^n} \tag{2}$$

Where;

$FC_{p,c}$ = fuel or electric costs for different powertrains, classes.

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[10] These ranges are as follows: 150, 200, and 250 miles.

$MT_{p,c,m}$ = maintenance costs, based on powertrain, class, and mileage.

r = discount rate, standard, 3 percent.

These values are summed and represented in present value accounting for the number of years (n) they are occurring this cost. The model accounts for vehicle ownership costs for five years. This equation does not account for insurance costs, as these are assumed to be relatively similar across powertrain technologies.

Fuel or electric costs are based on the following equation;

$$FC_{p,c} = p\left(GP \cdot \frac{m}{MPG}\right) + (1-p)\big(\alpha(EP_{home} \cdot EE_c \cdot m) + (1-\alpha)(EP_{pub} \cdot EE_c \cdot m)\big) \quad (3)$$

Where;

p = a binary value for an EV (0) or ICEV (1).

GP = projected annual gas price, in dollars per gallon.

m = annual vehicle miles traveled.

MPG = fuel efficiency in terms of miles per gallon of gasoline.

α = proportion of annual charging at home versus using a public DC fast charger, based on vehicle range.

EP = electricity price at home ($home$) and at public fast chargers (pub).

EE = electric efficiency in terms of kilowatts (kWh) per mile.

3.3 Data & Methodology

Capital Costs

To calculate the purchase price of a five-year-old vehicle in the years 2023, 2025, and 2030, two different methods were used. In the year 2023, data from Kelley Blue Book was consulted. The value is the average of the private party and trade-in values of a five-year-old

(2018) vehicle[11] in "very good condition", with standard trim and equipment, and with an annual mileage of 12,000 located in the San Francisco area (zip code 94115). Table 1 presents this value as a percentage of the 2018 vehicle manufacturer's suggested retail price (MSRP) as the 2023 resale value.

2023 Resale Value of a 2018 vehicle	BEV Short	BEV Mid	BEV Long	ICEV Compact	ICEV Midsize
	43%	42%	59%	79%	62%

Table 1. Percentage resale value of a 2018 vehicle in 2023.

In order to calculate projections for future resale values, it was assumed that the depreciation in the value of BEVs will be equal to the depreciation of ICEVs by 2030, reflecting BEV preference that is similar to ICEVs in the used car market, as was outlined in Bauer et al. (2021). Depreciation is typically higher for BEVs currently simply because of the technological improvements that rapidly improve EVs. A baseline of a 50 percent depreciation rate for a total of five years was used, as did Chakraborty et al. (2022). While the findings in Table 7 reflect that the ICEV resale value rates are considerably higher than 50 percent, these values can be attributed to the effects of the COVID-19 pandemic and supply chain shortage on used car demand. The resale values of used ICEVs considerably increased after the pandemic, even when EV resale values remained similar to what they were prior to the increased demand (Bauer et al. 2021). Therefore, for model simplicity and to depict a version of the differences between TCO not skewed by the supply chain shortage, a depreciation rate of 50 percent is used for ICEV

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[11] The models used are as follows:
BEV Short: Nissan Leaf.
BEV Mid: Chevrolet Bolt EV.
BEV Long: As this year and class combination was not available, a value was used for a comparable passenger truck, Kia Niro EV, Hyundai Kona EV. This was also done by Chakraborty et al. (2022).
ICEV Compact: Honda Civic, Toyota Corolla.
ICEV Midsize: Nissan Altima, Toyota Camry.

models, again following Chakraborty et al. (2022). However, this should be noted as a limitation of the model.

These depreciation values combined with present data and future projections on purchase price from the Chakraborty et al. study give values for purchase price of a five-year-old vehicle in 2023, 2025, and 2030 (Table 2).

	BEV Short	BEV Mid	BEV Long	ICEV Compact	ICEV Midsize
2023 Resale Value of a 2018 vehicle	$12,909	$15,845	$21,825	$8,022	$10,274
2025 Resale Value of a 2020 vehicle	$10,903	$13,989	$19,389	$8,454	$10,481
2030 Resale Value of a 2025 vehicle	$9,867	$11,679	$17,168	$10,274	$11,911

Table 2. Purchase price of a five-year-old vehicle

A standard value for a Level 2 charger, as calculated in Chakraborty et al., was added to all prices to total capital costs.

Operating Costs

The maintenance cost values are cents per mile for under and over 100,000 miles. This data was obtained through a Consumer Reports survey on the average annual costs (Harto 2020). The proportion of charging done at home versus the public DC fast chargers is also obtained through this study. Fuel efficiency projections for ICEVS are based on Corporate Average Fuel Economy (CAFE) standards, as calculated in Chakraborty et al. (2022). Retail gasoline prices are projected from California’s 2023 average (EIA 2023) and projected in accordance with the extrapolation of the Chakraborty et al. study through 2030. The cost of electricity is an average of the “off-peak rates” of the three energy providers in California: Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDG&E), and Southern California Edison (SCE). The projections of electricity costs through 2030 were also informed from the Chakraborty et al. study. An annual mileage of 12,000 was used. Thus, an annual fuel cost was calculated for each vehicle and class. The present value of the sum of all fuel and maintenance costs was then calculated.

It is also important to note that the model only outlines price and costs for battery EVs (BEVs), and not plug-in hybrid EVs, or any other ZEV. This was for simplicity and comparison reasons.

3.5 Results

The model showed that the total cost of ownership of EVs will reach total cost parity with ICEVs this year when comparing a BEV short range to a compact ICEV (Figure 2), even though price parity is not reached until 2029 (Figure 4). In 2024, a midsized ICEV will match cost parity of a mid-range BEV. After this year, a short-range BEV becomes the cheapest vehicle in terms of total cost of ownership. By 2030, the BEV short and mid ranges are the cheapest cars to own and a BEV long will be about to reach TCO cost parity with the ICEV mid. However, while a used short-range BEV will have a cheaper purchase price than a compact ICEV by 2029, a new short-range BEV and a compact ICEV will not reach purchase price parity before 2030. Due to factoring in profit margin in purchase price projections, as mentioned in Velzen et al. (2019), purchase price of a new EV may increase by 2030 (Figure 4).

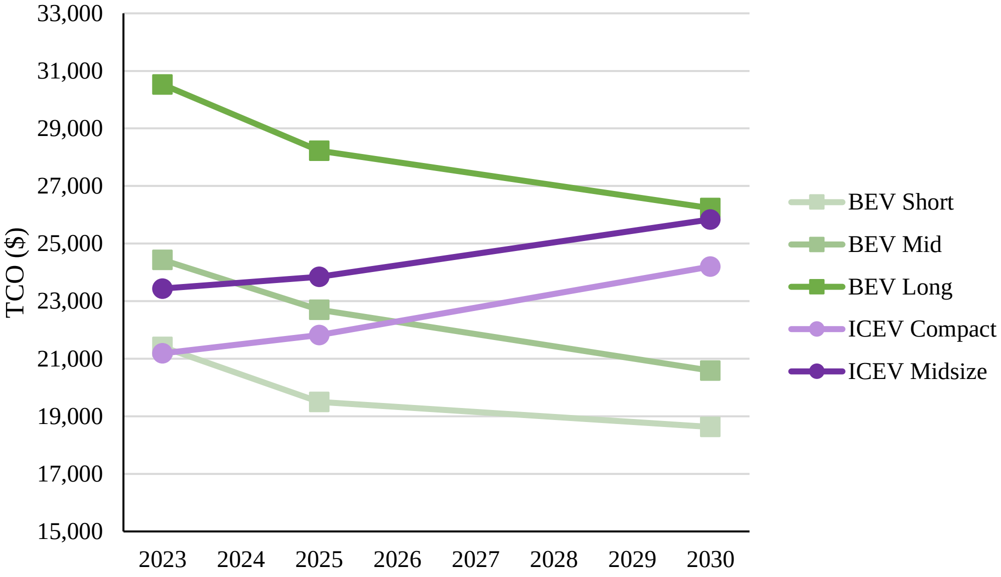

Figure 2. The total cost of ownership of different vehicle powertrain technologies and classes in dollars (2023-2030).

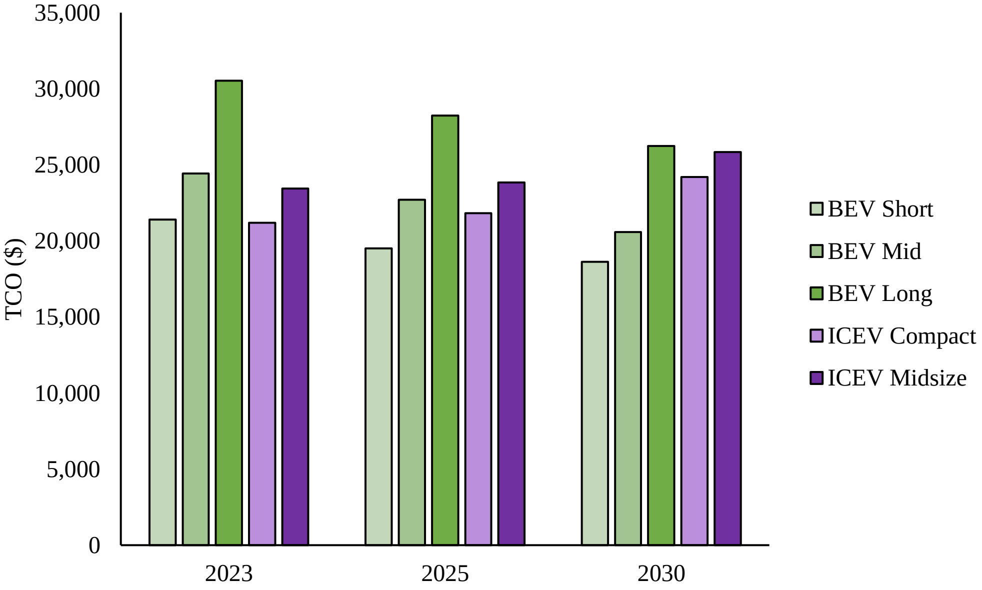

Figure 3. The total cost of ownership of different vehicle powertrain technologies and classes in dollars (2023-2030).

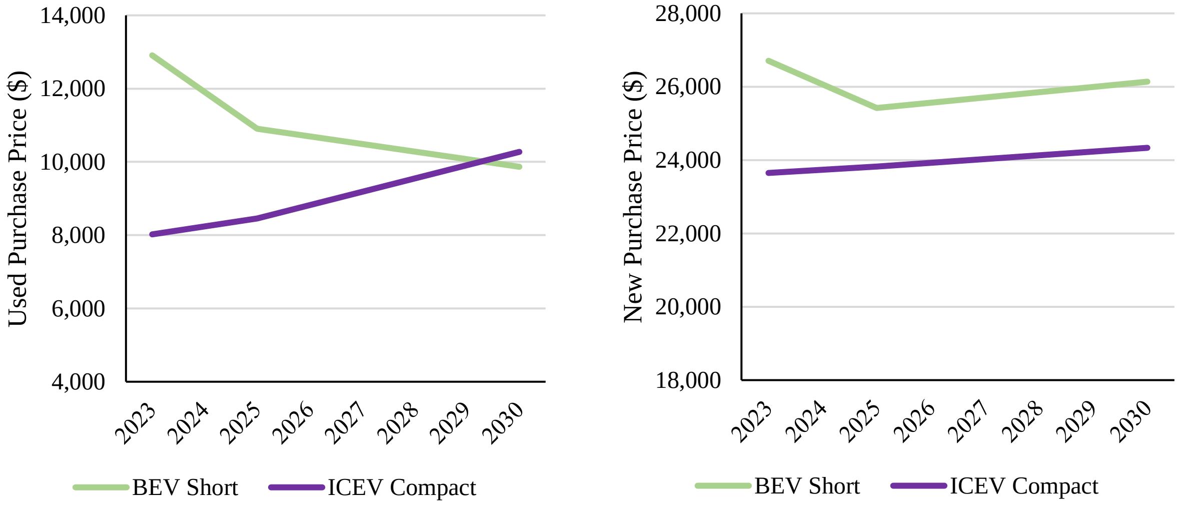

Figure 4. The purchase price of both used (five-year-old) and new vehicles for a short-range BEV and a compact ICEV (2023-2030). Note the scales of purchase price are different.

3.6 Discussion

This finding demonstrates that it is cost-effective on a total cost of ownership basis for a consumer, who is purchasing a used vehicle, to purchase an EV instead of an ICEV, in many cases. This should help to ease the barrier of cost for any Californian. However, some consumers will react just to purchase price points rather than changes in savings (Tal et al. 2022), in which case, these findings would indicate and explain a lack of push toward EV adoption until 2030 for used car vehicle purchases, and much past 2030, for new car vehicle purchases.

4. Policy Evaluations and Recommendations

Charging Infrastructure Investment

Charging station subsidies and investments are discussed below as policy levers that can stimulate charging station supply. Other interventions examined can correct additional market failures in charging infrastructure.

California will need to significantly increase infrastructure in order to support widespread uptake of EVs. Furthermore, the lack of charging infrastructure is cited as a key issue as an impediment for adoption of EVs, so an increase in infrastructure should increase purchase decisions by those who are already interested in driving an EV. Multiple studies have shown that charging infrastructure significantly increases EV adoption (Hall and Lutsey 2017, Bauer et al. 2021).

The market failure previously associated with charging infrastructure was a chicken and egg problem: the lack of EVs on the road made firms or stakeholders less interested in investing in charging infrastructure, and the less infrastructure that is available, the fewer people want to adopt EVs.

An additional market failure that arises and prevents optimal charging infrastructure is the incompatibility of different charging stations with different EVs. Currently, Tesla's supercharger network is the superior network – and mostly only available to Tesla owners. The next largest network, as of 2021, is only 10 percent relative to Tesla. There are three Tesla superchargers for every two chargers from other companies (Gardiner 2023). Driving from San Francisco to downtown Los Angeles in a Tesla will take eight hours with two charging stops. That same trip will take nine hours in a Chevrolet Bolt with three stops and a longer wait time given the lack of fast chargers (Gardiner 2023). This is inequitable; lower-income individuals and households who have cheaper EVs or are considering EVs are unable to reap the benefits of this infrastructure.

Recently, the federal government opened funding available for charging infrastructure, which will push Tesla into opening a portion of its charging network to other EVs. However, this still would not be ideal - all is the optimal amount. If charging infrastructure provided by a network is in any part exclusively for their vehicles, all firms may overbuild their network relative to the social optimum by creating duplicative investments (Rapson and Muehlegger 2021, 11).

A California legislator is pushing a bill to require all new public charging stations to be open to anyone. In theory, this would correct this market failure, and the result would be a plethora of charging stations, similar to gas stations today, where the market and competition would interact with firms to determine pricing and further investment.

The policy intervention here would be to mandate and require compatibility in public charging stations. Tesla could still make money off selling electricity but Tesla owners (typically representative of the higher-income EV owners) would not be the only ones internalizing the benefits from networks.

Charge point operators currently experience heavy initial capital expenditures, low utilization rates, and little revenue (PWC n.d.), so this challenging business model does not garner many firms’ investments.

This gap needs to be filled by the government. This policy can be in multiple ways, through charging station subsidies or through direct investment to install publicly accessible chargers. One study conducted by Zunian Luo (2022) analyzed the effectiveness of charging station subsidies. The study revealed that a one percent increase in subsidies leads to a 2.5 percent expansion in the supply of charging stations.

An estimate of the overall costs needed to establish infrastructure for the ZEV mandate looks at the least expensive pathway, providing mainly slower or Level 2 (L2) charging, and providing enough DC fast chargers (DCFCs) in order to support long distance travel for BEVs. Analysis by Davis et al. finds that minimum charging needs for public chargers are 1.9 million by 2035 - an increase of 12 to 24-fold from current amounts (2022). These charger installation costs will total $20 million between 2022 and 2035 – averaging about $1,580 per vehicle. Given the substantial amounts already being invested by the federal government, various states, and private enterprises, the costs, though significant, are not excessively high. This estimation further emphasizes the need for governmental intervention and investment.

DCFCs are the fastest option for charging and may be essential in order to improve the charging infrastructure that would likely pull drivers to switch to an EV. Moreover, this is particularly important for individuals who live in multi-dwelling units or other areas where it may not be possible to install an L2 charger at home. Without an adequate number of DCFCs, the transition to electric vehicles may be delayed for these groups. However, more widespread access to these chargers would help to promote greater equity in the transition to EVs.

Looking at DCFC infrastructure costs and challenges in California, a study from the Institute of Transportation Studies at UC Davis concluded that there are significant variations in the full project cost of installation and commission of DCFCs in proposed sites. These locations were most effective along corridors and in places where ZEV charging does not currently exist. They found costs ranged anywhere between $122,000 and $440,000 each, mainly due to location-specific costs. This estimation, is higher than previous literature that they found, citing the need to further increase infrastructure funding. Private networks will have limited incentive to build chargers in such locations that they deem unprofitable. Another note from the study is that these also may become cheaper with increased technology (Gamage, Tal, and Jenn 2023). Additional policy suggestions mentioned include encouraging working with local electrical utilities early in the stages of DCFC planning (Gamage, Tal, and Jenn 2023), to diminish costs.

Furthermore, infrastructure may be more effective than EV subsidies as a policy intervention. A study in 2022 shows that when measuring between subsidies for EVs and charging infrastructure investments, there is variance when there are different technological assumptions (Ledna et al. 2022). The study attempts to estimate the tradeoffs between an EV subsidy and expanded public charging infrastructure. They find that both policies are effective in increasing adoption. Under a low-technology assumption, mainly regarding battery cost, the authors find that an investment in charging infrastructure will provide a larger effect on EV adoption than EV subsidies. However, the economics of public charging infrastructure still are highly uncertain, with profitability and station utilization rates unclear. Under a high technology model, a combination of infrastructure investment and EV subsidies will be the most effective in promoting EV sales. Although the study concludes they "do not definitively identify an optimal policy" (9), the study's findings can imply that with the uncertainty that remains ahead, investment in infrastructure should be a top priority over EV subsidies.

Electric Vehicle Subsidies

The concept of EV subsidies as a policy tool aimed to promote behavior is quite simple. They are essentially financial incentives provided by governments to reduce the upfront cost of purchasing an EV compared to an ICEV. By lowering the cost of EVs, the government is attempting to make the market price of EVs more reflective of their social cost and, in turn, to incentivize consumers to purchase EVs over ICEVs.

They are effective. EV purchases have a strong demand elasticity with subsidies, as shown in many studies (Gallagher and Muehlegger 2011, Muehlegger and Rapson 2022, Clinton and Steinberg 2019). A 2018 study by Muehlegger and Rapson show that subsidies are also effective for low- and middle-income households, increasing sales by 21 percent when lowering EV prices by 10 percent.

However, without an income cap, they can be regressive. A study from 2010 to 2018 showed that EV tax rebates are predominantly distributed to more affluent and less disadvantaged census tracts, as they are the ones predominately purchasing electric vehicles. High rebate amounts appear in spatial clusters, concentrating in metropolitan regions (Guo et al. 2021). While this may change as EVs saturate the used vehicle market and price points fall, policy should account for and prepare for this possibility.

Theoretically, subsidies may benefit target households and individuals who would have purchased EVs regardless of a subsidy or not, thus reducing the effectiveness of the subsidy program. This adverse selection can be approached through additional income caps.

Income-based subsidies are more effective and more equitable than uniform subsidies. In a study assessing different scenarios for policy (Linn 2022), the one with an income cap was 40 percent more cost-effective than the uniform subsidies. The model looked at an income cap for a subsidy below $100,000. However, the study also looked at the impacts of an income-based subsidy in conjunction with a ZEV mandate and found it to be less effective. The author stated that the “ZEV policy is doing the lion’s share of the work… In those states, the vehicles would get sold without subsidies anyway, and the subsidies mainly shift costs of plug-ins from consumers and manufacturers to taxpayers. This reduces the cost effectiveness of the subsidies.” However, he added that “the subsidies do benefit low-income households” (Linn 2022).

An additional study looked at the effects of adding an income cap and increasing rebates for low-income consumers. The study found that the percentage of rebates issued to lower income households increased. The number of rebates issued to the highest income households decreased and the total number of rebates issued grew by 50 percent (Fuller and Brown 2020). It is effective in increasing and improving equity. To further take advantage of this finding, California can use more targeted incentives, by establishing more income brackets. This would most likely further improve program equity and cost-effectiveness.

However, because California already has a ZEV mandate in place and the above research shows that subsidies do not add significant additionality to EV sales when a ZEV mandate is already in place, EV subsidies do not need to be prioritized as much as infrastructure investment, which is more effective in increasing EV adoption anyway.

Fleet Turnover Improvement

The findings from the model earlier in this paper and from other studies show that slow vehicle turnover will be an obstacle (Alarfaj et al. 2020). Buying either type of vehicle will be more expensive in 2030 than it is today, and this increase in the sale price of either new or used vehicles may prompt car owners to hold onto their less fuel efficient ICEVs for longer periods. Scrap decisions and scrap elasticity have been known to produce emissions leakage under fuel efficiency standards, which is known as the Gruenspecht effect (Jacobsen and Benthem 2015). This could exist with the ZEV mandate. This delay in vehicle scrappage exacerbates slow vehicle turnover and could diminish the effectiveness of a transition to ZEVs in terms of carbon emissions.

In a perfect economic scenario, a policy combining a vehicle scrappage requirement with a purchase subsidy would offer a sufficient enough financial incentive for a household to change its behavior. An intuitive example is as follows (Linn 2020); a household has an old car that they will need to spend $2,000 on to continue operating. They could buy a new car for $3,000. They may choose to repair their gas-guzzler car. If a new car was $1,000 instead of $3,000, they may be more likely to scrap their old vehicle and buy a new car. While this over-simplified example does not factor in any other additional variables, the point goes that the higher the replacement cost, the less likely the individual is to scrap their old vehicle.

Unfortunately, a policy to subsidize a household or individual to scrap their old vehicle is not always effective in terms of reducing carbon emissions. Without the capability of screening households perfectly, this policy could provide a subsidy payment that would go to households who were already planning on scrapping their older vehicles. Funding these households' scrappages does not reduce carbon emissions by significant amounts. Adverse selection also occurs with this policy, as shown with the above EV subsidies as well.

There have been attempts to induce scrappage by implementing policies to buy back and scrap older cars, but these programs prove to be ineffective. For instance, the federal government's "Cash for Clunkers" program, which aimed to encourage people to trade in their older cars for newer, more fuel-efficient models, cost $2.9 billion and helped 700,000 car owners upgrade their vehicles in 2009, but it was not very efficient. A study on the car allowance rebate system showed that the original program primarily provided benefits to Americans who were already planning to trade in their vehicles and often missed those who were driving gas-guzzler cars and long distances. The program reduced emissions at a fiscal cost of about $300 per metric ton of carbon dioxide, which was substantially more expensive than other programs at that time (Busse et al. 2012, Li et al. 2013).

US Senator Chuck Schumer revived interest in linkage subsidies again when he proposed a new scrappage program in 2019. However, an evaluation of this program to an unlinked program showed that a linking program is expected to result in fewer EV sales and less spending relative to a program without linking. While linking also lowers purchase additionality, or vehicle purchase decision, the program linking would lead to a high degree of scrappage additionality (Ankey and Leard 2022).

California currently has a program Clean Cars 4 All, that links scrappage and an EV incentive. They also have a separate EV subsidy program, which is unlinked, and therefore, most likely more effective.

While a scrappage program should not be a priority for policymakers to invest in, there are some small changes that could be made. First of all, the requirement to purchase a new car linked to the current scrappage program can be eliminated.

A study in 2022 (Linn) considered hypothetical scrappage subsidies which had eligibility requirements of either age or mileage without linking the subsidy to a requirement to buy a new cleaner vehicle. According to Linn, this can “assess whether carefully selecting the eligibility requirements can improve emissions outcomes” (2), because an effective policy with scrappage would scrap vehicles that without the policy would still be driven a lot and emit a lot more emissions.

It showed that a fixed subsidy amount for all vehicles past a certain age would be costly - at roughly $600 per metric ton of carbon dioxide reduced. However, attempting to target the subsidy and program to cars with possible future emissions could reduce the amount of adverse selection that was previously occurring, such as in the “Cash for Clunkers” program (Linn 2020).

In trying to target the subsidy to be proportional with future emissions, policy could reduce the subsidy as a car increases with age, to push cars with greater potential future emissions out of the market faster.

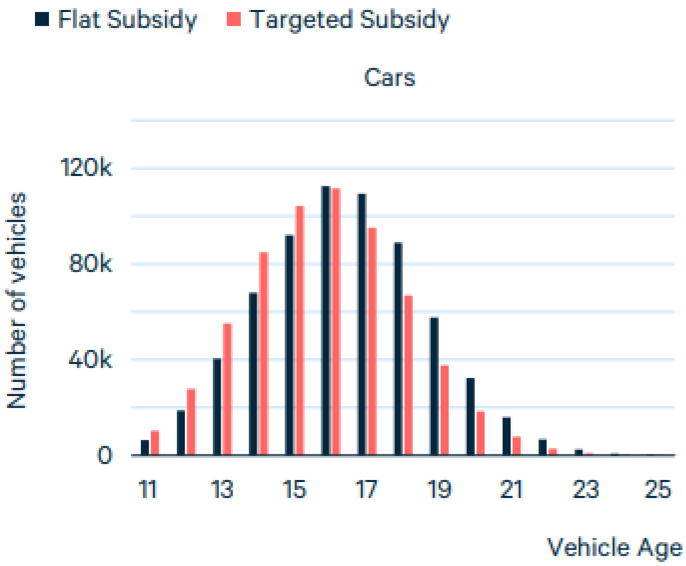

Figure 5. Results of both a flat ($500) subsidy and targeted subsidy proportional to estimated future emissions on the vehicle age and subsequent number of vehicles scrapped (Linn 2022).

The eligibility criteria for a program should be changed from being based on the year of the vehicle to be scrapped to being based on the odometer reading of the vehicle. This is a better predictor of a vehicle's future emissions and thus a better way to target for the subsidy. Two identical 20-year-old cars, one with an odometer reading of 100,000 and the other with 150,000 are likely to have a different amount of possible future emissions.

To quantify these assumptions, the study's model came up with the cost-effectiveness in dollars per metric ton of carbon avoided. Targeting subsidies based on of mileage improves cost-effectiveness by 30 percent more than targeting based on class and age (Linn 2020), from $403 dollars to $273 dollars per ton.

Because the key to accelerating fleet turnover depends on the used market, as the majority of car sales are used, a policy that targets used vehicles with many future years full of emissions ahead of them to bow out of the market would be very effective. Policy should not link new purchases to a scrappage program. The majority of the households and individuals who have an older emission-producing car and are eligible for California's Clean Cars 4 All are part of the demographic (lower income and older car) that typically buys used cars, so acquiring a new vehicle is not likely in line with their behavior and financial decisions.

By decoupling the two, the policy may not achieve results of large increases in EV sales early on, as the policy's purpose is just to decrease emissions and incentivize scrappage. However, as used cars are approaching price parity with used ICEVs, the policy should not limit this scrappage incentivize to a household that will just buy a new car.

Other Policy Options

Additional incentive policy includes opening up high occupancy vehicle (HOV) lanes to those who have purchased a ZEV, or discounting toll or express fast lanes for ZEVs. The former is a significant contributor to adoption (Jenn, Springel, and Gopal 2018) but discounting express lanes as an incentive for EVs does not impact EV sales significantly, by only one percent in the most extreme scenario, and further limits the effectiveness of the lanes in their purpose (Davis, Stark, and Garcia Sanchez 2023).

4.2 Policy Recommendations for California

California has taken many steps in the right direction to accelerate EV adoption. They are making optimal policy decisions in accordance with much of the research above.

Most literature on policy recommendation points to a 'all of the above' policy approach to furthering adoption of EVs (Ledna et all 2022). While this is accurate and commendable, Table 3 below provides a priority list of policies, in order to provide information on what will be most efficient, cost-effective, and equitable, to continue to invest in. In summary, it is recommended to spend the most amount of investment within charging infrastructure, as this will provide the greatest value for the money spent.

Given that other states and the entire nation are contemplating ZEV mandates and other policies to promote the adoption of electric vehicles, it is crucial for California to execute this correctly and choose effective policy, as it is being closely watched.

Proposed Policy or Action	Discussion	Policy Recommendation for California	Priority	Cost
Charging infrastructure investment	Significant driver of adoption. DCFC investment can more equitable.	Continue to invest in infrastructure, subsidize public chargers, prioritizing DCFCs. This should be California's top priority.	High	High
EV subsidies	Significant driver of adoption, can be less so than infrastructure investment. Can be regressive if not income capped. Additionally, has limited effectiveness when a ZEV mandate is already in place.	Improve and expand income caps and brackets, to increase equity. Continue to provide subsidies, but not with as much investment as infrastructure.	High	High, can be \$350-640 per ton of carbon reduced.[12]
Linking a scrappage program with an EV subsidy	Linkage can reduce effectiveness of policy.	Remove the requirement to buy a new car linked to the current scrappage program, and change eligibility based on odometer reading rather than year.	Medium-Low	High, not cost-effective, can be \$300-600 per ton of carbon reduced.
EVs access to HOV (high occupancy vehicle) lanes	Significant as a driver of adoption, but will prove ineffective as	Continue HOV lane access for ZEVs and phase out as necessary.	Low	Low, until increased EV adoption leads to greater congestion.

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[12] Gillingham and Stock estimated these values and noted a large degree of uncertainty (2018).

	EVs fill the roads.			
Express or HOT (high occupancy toll) lane discounts for EVs	Only slight increases in EV adoption and decreases effectiveness of other express lanes purposes.	Do not offer Express or HOT lane discounts, instead develop targeted incentives that focus on low-income EV adopters.	Low	Medium-Low

Table 3. An overview of policy recommendations for California

5. Conclusion

This thesis examined the transition to electric vehicle in California through passenger car EVs. This transition, while made inevitable by California's ZEV mandate, still poses significant challenges, such as a slow turnover, lack of infrastructure, and costs. These barriers to success will require extensive government intervention and investment.

California is well positioned to do this. The total cost of ownership model in this paper estimates EVs and ICEVs will reach total cost of ownership parity this year for some models. Used vehicles are expected to achieve price parity between EVs and ICEVs by 2029, and it is anticipated that price parity for new vehicles will be reached after 2030.

Policy is in good shape in California and recommendations are outlined in the chapters above in order to increase equity and efficiency of the transition to EVs. It is reasonable to conclude that the EV adoption push will need policy that follows a 'all of the above' approach as we push toward electrification of the transportation sector, and specifically prioritize infrastructure and equitable approaches to subsidies and other government intervention.

This study and the discussed transition have wide implications for other states and the nation, as the shift to EVs grows stronger.

Uncertainty remains in all aspects this thesis studied. The coming years in California’s transition to EVs will prove that constant policy review, evaluation and subsequent revision are necessary. The process of policy is consistently ongoing and the road to electric vehicles in California will reflect that.

Bibliography

Alarfaj, Abdullah F, W Michael Griffin, and Constantine Samaras. 2020. “Decarbonizing US Passenger Vehicle Transport under Electrification and Automation Uncertainty Has a Travel Budget.” *Environmental Research Letters* 15 (9): 0940c2. https://doi.org/10.1088/1748-9326/ab7c89.

Ankney, Kevin, and Benjamin Leard. 2022. “Should Electric Vehicle Purchase Subsidies Be Linked with Scrappage Requirements?” *Resources for the Future*. https://media.rff.org/documents/WP_22-13.pdf.

Bauer, Gordon, Chih-Wei Hsu, Mike Nicholas, and Nic Lutsey. 2021. “Charging up America: Assessing the Growing Need for U.S. Charging Infrastructure through 2030.” *International Council on Clean Transportation*. 2021. https://theicct.org/publication/charging-up-america-assessing-the-growing-need-for-u-s-charging-infrastructure-through-2030/.

Brown, Austin L., Daniel Sperling, Bernadette Austin, J. R. DeShazo, Lew Fulton, Timothy Lipman, Colin Murphy, et al. 2021. “Driving California’s Transportation Emissions to Zero.” *University of California Institute of Transportation Studies*, April. https://doi.org/10.7922/G2MC8X9X.

Bushnell, James, Erich Muehlegger, and David Rapson. 2022. “Energy Prices and Electric Vehicle Adoption.” *National Bureau of Economic Research*, no. w29842. https://doi.org/10.2139/ssrn.4056795.

Busse, Meghan R, Christopher R Knittel, Jorge Silva-Risso, and Florian Zettelmeyer. 2012. “Did ‘Cash for Clunkers’ Deliver? The Consumer Effects of the Car Allowance Rebate System,” https://www.scholars.northwestern.edu/en/publications/did-cash-for-clunkers-deliver-the-consumer-effects-of-the-car-all.

Chakraborty, Debapriya, Koral Buch, and Gil Tal. 2021. "Cost of Plug-in Electric Vehicle Ownership: The Cost of Transitioning to Five Million Plug-In Vehicles in California." *UC Davis: National Center for Sustainable Transportation.* https://doi.org/10.7922/G257199D

Clinton, Bentley C., and Daniel C. Steinberg. 2019. “Providing the Spark: Impact of Financial Incentives on Battery Electric Vehicle Adoption.” Journal of Environmental Economics and Management 98 (November): 102255. https://doi.org/10.1016/j.jeem.2019.102255.

Davis, Adam Wilkinson, Debapriya Chakraborty, and Gil Tal. 2022. “How Many Chargers Must California Install to Complete the Transition to Electric Vehicles? An Analysis of Electric Vehicle Adoption and Potential Charging Infrastructure Needs 2022-2045.” https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4113824.

———, Joshua Stark, and Juan Carlos Garcia Sanchez. 2023. “Assessing the Potential Impacts of Toll Discounts on Zero-Emission Vehicle Adoption.” *UC Davis: National Center for Sustainable Transportation*. https://doi.org/10.7922/G26T0JZM.

Experian. 2022. “New and used light vehicle sales in the United States from 2010 to 2021 (in million units).” Chart. Statista.

Fuller, Sam, and Austin Brown. 2020. “The effects of equitability policies on the ZEV market: Evidence from California’s Clean Vehicle Rebate Project.” *UC Davis: Policy Institute for Energy, Environment, and the Economy*. https://escholarship.org/uc/item/3kj611tv.

Gallagher, Kelly Sims, and Erich Muehlegger. 2011. “Giving Green to Get Green? Incentives and Consumer Adoption of Hybrid Vehicle Technology.” *Journal of Environmental Economics and Management* 61 (1): 1–15. https://doi.org/10.1016/j.jeem.2010.05.004.

Gamage, Tisura, Gil Tal, and Alan T. Jenn. 2023. “The Costs and Challenges of Installing Corridor DC Fast Chargers in California.” *Case Studies on Transport Policy* 11 (March): 100969. https://doi.org/10.1016/j.cstp.2023.100969.

Gardiner, Dustin. 2023. “Could California Become the First State to Require Tesla Charging Stations to Open to All EVs?” San Francisco Chronicle. March 2, 2023. https://www.sfchronicle.com/politics/article/california-tesla-chargers-bill-17811208.php.

Gill, Liz, Aleecia Gutierrez, and Terra Weeks. 2021. “2021 SB 100 Joint Agency Report, Achieving 100 Percent Clean Electricity in California: An Initial Assessment.” California Energy Commission. 2021. https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity.

Gillingham, Kenneth, and James H. Stock. 2018. "The Cost of Reducing Greenhouse Gas Emissions," *Journal of Economic Perspectives*, 32, 4:53-72.

Goldberg, Nicholas. 2021. “Column: Can L.A.’S Public Transit System Survive the Pandemic?” Los Angeles Times. April 7, 2021. https://www.latimes.com/opinion/story/2021-04-07/los-angeles-public-transit-crisis.

Guo, Shuocheng, and Eleftheria Kontou. 2021. "Disparities and equity issues in electric vehicles rebate allocation." Energy Policy 154: 112291.https://www.spglobal.com/mobility/en/research-analysis/average-age-of-vehicles-in-the-us-increases-to-122-years.html

Hall, Dale, and Nic Lutsey. 2017. “Emerging Best Practices for Electric Vehicle Charging Infrastructure.” The International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/EV-charging-best-practices_ICCT-white-paper_04102017_vF.pdf.

Harto, Chris. 2020. "Electric Vehicle Ownership Costs: Today's Electric Vehicles Offer Big Savings for Consumers." https://advocacy.consumerreports.org/wp-content/uploads/2020/10/EV-Ownership-Cost-Final-Report-1.pdf.

IHS Markit. 2021. "Average Age of Cars and Light Trucks in the U.S. Rises to 12.1 Years, Accelerated by COVID-19, according to IHS Markit." Ihsmarkit.com. 2021. https://news.ihsmarkit.com/prviewer/release_only/id/4759502/#:~:text=89%25%20of%202016%2D2020%20model.

IPCC. 2023. "Sixth Assessment Report — IPCC." 2023. https://www.ipcc.ch/assessment-report/ar6.

Jacobsen, Mark R., and Arthur A. van Benthem. 2015. "Vehicle Scrappage and Gasoline Policy." *American Economic Review* 105 (3): 1312–38. https://doi.org/10.1257/aer.20130935.

Jenn, Alan, Katalin Springel, and Anand R. Gopal. 2018. "Effectiveness of Electric Vehicle Incentives in the United States." *Energy Policy* 119 (August): 349–56. https://doi.org/10.1016/j.enpol.2018.04.065.

Ledna, Catherine, Matteo Muratori, Aaron Brooker, Eric Wood, and David Greene. 2022. "How to Support EV Adoption: Tradeoffs between Charging Infrastructure Investments and Vehicle Subsidies in California." *Energy Policy* 165 (165): 112931. https://doi.org/10.1016/j.enpol.2022.112931.

Li, Shanjun, Joshua Linn, and Elisheba Spiller. 2013. "Evaluating 'Cash-For-Clunkers': Program Effects on Auto Sales and the Environment." *Journal of Environmental Economics and Management* 65 (2): 175–93. https://doi.org/10.1016/j.jeem.2012.07.004.

Linn, Joshua. 2020. "How Targeted Vehicle Scrappage Subsidies Can Reduce Pollution Effectively." Resources for the Future. 2020. https://media.rff.org/documents/IB_20-09_Linn_vWnxgDH.pdf

———. 2022. "Balancing Equity and Effectiveness for Electric Vehicle Subsidies about the Author." https://media.rff.org/documents/WP_22-7_January_2022.pdf.

Lopez, Nadia. 2022. "Lower Cost, Slower Gains: California Prepares Controversial New Climate Strategy." *CalMatters*, April 28, 2022, sec. Environment. https://calmatters.org/environment/2022/04/california-climate-change-strategy/.

Luo, Zunian. 2022. "Powering Up a Slow Charging Market: How do Government Subsidies Affect Charging Station Supply?." *arXiv,* 2210.14908. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4292231.

Lutsey, Nic, and Michael Nicholas. 2019. "Update on Electric Vehicle Costs in the United States through 2030." International Council on Clean Transportation. 2019. https://theicct.org/publication/update-on-electric-vehicle-costs-in-the-united-states-through-2030/.

McConnell, Virginia, Benjamin Leard, and Fred Kardos. 2019. "California's Evolving Zero Emission Vehicle Program: Pulling New Technology into the Market." *Resources for the Future*. 2019. https://www.rff.org/publications/working-papers/californias-evolving-zero-emission-vehicle-program/.

Mitchell, Russ. 2022. "Proposition 30, Wealth Tax for Electric Vehicle Subsidies, Defeated at the Polls." Los Angeles Times. November 9, 2022. https://www.latimes.com/california/story/2022-11-08/2022-california-election-prop-30-ev-tax-results.

Morris, James. 2021. "Electric Vehicles Are Not Zero Emissions - but They Are Much Greener than Fossil Fuel and Hydrogen." Forbes. 2021. https://www.forbes.com/sites/jamesmorris/2021/10/23/electric-vehicles-are-not-zero-emissionsbut-they-are-much-greener-than-fossil-fuel-and-hydrogen/?sh=716c09b5197d.

Muehlegger, Erich, and David S. Rapson. 2022. "Subsidizing Low- and Middle-Income Adoption of Electric Vehicles: Quasi-Experimental Evidence from California." *Journal of Public Economics* 216 (December): 104752. https://doi.org/10.1016/j.jpubeco.2022.104752.

Our Country. 2018. "Transportation Briefing." https://ourcountyla.lacounty.gov/wp-content/uploads/2018/08/Our-County-Transportation-Briefing_For-Web.pdf.

Parker, Nathan, Hanna L. Breetz, Deborah Salon, Matthew Wigginton Conway, Jeffrey Williams, and Maxx Patterson. 2021. "Who Saves Money Buying Electric Vehicles? Heterogeneity in Total Cost of Ownership." *Transportation Research Part D: Transport and Environment* 96 (102893): 102893. https://doi.org/10.1016/j.trd.2021.102893.

Pierce, Gregory, Britta McOmber, and J.R. DeShazo. 2020. "Supporting Lower-Income Households' Purchase of Clean Vehicles: Implications From California-Wide Survey Results." Tech. Rep., *UCLA Luskin Center for Innovation*.

Plumer, Brad, Nadja Popovich, and Blacki Migliozzi. 2021. "Electric Cars Are Coming. How Long until They Rule the Road?" *The New York Times*, March 10, 2021, sec. Climate. https://www.nytimes.com/interactive/2021/03/10/climate/electric-vehicle-fleet-turnover.html.

PwC. n.d. "US Electric Vehicle Charging Market Growth by 2030." PwC. https://www.pwc.com/us/en/industries/industrial-products/library/electric-vehicle-charging-market-growth.html.

Rapson, David, and Erich Muehlegger. 2021. "The Economics of Electric Vehicles." *National Bureau of Economic Research*. https://doi.org/10.2139/ssrn.3897528.

Saha, Devashree, and Mark Muro. 2016. "Growth, Carbon, and Trump: State Progress and Drift on Economic Growth and Emissions 'Decoupling.'" Brookings. December 8, 2016.

https://www.brookings.edu/research/growth-carbon-and-trump-state-progress-and-drift-on-economic-growth-and-emissions-decoupling/.

Slowik, Peter, Aaron Isenstadt, Logan Pierce, and Stephanie Searle. 2022. “Assessment of Light-Duty Electric Vehicle Costs and Consumer Benefits in the United States in the 2022-2035 Time Frame.” International Council on Clean Transportation. https://theicct.org/wp-content/uploads/2022/10/ev-cost-benefits-2035-oct22.pdf.

Sperling, Daniel. 2018. *Three Revolutions: Steering Automated, Shared, and Electric Vehicles to a Better Future*. Washington, DC: Island Press.

St. John, Alexa. 2023. “The Used Electric Car Market Is Starting to Take off as Prices Slowly Drop.” Yahoo. 2023. https://www.yahoo.com/now/used-electric-car-market-starting-094200844.html.

Tal, Gil, Adam Davis, and Dahlia Garas. 2022. “California’s Advanced Clean Cars II: Issues and Implications.” Electric Vehicle Research Center Institute of Transportation Studies, UC Davis. https://escholarship.org/content/qt1g05z2x3/qt1g05z2x3_noSplash_07a2c4c9276a976e9fa21e8337c0e7d8.pdf.

Tucker, Sean. 2022. “Survey: 36% of Americans May Buy an EV.” Kelley Blue Book. July 7, 2022. https://www.kbb.com/car-news/survey-36-of-americans-may-buy-an-ev/.

US Census Bureau. 2021. “QuickFacts: California.” Census Bureau QuickFacts. United States Census Bureau. 2021. https://www.census.gov/quickfacts/ca.

Veloz. 2023. “Record-Shattering EV Sales Continue in Q1 2023 as California Reaches the 1.5 Million EVs Sold Milestone Two Years ahead of Schedule.” Veloz. April 21, 2023. https://www.veloz.org/record-shattering-ev-sales-continue-california-reaches-1-5-million-evs-sold/.

Velzen, Arjan van, Jan Anne Annema, Geerten van de Kaa, and Bert van Wee. 2019. “Proposing a More Comprehensive Future Total Cost of Ownership Estimation Framework for Electric Vehicles.” *Energy Policy* 129 (June): 1034–46. https://doi.org/10.1016/j.enpol.2019.02.071.

Wrinkler, Matthew. 2022. “California Poised to Overtake Germany as World’s No. 4 Economy.” Www.bloomberg.com. 2022. https://www.bloomberg.com/opinion/articles/2022-10-24/california-poised-to-overtake-germany-as-world-s-no-4-economy.