USED ELECTRIC VEHICLES DELIVER CONSUMER SAVINGS OVER GAS CARS

POLICY IMPLICATIONS AND TOTAL OWNERSHIP COST ANALYSIS FOR NON-LUXURY USED CARS AVAILABLE TO CALIFORNIA CONSUMERS TODAY

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SUMMARY

A rapid transition to electric vehicles (EVs) is essential to reaching carbon neutrality in the transportation sector, which generates more greenhouse gas emissions in California and the United States than any other sector. Motor vehicles are also a key source of local air pollution, which disproportionately damages the health and well-being of people of color and lower-income communities.[1] Indeed, when first establishing the zero-emissions vehicle requirement in 1990, California identified local air quality improvements as the exclusive regulatory objective, indicating the strong public health link.[2]

Though the environmental benefits of EVs are clear, the role of publicly funded consumer incentives for new EV buyers has raised questions of economic fairness. The early market success of luxury brand Tesla fostered a perception that EVs are out-of-reach toys for the wealthy. In response to equity concerns, California retooled incentive polices, such as offering higher rebates to low- and moderate-income households under the Clean Vehicle Rebate Project. In another example, the Clean Cars 4 All program offers point-of-sale incentives for new and used EV purchases by lower-income households. People living near poverty in communities enduring the heaviest air pollution loads are eligible for the highest level of support—$9,500 for qualified clean vehicles with trade-in of an older gas car.

This report provides new insights into the EV transition's economic equity impacts through a study of the consumer economics of used cars, excluding luxury vehicles. The analysis centers on evaluation of total cost of ownership, accounting for vehicle purchase cost as well as fuel, maintenance, and insurance expenses. Ownership analysis is then leveraged to provide new insights into the household budget effects of incentives such as those available under Clean Cars 4 All.

FINDINGS

The analysis calculates average EV ownership savings as the difference between the ownership cost for a sales-volume-weighted average EV and a comparable gasoline car. Table 1 presents the topline finding that average EVs yield savings of $1,100 for model year 2017 and $500 for model year 2018. This is over a typical five-and-a-half-year ownership period. EVs save their owners money because lower fuel and maintenance expenses outweigh a higher average vehicle price. On average, 2017 and 2018 model year EVs cost more to purchase by $1,800 and $2,400, respectively. This cost difference is referred to as the EV purchase price premium.

Table 1. EV ownership savings and purchase price premium

	2017 model year	2018 model year
EV ownership savings	$1,100	$500
EV purchase price premium	$1,800	$2,400

Source: Energy Innovation analysis

Market value declines rapidly immediately after purchase. New cars are worth less than half of their initial cost after five years. This depreciation effect shrinks the used EV purchase price premium relative to new vehicles. Results in Table 1 show a $600 higher price premium for 2018 model EVs compared to 2017 model EVs. These results are consistent with the expected declining price premium as EVs age.

Model year 2017 and 2018 vehicles were the focus of the data analysis for several reasons. First, the consumer effects of interest will be less pronounced in new model year vehicles. Such smaller effects are more difficult to discern from statistical noise. The greater difficulty of identifying cost effects in 2019 or

2020 EVs, combined with time and resource constraints, led to the decision to focus the analysis on model year 2018 and older vehicles.

The decision to exclude 2016 or earlier vintages follows from the insight that sampling the same make and model vehicles across years will make it easier to identify underlying cost trends. Otherwise, changes in year-to-year results are significantly driven by changes in the mix of vehicles sold. The fact that the Chevrolet Bolt was not introduced until 2017 is the second key reason to begin the analysis with model year 2017. In 2017, the Bolt set the all-time EV record in its Consumer Reports' range test, topping 250 miles traveled, outperforming its U.S. Environmental Protection Agency-rated range and all vehicles tested before then.[3] Because the Bolt reset expectations for fully electric economy vehicles, its inclusion in the study was deemed essential.

Used car ownership cost analysis enables new insights into the affordability implications of publicly funded incentives encouraging car buyers to choose EVs. The analysis finds that a $9,500 incentive, the maximum amount available under Clean Cars 4 All, leads to ownership cost reductions of nearly 40 percent compared to the gas car average. The analysis finds a state sales tax waiver would reduce the average purchase price premium for non-luxury EVs by 63 percent and 57 percent for model years 2017 and 2018, respectively. Table 2 details these policy evaluation results.

Table 2. Consumer affordability impacts of EV policies

Incentive policy evaluation	2017	2018
Ownership savings including $9,500 incentive	$10,400	$9,800
Reduction in EV ownership cost including $9,500 incentive compared to gas car	38%	34%
Sales tax waiver policy evaluation		
State sales tax on average EV	$1,170	$1,350
Reduction in purchase price premium due to state sales tax waiver for EVs	-63%	-57%

Source: Energy Innovation analysis

The finding that incentives such as those available under Clean Cars 4 All lower EV cost as much as nearly 40 percent compared to the cost of a gas car is striking. Evidence that a purchase price premium currently exists, standing between buyers and total ownership savings, is another significant finding.

Battery costs have fallen 89 percent in real terms since 2010,[4] bringing EVs close to parity with gasoline cars in up-front purchase price. In the future, battery prices will almost certainly continue to fall and performance will almost certainly continue to improve for two fundamental reasons. First, new battery chemistry options are making progress in the laboratory and are expected to enable leaps forward on cost and convenience.[5] Second, major advances are in the offing for the lithium-ion technology currently in use due to innovation, learning by doing, and economies of scale throughout the supply chain.[6]

The outlook for battery innovation is a key reason EV purchase prices are expected to fall below conventional vehicle purchase prices in a matter of years.[7] The International Council for Clean Transportation projected new EVs will be less expensive than comparable gas by 2024 for compact cars and by 2027 for SUVs.[8] Bloomberg New Energy Finance forecasts a similar crossover point for the purchase price of EVs and emphasized predictions have been insufficiently optimistic year after year: "In 2017, a Bloomberg New Energy Finance analysis forecast that the crossover point was in 2026, nine years out. In 2018, the crossover point was in 2024—six years . . . out. The crossover point, per the latest analysis, is now

2022 for large vehicles in the European Union. For that, we can thank the incredible shrinking electric vehicle battery, which is not so much shrinking in size as it is shrinking—dramatically—in cost."[9]

POLICY IMPLICATIONS

California's Senate Bill 350 launched a major effort to understand barriers to adoption and use of clean technologies in less advantaged communities—and to develop ways to overcome those barriers.[10] An information gap was found to be one of the obstacles to consumer adoption of EVs: "In making vehicle purchase decisions, clean vehicles are not yet viewed as affordable, reliable or as convenient as gas counterparts."[11] The findings presented here are offered in service of remedying this information gap, and point to the following recommendations for policymakers.

The topline conclusion of this research is that consumer incentive policies continue to play an important role in an effective, equitable transition to EVs. Consumer incentives broaden access to EV ownership savings. For lower-income households, the EV purchase price premium will be an especially large hurdle to benefitting from the stream of future energy and maintenance savings that EVs offer.[12]

Incentives for used EV buyers targeted to lower-income and other less advantaged communities can deliver dramatic economic equity benefits. The nearly 40 percent reduction in ownership cost appears to represent an equity benefit that is unsurpassed among other energy, climate, and transportation policies. The impact of these savings is amplified by the relative burden of transportation costs for less wealthy households. Transportation is the second-largest expense for all U.S. households and presents a particular burden for lower-income households. As a share of after-tax income, transportation costs for households making $22,487 or less per year are more than three times larger than for households with income of $120,729 or more (37.4 percent and 11 percent of total expenditures, respectively).[13]

Incentive support targeted at the median car buyer remains important. Marketing surveys find car buyers in general place significant weight on purchase price.[14] Broad encouragement of consumer uptake is needed as EV sales expand beyond early enthusiasts to mainstream buyers. Continued funding and greater certainty about future allocations are essential for optimizing the state's flagship Clean Vehicles Rebate Program.

Expanded governmental support for EV financing is another priority for a fair and fast transition to EVs. Though used cars are less expensive than new cars, used car buyers still frequently use credit. Lower interest rates greatly reduce the cost of credit. Favorable loan terms—low or zero down payments and interest rates—greatly reduce the cost of credit and would expand access. One immediately available option is to allow EV buyers to partner with electric utilities to secure better financing. Such policies have a track record of success and could be established under current regulatory authority, without new legislation.[15]

Lower electricity prices improve EV affordability. Therefore, to better support consumer EV uptake, California should change the way revenue generated from cap-and-trade program auctions is returned to electricity-sector customers. The state should use this revenue for rate reduction instead of returning it to people on a lump-sum basis, currently labeled in utility bills as the "California Climate Credit." That approach made sense when the policy was set over a decade ago, but no longer.

Two additional policy recommendations related to EV policy, though not directly tied to quantitative results, are offered. The first relates to charging infrastructure. The result of this study implicitly assumes EV owners will be able to install charging infrastructure. In fact, renters, and some, if not most, residents of multi-unit dwellings will be unable to install EV chargers. **Policymakers should anticipate the need for**

ongoing policy work to ensure widespread and equitable access to charging infrastructure, especially in existing multi-unit buildings.[16]

This consumer affordability study does not directly address job creation. However, separate research shows that California's EV leadership has already paid off by boosting motor vehicle manufacturing jobs to record heights—nearly double historical levels.[17] Building on this success, **California policymakers should seek to grow jobs in the battery-electric storage manufacturing industry, including the lithium production aspects of the supply chain.** California also already hosts battery manufacturers, including Los Angeles-based Romeo Power, and companies working on the next generation of battery technology, such as San Jose-based QuantumScape. The report, "Building on the Lithium Valley," sketches out a vision for turning lithium dissolved in the water of California's Salton Sea into a reliable, responsibly managed source for lithium extraction.[18]

PUBLIC POLICY REMAINS ESSENTIAL

A convergence of technological, economic, and political trends is creating optimism that the transition to EVs can occur as quickly as climate change demands. Consumer demand is growing quickly and the share of EVs in new car sales jumped to 4.4 percent in 2020, up from 2.5 percent a year earlier. EV sales grew in absolute terms in 2020 even as overall car sales shrank because of the pandemic. A wave of both governmental commitments and industry support further demonstrates growing political will. Seventeen nations have pledged to fully transition new car sales to ZEVs, including the largest European economies.[19] In January 2021, General Motors promised the vehicles it produces will be electric, or otherwise emit no tailpipe emissions, by 2035. Less than two months later, Volvo set a 2030 end-date for its complete transition to zero-emission vehicles.

The momentum behind EVs is real, but it would be a mistake to outsource the transition to market forces. Consider the nearly ubiquitous petroleum fueling system, built up over more than a century: today its convenience represents a societal-scale hurdle to any challenger. This is just one example of the blockages facing EVs. Such inertia necessitates a continuing role for smart public policies in successful transportation electrification.

The climate and public health advantages of EVs are well established. This research demonstrates that non-luxury EVs currently deliver affordability benefits that are very likely to grow. EVs are certainly not a silver bullet—California's transportation system must support greater mobility choices, reducing unchosen dependence on motor vehicle travel. Yet a "silver bullet" standard would be unrealistic. The maturation and further promise of EVs as a tool for transportation decarbonization provide genuine reason for optimism in the battles to reduce global warming pollution, to improve public health and to build a fairer economy.

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Glossary and Key Abbreviations

Term	Abbreviation	Meaning
battery-electric vehicle	BEV	Vehicle solely powered by electricity
electric vehicle	EV	Plug-in vehicle, including BEVs and PHVs
gasoline-fueled car	gas car	A typical car or light truck with internal combustion engine
plug-in hybrid vehicle	PHV	Vehicle with two energy systems, one gasoline fueled and the other battery electric
zero-emission vehicle	ZEV	EVs and hydrogen fuel-cell vehicles

INTRODUCTION

The record wildfire devastation in California and across Western North America in 2020 offers fresh evidence of the cost of climate inaction. Humanity still has a window of opportunity to keep warming to safe levels. Maintaining a hospitable environment for future generations will require rapidly reducing greenhouse gas emissions over the next decade.[20] The possible consequences of climate change are almost too terrifying to imagine. Last year's fires will pale in comparison to the future price of climate inaction.

Fortunately, great leaps in clean energy technology provide reason for optimism. Decades of research, learning by doing, entrepreneurship, and improving economies of scale have produced rapid innovation. Renewable technologies are the lowest-cost options for generating electricity in every major economy on earth.[21] Electric vehicles (EVs) are one of the most promising new technologies, increasingly recognized as the technological linchpin for reaching carbon neutrality in the transportation sector. This technological advance creates new hope for a rapid transition in the transportation sector, the largest source of hazardous local air pollution and greenhouse gas emissions in California.

Spurred by these climate and public health imperatives as well as the economic development opportunity, Governor Newsom's administration made new strides in clean trucks and cars last year. The state's policymakers have taken steps to ensure the benefits of transportation electrification are broadly shared. Though the environmental justice benefits of EVs are widely accepted, the early market success of the luxury brand Tesla fostered a perception that EVs are out-of-reach toys of the wealthy. Moreover, new car buyers are in general much wealthier than the average person.

In response to equity concerns, California retooled incentive design. The state was the first to introduce income caps on consumer incentives—making high-income people ineligible for incentives for EV purchases. The state also developed policies specifically targeting incentives to less advantaged people.

This study provides new evidence on the affordability of non-luxury used EVs, suggesting alignment—or at least no contradiction—between transportation electrification and equity goals. In brief, our study finds average total ownership cost savings for buyers of EVs for model years 2017 and 2018. Ownership savings are modest on their own, but the state's Clean Cars 4 All program offers point-of-sale incentives to used EV buyers that supercharge the effect. Households near the poverty line in the areas with the highest pollution burdens are eligible for incentives of up to $9,500. The net effect is to reduce total cost of vehicle ownership nearly 40 percent for an average EV owner compared to the cost to own and operate a similar conventional gasoline-fueled car. The effect is even more remarkable considering transportation costs are the second-largest component of lower-income household budgets.[22]

The remainder of this report provides a fuller discussion of its motivation, the policy context, methodology, results, and policy implications.

MOTIVATION

In response to the Newsom administration's initial proposal to add roughly $500 billion to depleted budgets for EV incentives, with the lion's share going to the Clean Cars 4 All program, some have raised economic equity concerns. One lawmaker said: "We're paying people to buy cars, yet people are homeless, and they're being forced to sleep in their cars. It can't get any more ironic than that."[23]

This work seeks to add to the scant research available to help answer questions about the affordability and equity effects of used EVs. Statistics underline the used car market's importance. It is more than twice the size of the new car market, with 40 million used car sales versus 17 million new car sales in 2019 nationally.[24] At least a decade into the transportation electrification revolution, EVs are increasingly available in the used car market. Because EVs are an emerging technology, research thus far has naturally gravitated toward analysis of new car sales.

The consumer economics of the used car market are particularly germane for lower- and moderate-income households. New vehicle buyers are wealthier than the average household. Many people go a lifetime without the privilege of buying a new car.

CONTEXT

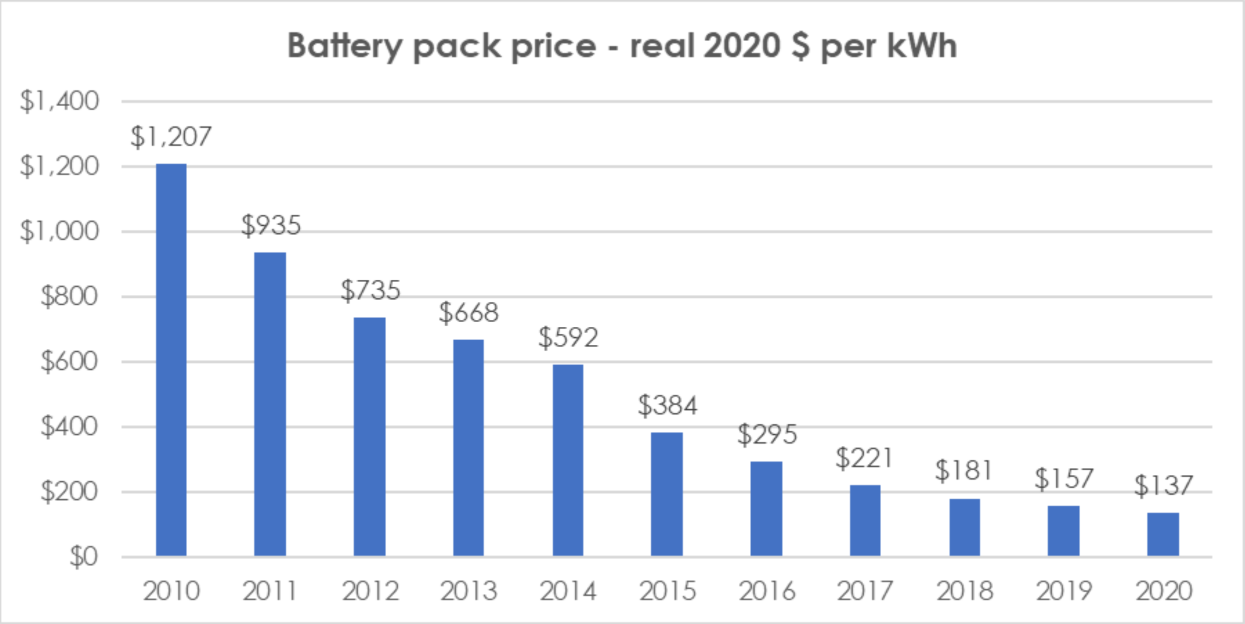
LEARNING CURVES AND PURCHASE PRICE PARITY

Evidence of a declining price premium bodes well for future affordability benefits provided by used EVs, since new car prices are a key determinant of used car prices. On the topic of when EVs will, on average, reach purchase price parity, 2019 research from the International Council for Clean Transportation projected new EVs will cost less than gasoline-fueled competitors by 2024 for compact cars and by 2027 for SUVs.[25] Bloomberg New Energy Finance forecasts a similar crossover point for the purchase price of EVs and also observes that predictions about reaching that point have been insufficiently optimistic year after year: "In 2017, a Bloomberg New Energy Finance analysis forecast that the crossover point was in 2026, nine years out. In 2018, the crossover point was in 2024—six years . . . out. The crossover point, per the latest analysis, is now 2022 for large vehicles in the European Union. For that, we can thank the incredible shrinking electric vehicle battery, which is not so much shrinking in size as it is shrinking—dramatically—in cost."[26]

Learning curves underpin projections of future crossover points when EVs will cost less to purchase than comparable gas vehicles. The term "learning curves" refers to performance improvements and cost reductions typically observed over time for new technologies once they reach minimum commercial viability. Learning is a function of experience—learning by doing. Learning curves also encompass the economies of scale that are achieved as production scales up. As put succinctly by a CEO in the offshore wind industry: "The main thing that will make floating wind reduce in price and really cost competitive is volume."[27]

EV battery pack costs have fallen sharply—by 89 percent in real terms since 2010, according to market data from Bloomberg New Energy Finance. Figure 1 illustrates this trend. The figure charts declining retail price measured as the sales-volume-weighted average price for battery packs, including battery cells and other inputs needed to produce the whole battery pack.

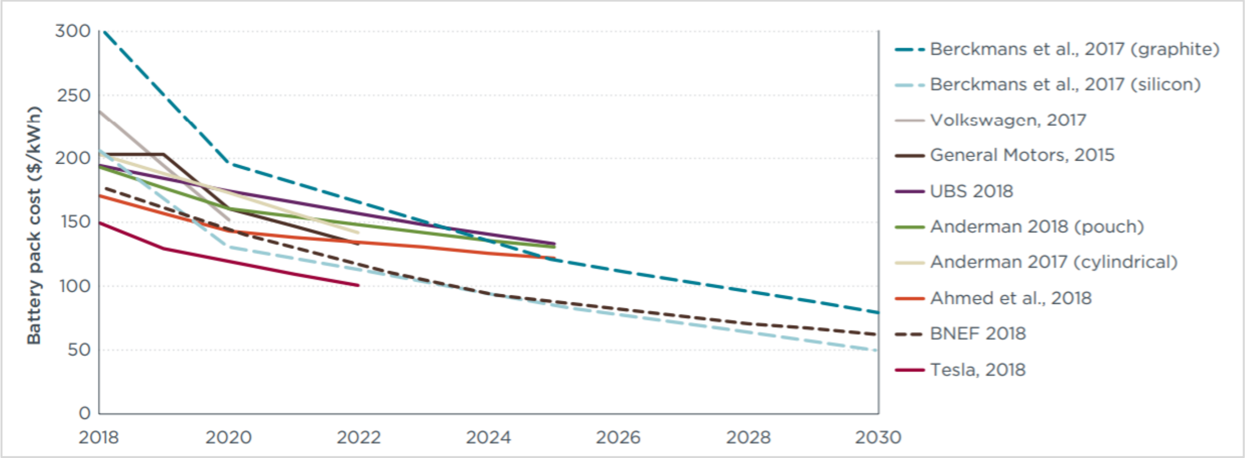
Figure 1. The price of EV battery packs fell 89 percent from 2010 to 2020 in real terms



Source: Bloomberg New Energy Finance[28]

In contrast to the historical view shown in Figure 1, the next figure presents a forward-looking outlook. Figure 2 depicts ten projections of expected future battery costs from a range of sources: automakers, consultants, and researchers. One need not wrestle with all the details to observe the overwhelming agreement across these different perspectives that battery innovation is likely to continue.

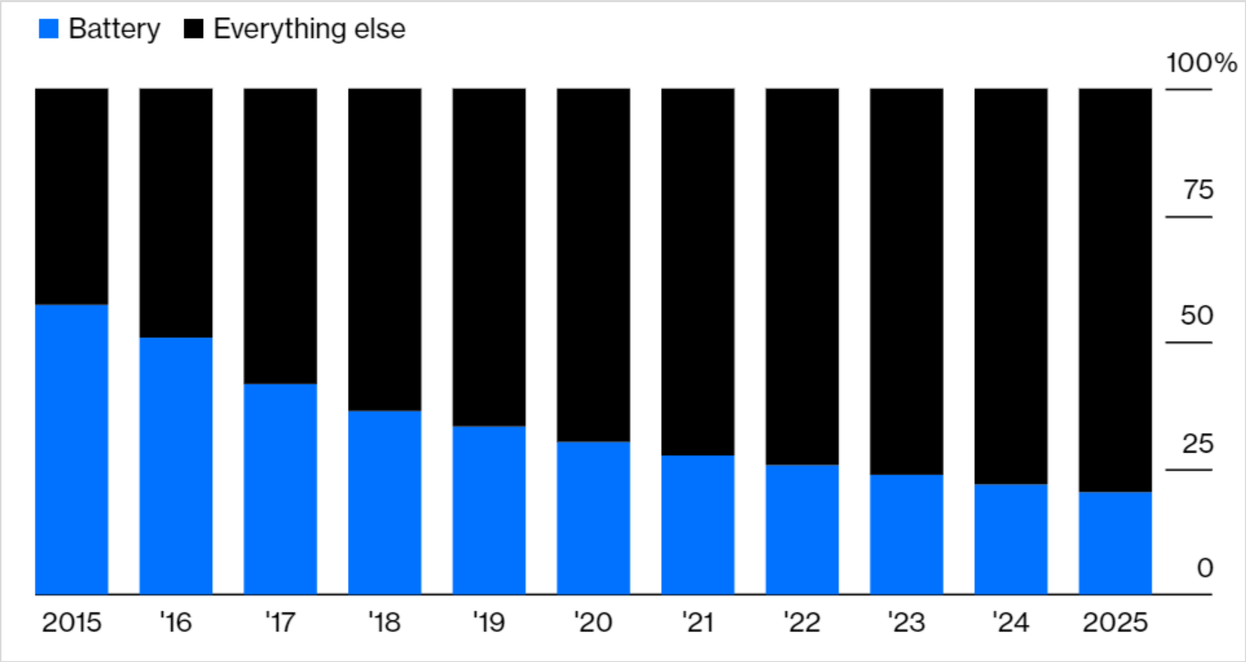
Figure 2. Ten forecasts of expected future battery costs from automakers, analysts, and researchers



Source: International Council for Clean Transportation[29]

The next figure combines the past- and future-looking trends illustrated in the last two figures to show the effect of declining battery costs on overall vehicle costs. Figure 3 shows that Bloomberg New Energy Finance expects the percentage of battery costs in overall vehicle production costs to drop from more than one half of total costs in 2015 to less than one quarter of total costs in 2025.

Figure 3. The declining share of battery cost in total vehicle production cost



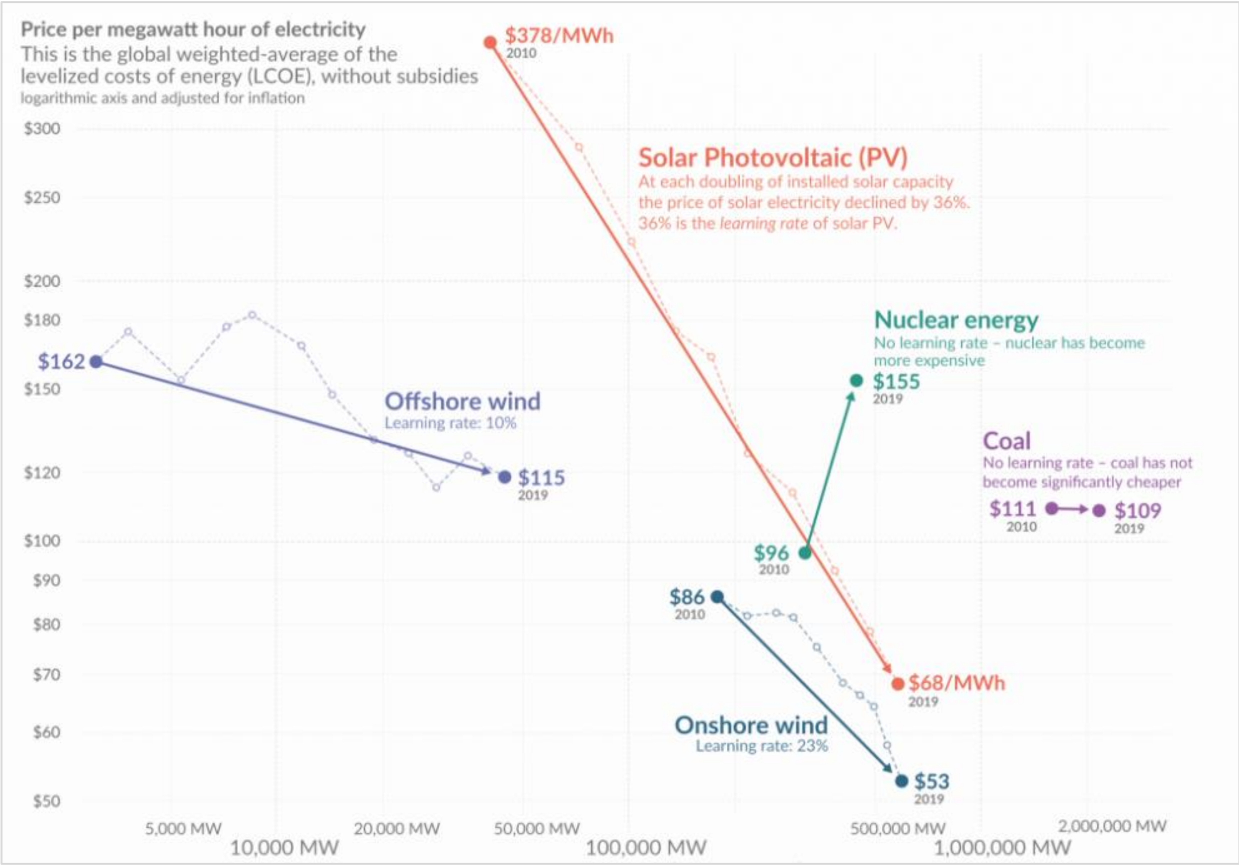
Source: Bloomberg New Energy Finance[30]

An array of studies using different methods—sophisticated statistical analysis,[31] economic history,[32] and case studies[33]—have also shed light on different aspects of learning curves. An article in the *Review of Environmental Economics and Policy* finds, "strong evidence that environmental regulations induce innovation activity in cleaner technologies."[34] The concept of learning curves is not a new one. It was the focus of a year 2000 report from the International Energy Agency, for example.[35]

Solar technology has emerged as a disruptor in international power markets. The International Energy Agency forecasts that more solar photovoltaic capacity will be installed over the next decade than any other technology, putting solar "on track to set new records for deployment every year after 2022."[36] Even as solar photovoltaic power generation is rightly recognized as the most remarkable example of learning curves in clean energy from recent history, learning curves are also evident in wind power generation, as shown in Figure 4, below.

Figure 4 illustrates the particularly impressive innovation in solar and wind technologies over the last decade. To understand why renewables have performed so well, note that the operational costs of fossil fuels and nuclear power are higher. Renewable energy plants are different: the operating costs of renewable electricity generating technologies are comparatively low and there are no fuel costs. The cost of renewable power technologies is almost entirely decided by the cost of the power plant, the cost of the technology itself, and financing costs. The disproportionate importance of technology costs as a share of total costs associated with wind and solar power plants explains why they exhibit pronounced learning curves.

Figure 4. The effects of learning curves on solar photovoltaic and wind power technologies



Source: OurWorldinData.org[37]

Learning curves are by no means unique to renewable energy technologies and batteries. In the realm of demand-side clean technologies, the U.S. Department of Energy found that the cost of highly efficient LED lights declined 94 percent from 2008 to 2015.[38]

CALIFORNIA POLICY

California's commitment to transition to 100 percent zero-emission new vehicle sales by 2035 generated more headlines, but the state also made transportation policy history last year with its Advanced Clean Trucks rule. This policy sets the world's first zero-emission requirements for trucks and represents a new chapter for the state's innovation in zero-emission vehicle (ZEV) policy. California passed the world's first ZEV standard in 1990, focusing entirely on local air quality challenges. The state's continued policy leadership has clearly played a role in the emergence of EV technology as the odds-on favorite to disrupt transportation in the coming years and decades.

The state's approach to consumer incentives has evolved based on evidence that early incentive programs primarily benefitted wealthier, less diverse areas. The first reforms set income eligibility limits. Today, the Clean Cars 4 All program exclusively targets moderate- and lower-income households, with the largest benefits going to the lowest-income households in the neighborhoods burdened by the heaviest pollution loads. The program supports buyers of new and used EVs, with incentives ranging from $5,500 to $9,500, plus up to $2,000 to install a vehicle charger.[39] Note that Clean Cars 4 All supports public transit in addition to rebates for EV purchases. The state Clean Vehicle Assistance Program offers both grants and favorable loans to support EV buyers. All such programs, however, lack sufficient funding to meet demand.

Though vehicle electrification is the focus of this study, California's decarbonization strategy in the transportation sector is multi-faceted—as it must be to succeed. The Sustainable Communities Program is an umbrella for the portfolio of efforts aiming to increase mobility options to reduce dependence on motor vehicle travel, thereby reducing air pollution. The overarching aim is to support growth of walkable, transit-oriented communities as well as new micro-mobility options, such as shared electric bikes or scooters.

Equity has been a longstanding focus of attention in California. For example, Assembly Bill 1015, superseding Senate Bill 535, establishes the minimum requirement that 35 percent of revenue from cap-and-trade allowance auctions is directed to projects benefitting people in lower-income and disadvantaged communities. Carbon pricing revenue has gone to support zero-emission bus purchases by local governments and to launch subsidized EV sharing programs for lower-income neighborhoods in Sacramento and Los Angeles. More recently, the Clean Mobility Voucher Options program has channeled more flexible fiscal and technical support to communities.

Transportation policy involves cars, trucks, transit, sustainable cities, sustainable freight, and off-road vehicles, yet it is just one facet of the state's overall climate policy portfolio. While touching on electricity pricing, this work does not cover the industry sector, building sector, short-lived climate pollutants, or most aspects of electricity sector policies.

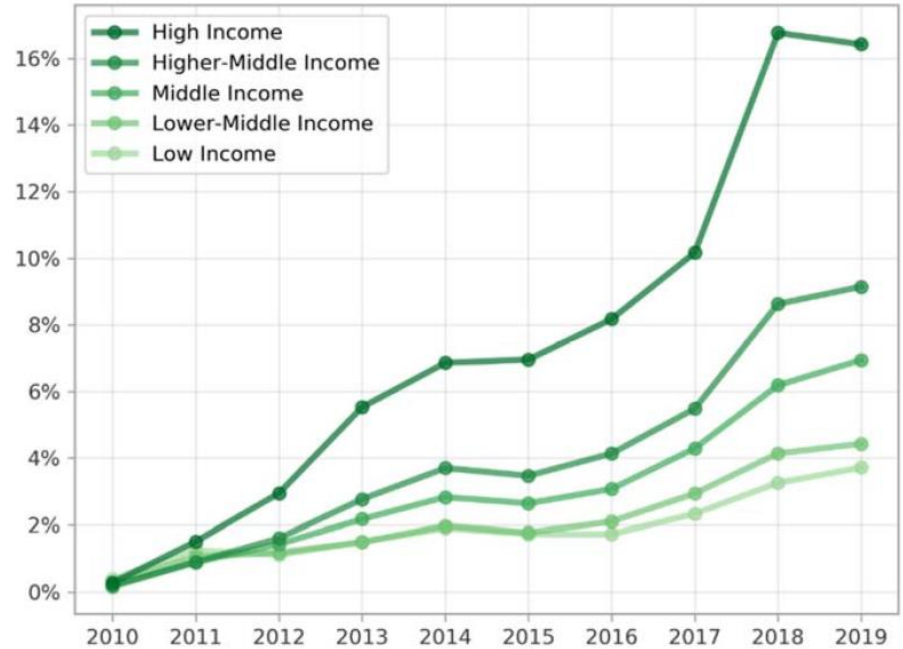
RESEARCH LITERATURE

In the relatively sparse body of research literature, the most similar study is a recent one by Consumer Reports, using national-level fuel prices instead of the California-specific ones used in this study. The Consumer Reports study is focused on new cars but includes a chapter calculating total cost of ownership for used cars, which points to used EVs as a total ownership cost saving opportunity.[40] Consumer Reports analysis concludes used EVs yield ownership savings because "used-car buyers capture a large fraction of the lifetime utility of a vehicle while paying a relatively low percentage of the new-car price."[41]

The Center for Sustainable Energy has produced other directly relevant work. The Center serves as a contractor for implementing California's EV rebate programs and publishes statistical assessments. The Center's most recent report shows the unequal rates of EV adoption for new car buyers in California, with 16 percent adoption at the uppermost incomes versus 4 percent for the lowest incomes, as illustrated in Figure 5, below.[42] The trend over time shows an increasing EV adoption gap between more and less wealthy new car buyers, except for a slight narrowing of the difference in the most recent data for 2019.

A recent International Council on Clean Transportation article identifies used EVs as a promising means for securing economic equity benefits.[43] One difference between that study and this one concerns incentives for new EV buyers. The International Council on Clean Transportation's findings do not factor in government incentives for new car buyers. The "EV ownership savings" found by the analysis reported in this paper do indirectly reflect new car incentives previously received.

Figure 5. California EV market share of new car sales by income levels



Source: Center for Sustainable Energy[44]

Finally, the Institute for Transportation Studies at the University of California, Davis is a leader in policy-relevant research, and its Plug-in Hybrid and Electric Vehicle Research Center is studying the used EV market. Its "Electric Vehicle Explorer" web page provides ownership cost estimates comparing used EVs and conventional cars based on customizable inputs.[i]

METHODOLOGY

Policymakers benefit from summary metrics that "boil down" research findings. This section outlines the methodology used to develop such a summary metric for this study. EV ownership savings are calculated as the difference between the sales-volume-weighted average ownership costs for EVs and ownership costs for the weighted-average of similar gas cars. The same approach is used to estimate the EV purchase price premium, which is calculated as the difference in purchase price for an average EV and an average gas car.

The ownership cost for any individual or household will depend on their specific circumstances. At the risk of stating the obvious, not every vehicle travels 11,400 miles per year—the input value underpinning the main results. Similarly, some households maintain ownership for shorter or longer periods than the average length of used car ownership. Sensitivity analysis is used to explore and illustrate how results change when varying these and other input assumptions.

This methodology section discusses elements included in the total-cost-of-ownership methodology; reasons for selecting model years 2017 and 2018 for data analysis; details of the sales-volume-weighted average approach for average EV and gas cars; and the average ownership cost saving and price premium,

[i] The Electric Vehicle Explorer web page can be accessed at https://phev.ucdavis.edu/project/ev-explorer/

including an expression in math notation. Finally, the limitations subsection defines the scope and limits of the work. Appendix B provides further details on research methods.

TOTAL COST OF OWNERSHIP

Total cost of ownership analysis compares the cost of different types of equipment from the perspective of prospective buyers. It is a standard financial planning tool. Total cost of ownership analysis is commonly a part of regulatory assessments of vehicle policies. For example, see Appendix D in the California Air Resources Board's Advanced Clean Trucks regulatory proceeding.[45]

Total cost of ownership for vehicles includes the cost to purchase a vehicle as well as annual fuel, maintenance, and insurance expenses. For battery-electric vehicles (BEVs), ownership costs are also assumed to include charger installation cost. For short-range BEVs—those with a range of less than 100 miles—the analysis adds a depreciation penalty at the end of the ownership period.

Like most total-cost-of-ownership studies of motor vehicles, this study takes a net present value approach. Costs incurred after the first year of ownership are subject to an 8 percent discount rate.[ii] The analysis assumes an ownership period of five and a half years, a recent average for used cars.[46] A description and references for each component for total cost of ownership are briefly defined next.

Vehicle price. The cost of purchasing a vehicle is the single largest part of total ownership cost. Vehicle prices are taken from the Consumer Reports "car value estimator" web page.[47] Instead of the lower "trade-in" value—the estimated price a dealership would be expected to offer—the higher "private party" value is used, reflecting "the price you could expect for a vehicle sales transaction between two consumers."[48]

Charger. BEV owners are assumed to invest in a home charger, estimated to cost $1,836, including labor installation expenses.[49] Plug-in hybrid (PHV) buyers are assumed to forego the added cost of installing an electric charger. PHV owners can use their gasoline-combustion powertrain when the electric range is exhausted, making them less dependent on their electric powertrain and able to forgo the expense of a charger, as many do.

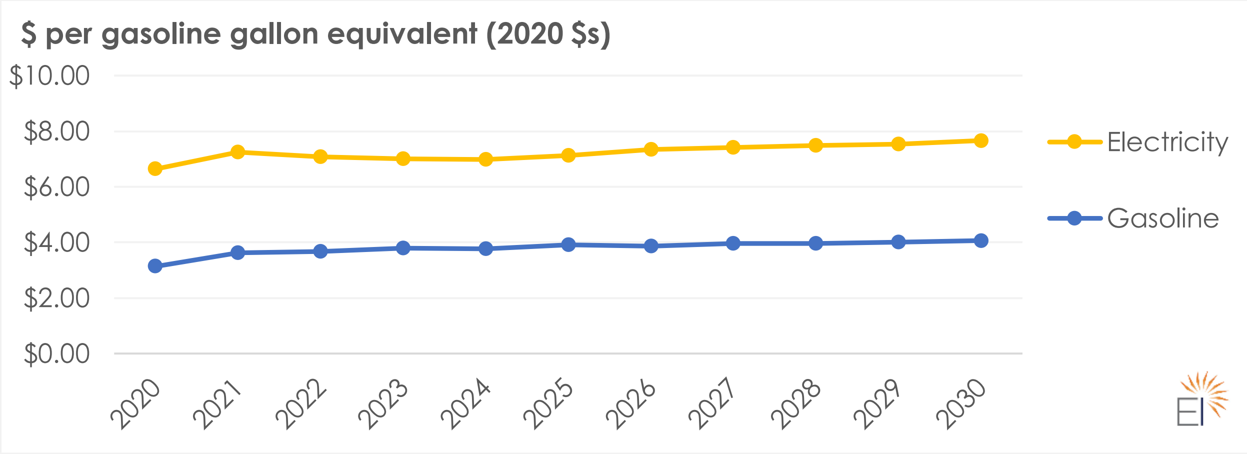
Fuel. Fuel expenditures are a function of fuel efficiency, fuel prices, and distance driven. Vehicles are assumed to travel 11,400 miles per year, the national light-duty vehicle average in recent data.[50] Fuel efficiency specifications for each vehicle make and model are drawn from the U.S. Department of Energy's "fueleconomy.gov" website, as are battery specifications and new vehicle range. Battery degradation is assumed to lead to a 10 percent reduction in battery range compared to a new vehicle.[51]

Fuel prices are based on current prices for the first year of ownership. Future year prices are a function of current price adjusted by the year-over-year changes in the Pacific region forecast in the U.S. Energy Information Administration's 2021 Annual Energy Outlook. Gasoline prices for 2021 and 2022 are based on the U.S. Energy Information Administration's Short-Term Energy Outlook. This leads to an estimated 2021 price of $3.62 per gallon, lower than recent levels.

[ii] Net present value methodologies account for future cash flow impacts in current dollar value terms. Money in hand now is considered more valuable than money in the future. Future money is less valuable partly because inflation erodes its buying power. Behavioral economists have also pointed to evolutionary reasons for time preferences. The effect of the discount rate (d) for a given year 't' years in the future can be represented mathematically as the scalar: $1 / (1+ d)^t$. For this study, with the 8 percent value used in the main, discounting means that one dollar saved in the second year of ownership is worth approximately 93 cents and one dollar saved in the fifth year of ownership is worth approximately 74 cents.

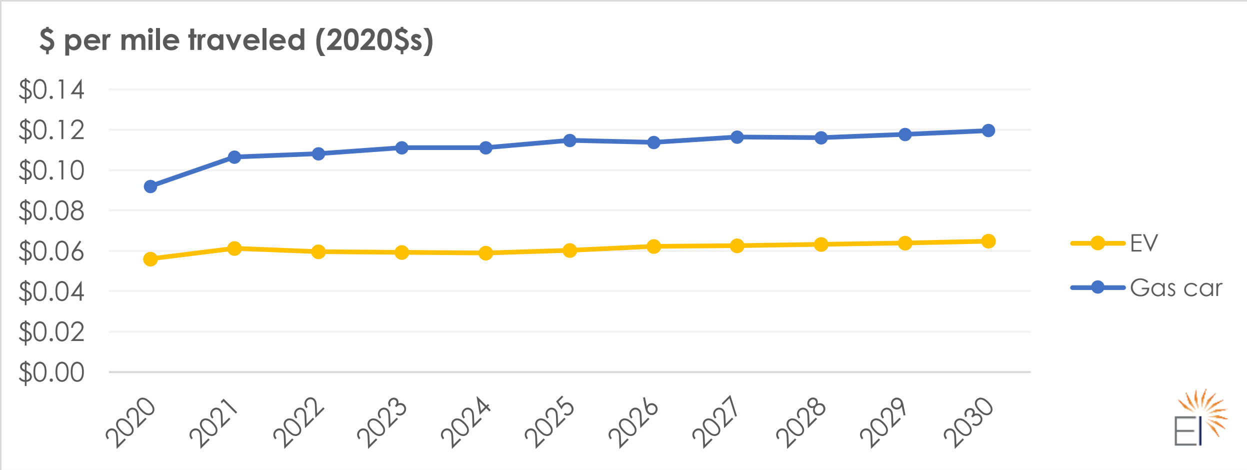
EV electricity prices are a weighted average of home charging, workplace charging, other public charging, and fast charging prices. BEV owners are assumed to access fast charging—the quickest and most expensive option for public charging, relying on direct current technology—for 5 percent of charging electricity demanded. PHV owner are assumed to avoid this costly charging option, instead using gasoline capability for longer-range trips that might lead BEV drivers to access fast charging. The small fraction of fast charging in the average BEV owner's basket of charging means the divergence in average electricity prices is not so large. The difference for BEVs and PHVs amounts to less than a cent per kilowatt hour for rates around 18 cents per kilowatt hour. Larger proportions of fast charging are tested as a sensitivity analysis. For simplicity, the graph of future expected fuel prices in Figure 6, below, charts a single EV price, calculated as the weighted average of BEVs and PHVs.

Figure 6. Transportation fuel price outlook



Fuel costs also hinge on vehicle fuel efficiency, and in fact the EV efficiency advantage more than outweighs the higher cost of electricity per unit of energy content.[iii] Below, Figure 7 illustrates that gas cars are more expensive in terms of the more important metric of cost per mile traveled.

Figure 7. EV efficiency advantage yields lower fuel cost per mile traveled



[iii] For an equivalent in the more familiar kilowatt-hour units, the electricity price is $0.18 per kWh in 2021.

Each EV's "utility factor" also has a role in determining fuel cost. Utility factors indicate the share of miles expected to be covered with electricity vs. gasoline for each EV, given its all-electric range. In practice, for PHVs, this determines the share of vehicle miles traveled with its electric versus internal combustion powertrains. For BEVs, the cost of travel demand satisfied with gasoline-combustion is determined by its counterpart vehicle's fuel cost per mile. For example, the gasoline cost per mile for the Chevrolet Bolt is based on the Chevrolet Sonic's fuel cost per mile.

Maintenance. Maintenance costs are specified according to averages for gas cars, BEVs, and PHVs, specifically with empirical data from Consumer Reports′ 2019 and 2020 annual reliability surveys, which sample hundreds of thousands of vehicle owners. Maintenance costs cover regular maintenance and unexpected repairs. Consumer Reports' analysis finds EVs have 60 percent lower maintenance expenses[52]

Insurance. The difference in insurance cost for EVs versus gas cars is not large. It is worthwhile including nonetheless because of the interest in analyzing the broader EV savings relative to total cost for a gasoline car. A recent study by the International Council on Clean Transportation estimates the cost of insurance for a new EV to be $170 per month compared to $153 for a new gas car.[53] To account for the fact that insurance is more expensive for new cars, we scale down this difference to align with the average cost of insurance in California.[54] This leads to a net increase of $515 in insurance costs for EVs over the average ownership period on a net present value basis.

Depreciation. Depreciation refers to the decline in value that occurs as a new vehicle advances in age and number of miles driven. The depreciation variable accounts for differences in residual value—the value at the end of the ownership period. Work by Consumer Reports in 2020 found residual value differences are diminishing as BEVs improve in range, convenience, and other quality markers, and accounting for federal tax credits. Mid- and higher-range BEVs show no significant difference in depreciation compared to gas cars. Short-range BEVs do show evidence of depreciating more quickly than conventional cars: "The data show that with the exception of mainstream BEVs with less than 100 miles of range, all EV categories are expected to hold their value approximately as well as comparable internal combustion engine vehicles."[55] Therefore, for BEVs with less than 100 miles of range, this study approximates lost residual value beyond standard depreciation and adds it to ownership cost under deprecation. This depreciation cost applies to three vehicles sampled in this study: the 2017 model year Nissan Leaf and the Kia Soul EV for the 2017 and 2018 model years.

SAMPLING OF 2017 AND 2018 MODEL YEAR VEHICLES

The decision to focus data analysis on 2017 and 2018 model year vehicles resulted from the interplay of several factors. The average new car lease lasts three years, which suggests a reasonably abundant supply of those model year vehicles. Vehicles from that period have also aged enough to exhibit significant depreciation in value since first purchase. The result of depreciation is that it reduces the importance of the EVs purchase price premium, meaning "used-car buyers capture a large fraction of the lifetime utility of a vehicle while paying a relatively low percentage of the new-car price."[56] Model year 2019 or 2020 vehicles would exhibit weaker depreciation effects, since less time has passed since purchase, making it more difficult to detect the hypothesized used EVs effect. Therefore, sampling was limited to 2018 or older cars.

The decision to exclude 2016 or earlier vintages follows from the insight that sampling and analyzing the same set of makes and models over time makes it easier to disentangle innovation and cost trends. Otherwise, results are significantly driven by the large changes in the mix of vehicles sold from year to year. EV trends are evolving quickly because the technology and market are not yet fully mature. For instance, the Tesla Model 3 shook up the industry when it was introduced in 2018, grabbing a leading market share in its debut year.

More importantly, the Chevrolet Bolt had not yet been introduced in 2016. The introduction of the Chevrolet Bolt in 2017 is the second key reason to begin the analysis with model year 2017. In 2017, the Bolt set the all-time EV record in its Consumer Reports' range test, topping 250 miles traveled, outperforming its U.S. Environmental Protection Agency-rated range and all vehicle tested before then.[57] Because the Bolt reset expectations for fully electric economy vehicles, its inclusion in the study was deemed essential.

SALES-WEIGHTED AVERAGE EV AND COMMENSURATE GAS CAR

The goal for constructing generic vehicle types was to achieve commensurability—an apples-to-apples comparison, in informal terms. The method seeks to approximate a representative sample through broad coverage of top-selling, non-luxury EVs. This is a type of quasi-representativeness that can be distinguished from random sampling data collection techniques.

The California Energy Commission's Zero Emission Vehicle and Infrastructure Statistics web page is the source for sales data.[58] In practice, the approach involves aggregating the top selling EVs for model years 2017 and 2018 and subtracting vehicles identified as luxury or not available in both years. The included EVs range from subcompact to mid-size. The Chrysler Pacifica PHV was available in both 2017 and 2018. Because it is clearly distinguishable in size and cost from other vehicles included, it was excluded from the analysis. However, the conventional Pacifica and the PHV version are compared as a pair in the Results section.

Applying this approach produces a sample of five BEVs and four PHVs. Details on makes and models represented by the "average" EV and their sales are listed in Table 3.

Table 3. EV models sampled and 2017-2018 sales

Make	Model	Label	2017-2018 model year sales	Sales percentage
Chevrolet	Volt	PHV-Volt	24,284	28%
Chevrolet	Bolt	BEV-Bolt	22,548	26%
Toyota	Prius Prime	PHV-Prius	21,311	25%
Nissan	Leaf	BEV-Leaf	9,920	11%
Volkswagen	e-Golf	BEV-Golf	4,308	5%
Kia	Soul EV	BEV-Soul	1,400	2%
Kia	Optima	PHV-Optima	1,239	1%
Hyundai	Sonata	PHV-Sonata	1,012	1%
Hyundai	Ioniq	BEV-Ioniq	784	1%
		Total	86,806	100%

Source: California Energy Commission[59]

The approach to developing the "average" gas vehicle takes advantage of the fact that most—all but three—of the included EV models are also available with gasoline-combustion-only powertrains. Whenever a gasoline-fueled version of an EV was offered, it is used as the obvious choice for that EV's gas car counterparts in the weighted-average gas car calculation. This approach reduces the statistical noise from non-powertrain-related differences between vehicles.

Some EVs— the Bolt, Volt, and Leaf — have no gas-fueled powertrain version. In these instances, cargo and size specifications were used to identify similar vehicles.

Table 4 gives specifications for the Bolt, Volt, and Leaf and the gas vehicles selected as their analogs for inclusion in the average gas vehicle.

Table 4. Specifications for Bolt, Volt, and Leaf and their gas car counterparts

	EV	Gas car		EV	Gas car		EV	Gas car
Make	Chevrolet	Chevrolet		Chevrolet	Chevrolet		Nissan	Nissan
Model	Bolt	Sonic		Volt	Cruze		Leaf	Versa
Passenger volume	94 ft^3	91 ft^3		90 ft^3	95 ft^3		92 ft^3	94 ft^3
Cargo volume	17 ft^3	19 ft^3		11 ft^3	19 ft^3		24 ft^3	19 ft^3
Length	164 inches	160 inches		180 inches	175 inches		176 inches	163 inches

Hatchback versions selected for both Chevrolet Cruze and Nissan Versa.

Sources: Kelly Blue Book,[60] U.S. Department of Energy[61]

LIMITATIONS

This study provides insights on the cost savings resulting from the increasing availability of non-luxury used EVs, offering a current consumer perspective on transportation electrification. Like any study, there are boundaries to our analytical scope. Analysis of total ownership costs ignores the effects of reducing local and global air pollutant emissions, including public health and climate benefits.

The ownership perspective is just one of several economic dimensions to a transition to EVs. Last year, the International Council on Clean Transportation published an influential study of EV production costs in the U.S., factoring in not just the cost of manufacturing but also research and marketing costs.[62]

Macroeconomic impacts are also beyond the scope of total-cost-of-ownership analysis, but other research provides reason for optimism that electrification will provide job creation and growth benefits. A Next10 study estimates that, in 2030, the state's EV policies will create 500,000 additional jobs in California while boosting real income by $300 billion, noting that "employment and income benefits are proportionately higher among Disadvantaged Communities."[63]

RESULTS

TOPLINE

The review of findings begins with the topline results, i.e., the highest-level summary findings, on total cost of ownership and purchase price. As detailed in the comparative metrics discussion, EV ownership savings refer to the net difference in total ownership cost between an average EV and a comparable gas car. Ownership savings are estimated to be $1,100 for model year 2017 EVs and $500 for model year 2018 EVs. Lower fuel and maintenance expenses generate savings for EV buyers but, for the 2017 and 2018 model years evaluated, EVs cost more to buy than comparable gas cars. In other words, they carry a purchase price premium. This study finds the current purchase price premium to be $1,800 for model year 2017 and $2,400 for model year 2018.

Table 5. EV ownership savings and purchase price premium

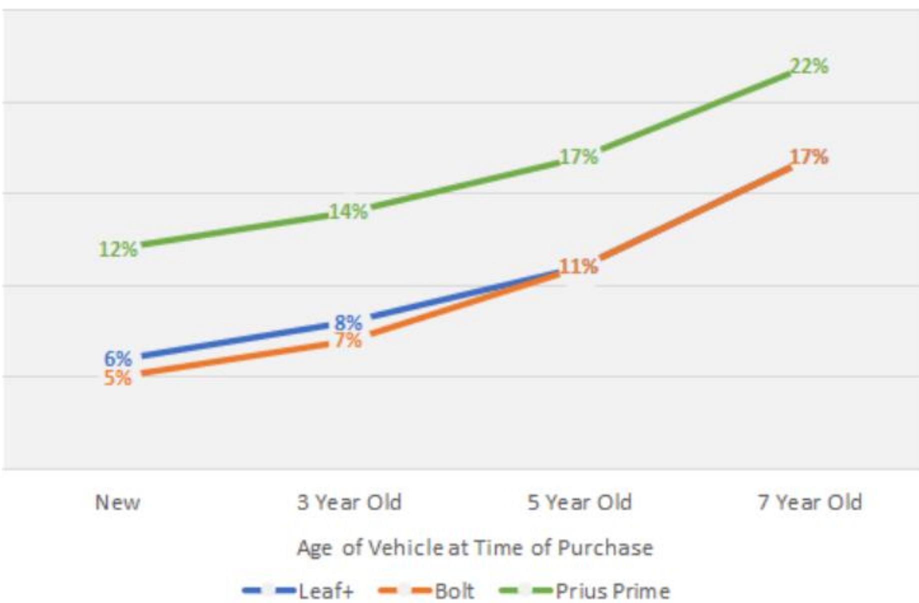
	2017 model year vehicles	2018 model year vehicles
EV ownership savings	$1,100	$500
EV purchase price premium	$1,800	$2,400

Source: Energy Innovation analysis

Initially, the market value of motor vehicles declines markedly, falling by more than half in the first five years. Depreciation affects both EVs and gas cars, shrinking the absolute size of the difference in vehicle prices over time.[iv] Depreciation also reduces the magnitude of vehicle purchase price as a share of total ownership cost, while increasing the share of fuel and maintenance in ownership cost. These are the origins of EV ownership savings in these results.

The $600 greater total ownership savings for 2017 compared to 2018 vehicles, shown in Table 5 is directly traceable to the $600 difference in the vehicle purchase price premium for the 2018 model EV at $2,400 and the 2017 model year EV at $1,800. This makes intuitive sense, as other changes between years are minimal. Vehicle fuel efficiency does not change markedly from year to year. The most notable change, the introduction of the second-generation Nissan Leaf in 2018 means there is no associated depreciation penalty in that model year. Yet the lower depreciation cost in model year 2018 is too small to noticeably effect these topline results.

Figure 8. Ownership savings grow with increasing age of used EV at time of purchase



Source: Consumer Reports[64]

[iv] A numerical example may clarify how depreciation shrinks the EV purchase price premium even if depreciation affects EVs and gas cars at the same percentage rate. Consider a stylized hypothetical with an initial difference between two values: 100,000 – 90,000 = 10,000. Suppose both values are reduced by a factor of 1,000. After this depreciation of the initial values, the difference now stands at: 100 – 90 = 10. Even though both initial values are affected equally, the absolute difference between the two values decreases. This illustrates how vehicle depreciation reduces the size of the price premium over time.

This study's finding of greater ownership savings in 2017 than 2018 is consistent with Consumer Reports' used EV research. That work identified a multi-year trend of total ownership savings increasing with used EV age, as illustrated in a graph excerpted above (Figure 8).

We turn next to use ownership cost results to provide new visibility into the affordability impacts of consumer incentives. California's Senate Bill 771 is among the proposals to introduce such tax waivers to induce EV purchases.[65] The first analysis is of the effect of a $9,500 consumer rebate—the maximum amount available under Clean Cars 4 All. The research finds such an incentive leads to ownership savings for non-luxury used EVs of nearly 40 percent compared to comparable gasoline vehicles. The analysis finds the effect of waiving the state's 7.5 percent sales tax for EV sales is equivalent to reducing the average purchase price premium for non-luxury EVs by an estimated 63 percent and 57 percent for model years 2017 and 2018, respectively. Table 6 gives results for affordability effects of consumer incentives and tax waivers for buyers of the 2017 and 2018 EV models studied.

Table 6. Consumer affordability impacts of EV policies

Incentive policy evaluation	2017	2018
Ownership savings including $9,500 incentive	$10,400	$9,800
Reduction in EV ownership cost including $9,500 incentive compared to gas car	38%	34%
Sales tax waiver policy evaluation		
State sales tax on average EV	$1,170	$1,350
Reduction in purchase price premium due to state sales tax waiver for EVs	-63%	-57%

Source: Energy Innovation analysis

The finding that incentives such as those available under Clean Cars 4 All lower EV cost by nearly 40 percent compared to gas cars is striking. If another clean energy or climate policy delivers such dramatic affordability benefits, our research did not uncover it.

TOTAL OWNERSHIP COST BY POWERTRAIN

The next set of results drill down deeper, examining the separate BEV and PHV results underlying their aggregation in average EV results. Graphical breakdowns of ownership cost for different vehicle types, provide a visual representation of the fundamental narrative: the higher fuel and maintenance costs of gas cars make them more expensive from the total cost of ownership perspective. costs by powertrain type for model year 2017 and model year 2018 are in Figure 9 and Figure 10, respectively.

Figure 9. Breakdown of ownership costs for different vehicle types – 2017 model year

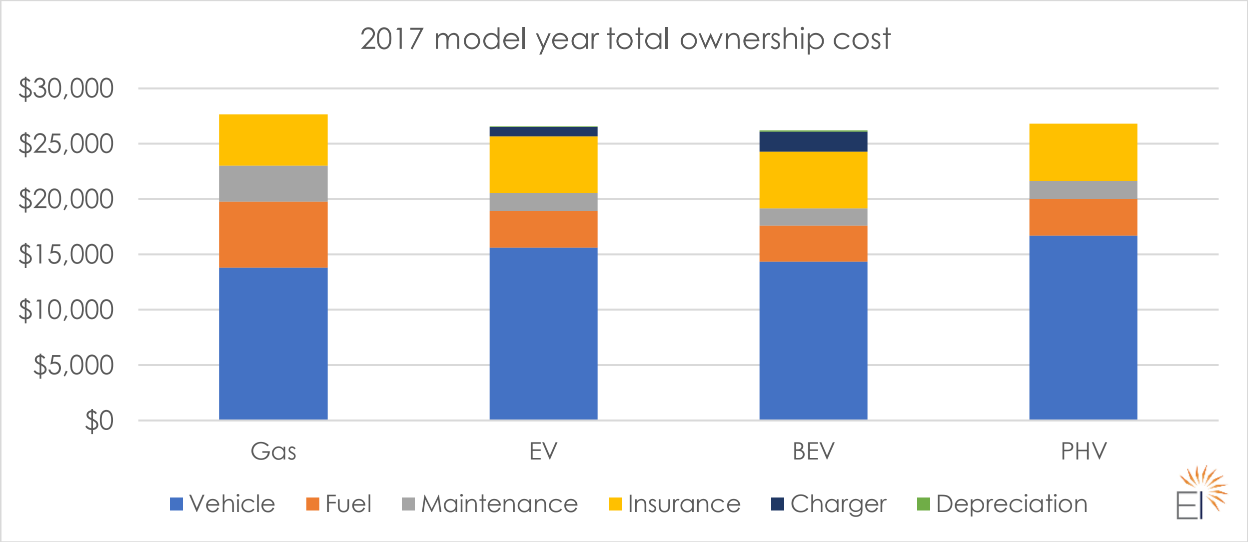


Figure 10. Breakdown of ownership costs for different vehicle types – 2018 model year

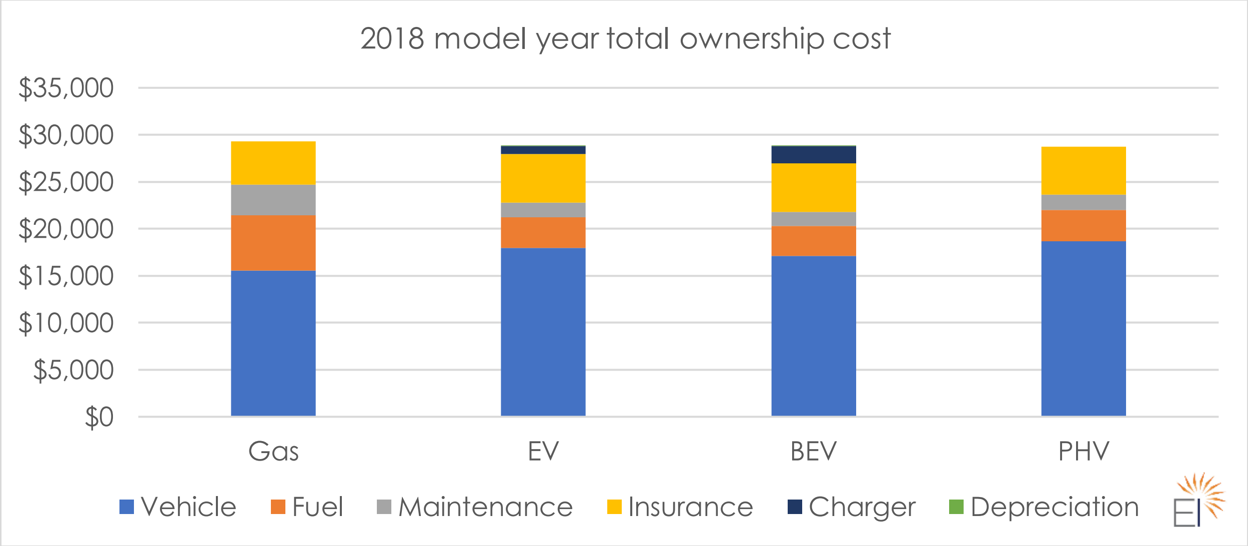


Table 7, next, gives numerical results for total ownership savigs and purchase price premium, including the more detailed breakdown by powertrain, across the two model years.

Table 7. Breaking down total ownership savings and price premium for different vehicle types

2017 model year	Ownership savings	Price premium
EV	$1,100	$1,800
BEV	$1,400	$600
PHV	$800	$2,900
2018 model year	Ownership savings	Price premium
EV	$500	$2,400
BEV	$500	$1,500
PHV	$500	$3,100

Source: Energy Innovation analysis

Two notable trends are illustrated in Table 7. First, results highlight the lower purchase price premium for BEVs compared to PHVs in both years. This result can be traced to the expected steeper loss in residual resale value for short-range BEVs.[v] A residual loss in market value for the first buyer is a boon for the second owner.

Second, results in Table 7 show a narrowing of the price premium difference between BEVs and PHVS, which dropped from $2,300 in 2017 to $1,500 in 2018. This narrowing difference can be traced to the 2018 introduction of the next-generation Nissan Leaf, with a new range rated at 151 miles per full charge, which left the Kia Soul EV as the only vehicle in 2018 with a sub-100 mile range.

Table 8. Range specifications for short-range BEVs

	New vehicle 2017 model	New vehicle 2018 model	Used vehicle 2017 model	Used vehicle 2018 model
Kia Soul EV range	93 miles	111 miles	84 miles	100 miles[vi]
Leaf range	107 miles	151 miles	96 miles	136 miles

Source: Energy Innovation analysis and U.S. Department of Energy

The minimal size of the depreciation effect is another key result. The modest aggregate effect is a function of several factors. First, a used EV's purchase price already reflects depreciation under the first owner. Second, the standard application of annual discounting imposes a steep time discount, making a dollar in the residual value penalty at time of resale only worth roughly 65 cents in current dollars. Third, the overall effect on EVs is further lessened by the fact that only a small subset – two vehicles in 2017 and one in 2018 – are subject to additional depreciation effects. Though the impact on average EV cost is small, the residual effect penalty estimated for the affected vehicles is hardly trivial, as Table 9 shows.

[v] Covered in the "Depreciation" portion of the Methodology section.

[vi] Though the table list's model's range as 100 miles, this is a result of rounding. At three significant figures, the value equals 99.9. Therefore, the 2018 Kia Soul EV is treated as a short-range BEV for purposes of assigning costs in the depreciation category.

Table 9. Residual resale price effects for short-range (sub-100 miles) BEVs

	Present value	Undiscounted value
2017 Leaf	$405	$572
2017 Soul-EV	$495	$700
2018 Soul-EV	$589	$833

Source: Energy Innovation analysis

Another perspective on results is developed through "pairwise analysis"—comparing ownership savings and price premium for a given EV against its gas counterpart. This deeper level of disaggregation reveals a pattern broadly aligning with higher-level results. Figure 11 and Figure 12 gives pairwise results for ownership savings and price premium, respectively, both of which are broadly in line the topline findings. Total ownership savings are larger and purchase price premium smaller for 2017 model year EVs. Total ownership savings decrease in 2018 for seven of nine EVs. The 2018 purchase price premium is larger for six of nine EVs. The strong purchase price premium for the Bolt reflects strong consumer demand. The Bolt was the top-selling subcompact in 2020 after ranking second in 2019.[66]

Figure 11. Pairwise analysis of total ownership savings

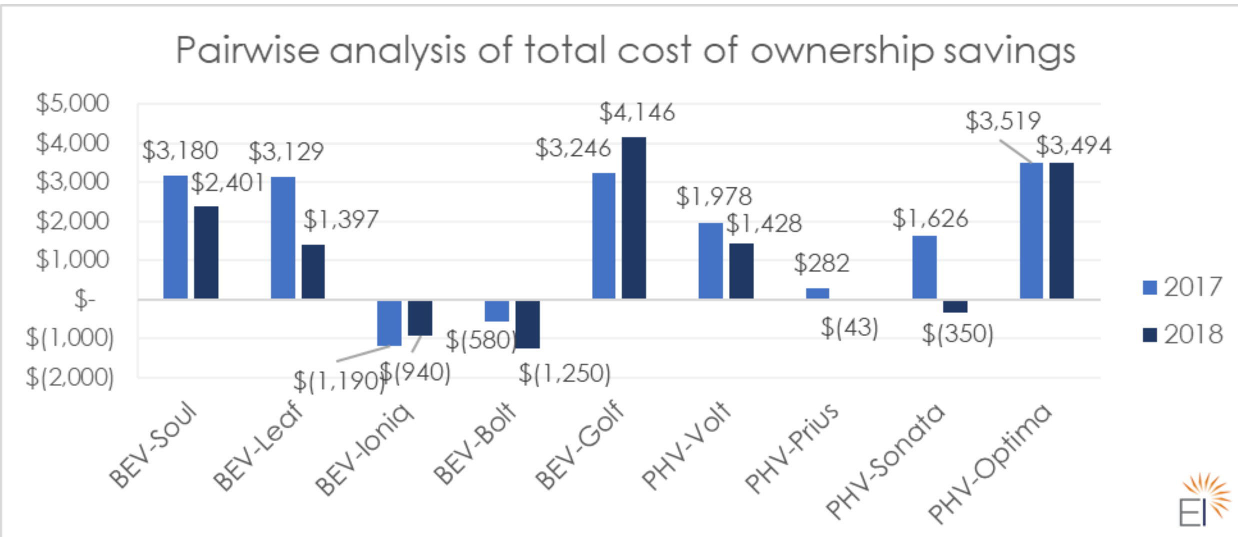
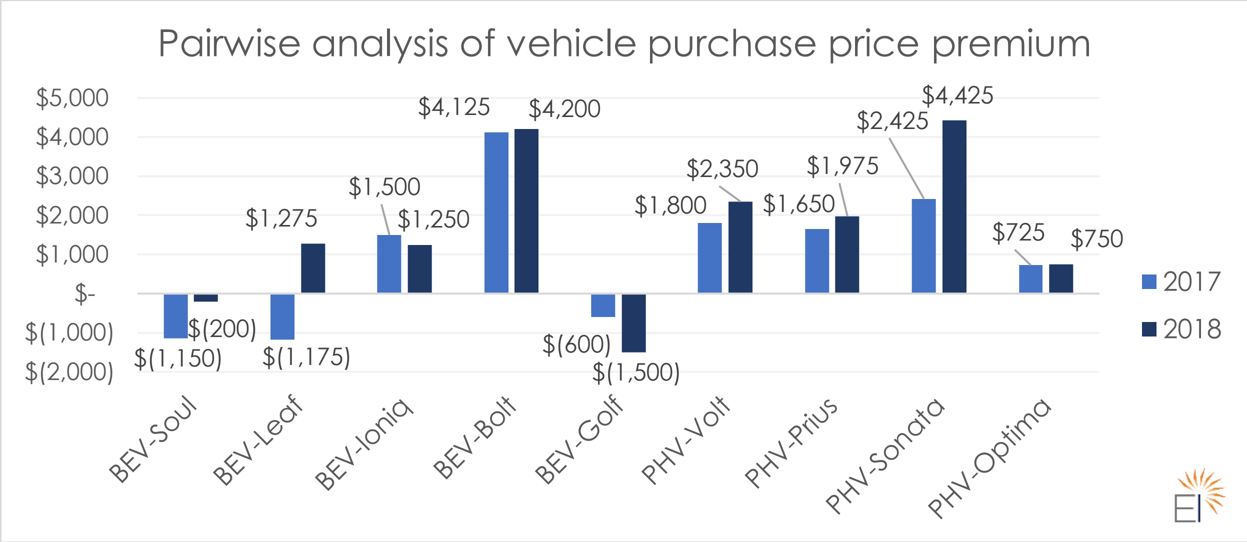
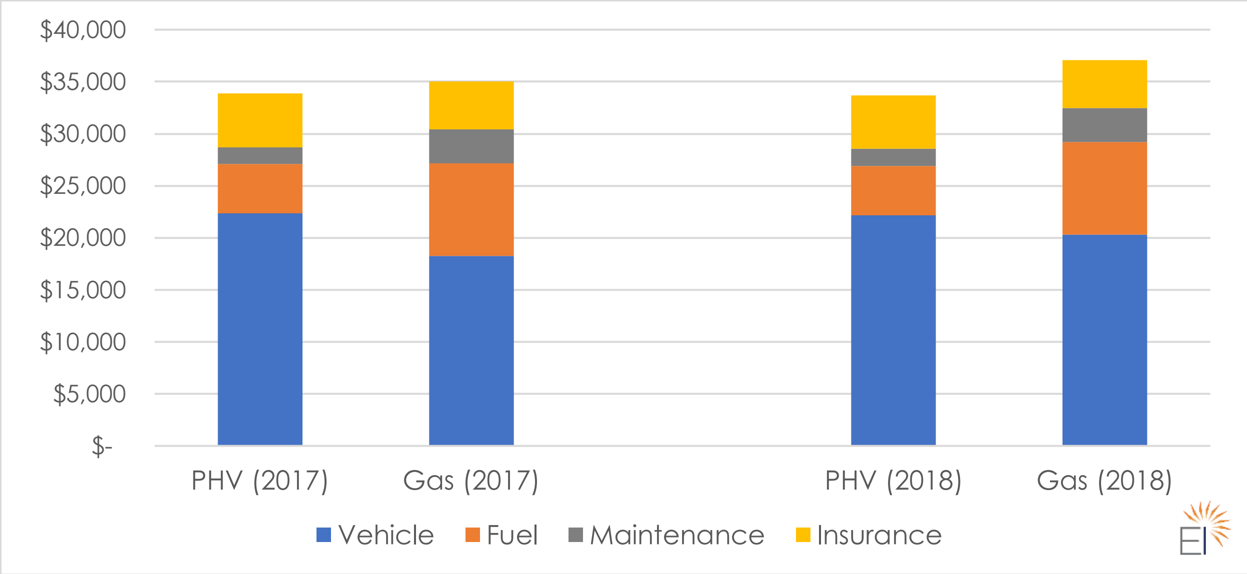


Figure 12. Pairwise analysis of vehicle price premium



Results presented thus far have excluded the Chrysler Pacifica minivan in favor of limiting analysis to vehicles of more similar size. Figure 13 breaks down the Pacifica's total costs for the PHV models versus the gas-fueled models.

Figure 13. Chrysler Pacifica minivan pairwise comparison finds EV ownership savings



POLICY IMPLICATIONS

California's Senate Bill 350 launched a major effort to understand barriers to adoption and use of clean technologies in less advantaged communities—and to develop ways to overcome those barriers.[67] An information gap was found to be an obstacle to consumer adoption of EVs: "In making vehicle purchase decisions, clean vehicles are not yet viewed as affordable, reliable or as convenient as gas counterparts."[68] The findings presented here are offered in service of remedying this information gap, and coupled with other sources, yields policy recommendations on five topics:

1. ***INCENTIVES.*** Consumer incentives for potential EV buyers continue to have an important role in an effective, equitable transition. Targeted incentives can deliver dramatic economic equity benefits and without such incentives, lower-income households are most at risk of being unable to access EV ownership savings.[69] Incentive support targeted at the median car buyer remains important. Greater funding certainty will give consumers confidence support will be there when needed, increasing policy efficacy.
2. ***FINANCING.*** The California Public Utility Commission should instruct utilities to offer financing support for EV purchases, starting with used vehicles, through on-bill investment options for utility customers. Policies enabling energy upgrades through utility bill investment have a track record of success and could be established under current regulatory authority, without new legislation.[70] In general, financing policies leading to favorable loan terms—low or zero down payments and interest rates—can significantly lower consumer cost.
3. ***ELECTRICITY PRICING***. Cap-and-trade program revenue should be returned to utility customers to reduce electricity rates, recognizing that lower electricity prices improve incentives for potential EV buyers. The current, more than decade-old, approach returns funds to people on a lump-sum basis.
4. ***INFRASTRUCTURE.*** California policy should continue to develop ongoing direct support for EV charging to ensure widespread and equitable access.[71] Absent policy intervention, there is a high risk of gaps in service for existing multi-unit buildings, particularly for those located in higher density urban areas and in less wealthy neighborhoods.
5. ***CLEAN ENERGY MANUFACTURING***. California policy should target manufacturing and other good jobs development in the battery-electric storage industry, from final battery assembly to production of the lithium metal inputs. The technology is important to the future of both the electric grid and transportation. Moreover, the state's battery exports grew by a factor of four over the last decade.

INCENTIVES

The topline conclusion of this research is that consumer incentive policies continue to play an important role in an effective, equitable transition to EVs. Used EVs cost more to purchase in the absence of government support, and car buyers are known to be particularly attentive to up-front cost.

Consumer incentives are a tool for broadening access to EV ownership savings. The EV purchase price premium will be an especially large hurdle for lower-income households, which often cannot afford the added up-front investment needed to unlock the stream of future energy and maintenance savings that EVs offer.[72] The purchase premium for new EVs is shrinking over time, and eventually new EVs are expected to cost less than new conventional cars. For now, incentives play a critical role in overcoming the purchase price premium, increasing accessibility, and ensuring consumer savings from day one.

Results also show that **used EV incentives like those available under Clean Cars 4 All can deliver dramatic economic benefits to less wealthy households and areas historically overburdened with pollution.** The nearly 40 percent reduction in ownership cost appears to represent an equity benefit that is unmatched among other energy, climate, and transportation policies. The impact of these savings is amplified by the relative burden of transportation costs for less wealthy households. Transportation is the second-largest expense for all U.S. households, but presents a particular burden for people with relatively low income.[vii] As a share of after-tax income, transportation costs for households making $22,487 or less per year are more than three times larger than for households with income of $120,729 or more (37.4 percent and 11.0 percent of total expenditures, respectively).[73]

Incentive support targeted at the median car buyer remains important. Broad encouragement of consumer uptake is needed as new EV sales expand beyond early enthusiasts to mainstream buyers. Continued funding and greater certainty about future allocations are essential for optimizing the state's flagship Clean Vehicles Rebate Program.

This study does not directly address how to optimize incentive levels for maximum effectiveness from the perspective of public finance efficiency. The State Auditor recently pointed out the missed opportunities for collecting data on program performance, using incentive programs as a case study. The State Auditor's sensible recommendations merit action by the California Air Resources Board, supported by the legislature with additional resources as appropriate. More data should be collected across the board, as well as to specifically support optimizing vehicle incentive programs.

Although incentive programs could benefit from refinements in design, academic and finance research has conclusively demonstrated the importance of these programs. "Credits and rebates play a key role in building the consumer market for cleaner electric vehicles," conclude specialists from the Institute for Transportation Studies at the University of California, Davis.[74] The research team identified 32 separate, high-quality studies showing the positive and statistically significant relationship between consumer incentives and EV sales. In the realm of market research, UBS's global research unit surveyed 10,000 new car buyers on factors important to determining whether they would buy an EV. Higher purchase price was the most frequently named concern.[75]

FINANCING

Expanded governmental support for EV financing is another priority for a fair and fast transition to EVs. Though used cars are less expensive than new cars, used car buyers still frequently use credit. Favorable loan terms—low or zero down payments and interest rates—greatly reduce the cost of credit and would expand access. The Public Utilities Commission's Transportation Electrification Framework identifies and gives emphasis to solving the barriers created by up-front costs and the tighter income constraints of less wealthy households.

One immediately available financing policy option would allow EV buyers to partner with electric utilities to secure better financing. Such policies have a track record of success, though they have not yet covered EV purchases. In these programs, sometimes referred to as on-bill financing programs, utilities use their

[vii] Transportation costs include public transit and airline travel but the lion's share of spending – over 90 percent – relates to motor vehicle ownership and use.

strong credit to secure favorable rates on behalf of customers, who in turn pay loans back as part of their regular utility bill. Eighteen states have offered on-bill financing, amounting to $30 million in financing. Repayment rates are high even in lower-income areas.[viii] The California Public Utilities Commission would not need new legislation to order utilities to offer such on-bill financing—it can do so using current regulatory authority.[76]

To understand why financing policies are essential to decarbonization success, we must recognize that much "infrastructure" is small and distributed, located "behind the meter" on the customer's property. The EV in the garage, the solar panels on the roof, the heat pump and battery in the basement, all connected to and interacting with the grid—this is the infrastructure of the future.

Financing policy design may involve either direct lending or loan guarantees. Loan guarantees reduce risk for private lenders through management of compensation funds, other insurance mechanisms, or legal commitments to cover losses. Loan guarantees reduce private lender risk, lowering interest rates. California has established several financing programs that directly or indirectly advance clean energy, principally within the State Treasurer's Office.[ix] The Newsom administration has developed innovative approaches to leverage public funds for maximum private investment through government loan guarantees or revolving loan funds, including for EV charging infrastructure.

The U.S. Department of Energy's Loans Program Office's track record offers empirical evidence that clean energy financing policies are a cost-effective way to use public dollars. One way to boil down the effect is to compare interest and fee payments generated by the program with losses incurred due to defaults. In a recent GAO assessment, incoming revenue exceeded portfolio losses by more than $1 billion.[77] From this perspective, the Loans Program Office is a net revenue earner, adding to the public treasury rather than drawing it down. In congressional testimony, the director of the office observed: "Actual and estimated losses for the portfolio represent just above 2 percent of closed and committed loans and loan guarantees—a rate that would be viewed favorably even in the private sector for a portfolio of a similar type."[78]

The emergence of utility-scale solar power technology illustrates the Loans Program Office's effectiveness as a clean energy accelerator. In 2011, federal loan guarantees helped to build the first five utility-scale solar power generation plants constructed in the U.S. These projects are repaying their loans on schedule. Arguably more important is the fact that the projects have helped to launch a thriving industry. Since those first government-backed projects, purely private capital has stepped in, and solar power has become the fastest-growing renewable power source in the U.S.

A New Deal case study illustrates the transformative potential of financing policies. The Rural Electrification Administration offered rural electric cooperatives low-interest, 20-year loans. The program succeeded in

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[viii] The referenced report, with identifying details in the end note, states: "Utilities that have experience offering tariffed on-bill programs have reported results that indicate consistently high adoption rates for building energy efficiency upgrades and low charge-off rates for nonpayment, even in areas characterized by conditions of persistent poverty."

[ix] The California Alternative Energy and Advanced Transportation Financing Authority (CAEATFA) is an important center for state financing policies. CAEATFA's Sales and Use Tax Exclusion Program allows qualifying clean energy manufacturers to avoid paying sales tax on new capital equipment in their factories. CAEATFA manages the California Hub for Energy Efficiency Financing Pilot Programs for the California Public Utilities Commission. In the most recent data we found, from December 2019, we learned the residential pilot supported upgrades to approximately 600 homes since 2016. The small business pilot was launched more recently, in 2019.

increasing the percentage of rural households served by the electricity grid from 10 percent in 1935 to 40 percent in 1940 and 90 percent in 1950. With a high repayment rate, the program earned the federal treasury a small net gain.[79]

The Reconstruction Finance Corporation, as its name suggested, played a central role in the financing policy response to the Great Depression. It created a novel loan loss reserve fund, managed by the government but seeded with funds from private companies, to unlock credit in the home mortgage market. The program unleashed a surge of investment, creating an estimated 750,000 jobs "all without the government needing to spend a dime of taxpayer money."[80] The implementation of federal home loans support demonstrates the promise of such credit-based policies, but also offer cautionary tales about unfair implementation. In New Deal home mortgage support, racial and ethnic bias led to entire neighborhoods being labeled high-risk, "red-lined," facing higher interest rates or exclusion.[81] This history creates an obligation for fair access as a bedrock principle of such policies going forward.

PRICING

California electricity rates are under pressure from wildfire-related costs. At the risk of stating the obvious, the price of electricity is an important factor in the financial attractiveness of switching to an EV, so higher electricity prices create a drag on consumer adoption. Legal liabilities from past wildfires along with planned spending to reduce future wildfire risk are estimated at more than $38 billion. These costs are not yet accounted for, and, absent corrective action, are expected to roll into electricity prices in coming years.[82]

One step toward lessening this problem would be changing how carbon pricing revenue is used for the public good by using it to reduce electricity rates. Since the inception of the cap-and-trade program, revenue from the sale of carbon allowances has been returned to people on a lump-sum basis through the "California Climate Credit" on all utility bills in the state. The California Air Resources Board explains the approach as follows: "For investor-owned utility ratepayers, all Cap-and-Trade Program costs are passed through in electricity rates, and proceeds from the auction of allocated allowances are used to benefit ratepayers."[83]

The rationale for the lump-sum payment was that it put carbon revenue to use for consumers, lowering total bills while also allowing electricity rates to increase because of the addition of the carbon price. Higher rates were viewed as advantageous for encouraging conservation and energy efficiency. At the time, electrification had not emerged as the leading decarbonization strategy that it is today.

Adjusting the formula for carbon pricing revenue so that it reduces rates is just a first step. Indeed, discussions are already underway about identifying additional revenue streams to mitigate future electricity price increases.

INFRASTRUCTURE

California is aiming to attract private capital to underwrite some of the investment required to keep up with EV charging needs. Such efforts are a smart way to leverage public funds. At the same time, as the Public Utilities Commission's Transportation Electrification Framework acknowledges, it is important to anticipate the need for ongoing policy work and direct public investment to ensure widespread and equitable access to charging infrastructure, especially in multi-unit buildings.[84] Because the infrastructure build-out is in a relatively early stage, it makes sense to consider a wide range of options. Channeling investment through electric utilities is one proven approach. California should consider establishing a new public charging authority dedicated to this task. While the merits of various policy design options deserve further evaluation, it seems clear that without new and sustained efforts there is a risk of large service gaps, particularly for residents of existing multi-unit buildings.

Attracting private capital is an important strategy, but its effectiveness depends on a profit motive. The viability of EV charging as a stand-alone business appears in some doubt. The California Energy Commission's recent evaluation of future charging infrastructure needs points out: "Charging businesses are evolving beyond a model of selling electricity, which alone may be insufficient for sustainable operations."[85]

The task of bundling services to cobble together a viable business model will be easier in wealthier places. Again, it is critical to consider other policy approaches to reach communities at risk of being left behind, particularly for residents of existing multi-unit dwellings. If mobility is not a human right, it is at least an essential service.

For practical reasons anchored in behavioral economics, existing building owners are unlikely to install enough EV chargers on their own.[86] A report by Adena Energy and Clean Energy Works identifies a promising approach to overcoming these challenges in some circumstances: allowing for third-party investment, ownership, and operation.[87]

Policies that promote third-party investment can unlock additional capital for funding the infrastructure needed to serve existing buildings or in community-scale projects.[88] Even with such novel approaches, ongoing public investment and policy support probably will be needed to attract private capital to some locations. Ensuring fair access to residents of existing multi-unit buildings appears to be a particularly daunting challenge.[89]

A recent California Energy Commission assessment found public chargers are mostly absent or scarce in dense urban residential census tracts and concludes: "Preliminary distribution analysis indicates that more public EV infrastructure investments and deployments may need to be targeted in low-income communities and high-population-density neighborhoods to enable more proportionate infrastructure deployment throughout the state."[90]

MANUFACTURING

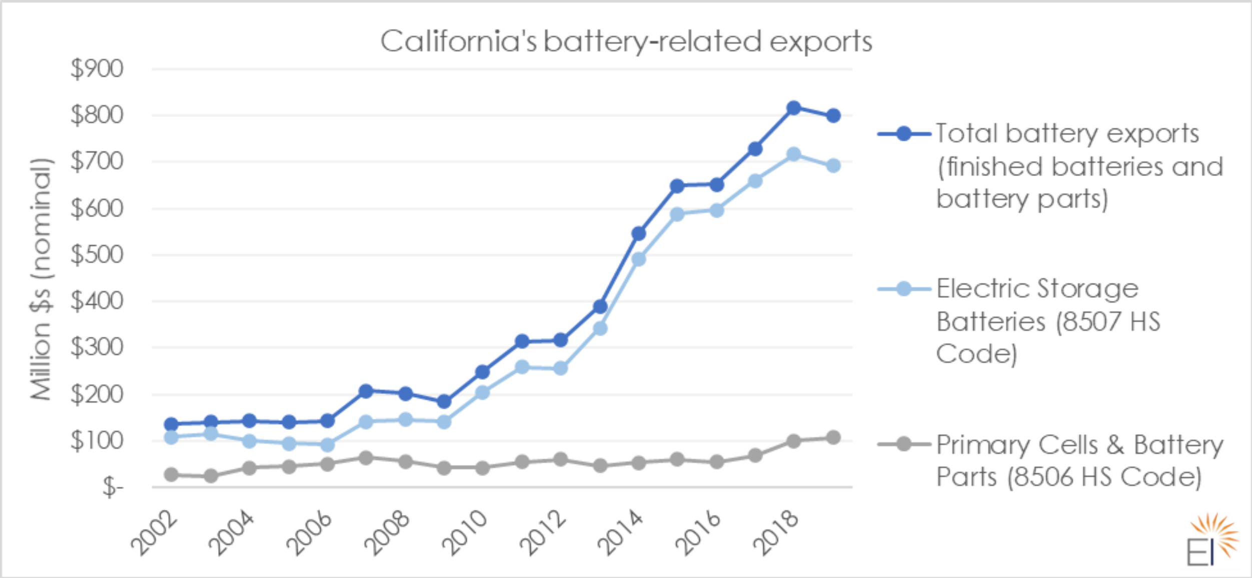
California policymakers have set their sights on using new transportation technologies as instruments for economic development. Governor Newsom has commented that EVs "are the next big global industry and California wants to dominate it."[91] The governor has cited the manufacturing aspect of the industry as key to making the most of this "economic imperative."[92]

California's EV leadership has already paid off by boosting motor vehicle manufacturing jobs to record heights—nearly double historical levels (more than 18,000 jobs compared to around 9,000 or less in earlier decades).[93] The broader EV industry employs more than 250,000 Californians across the state, offering an average wage of more than $90,000 per year.[94]

A global competition is unfolding to supply the world with EVs and other new technologies essential to battling climate change. In pursuit of this opportunity, **California policymakers should seek to grow jobs in the battery-electric storage manufacturing industry, including the lithium production aspects of the supply chain.**

Figure 14 shows battery exports have been growing steadily, increasing in monetary value by a factor of four since 2008.

Figure 14. Battery exports grew by more than a factor of four in recent history



"HS Code" refers to Harmonized System Code for categorizing trade data.

Source: U.S. Census Bureau data.[95]

California hosts both battery manufacturers, like Los Angeles-based Romeo Power, and companies working on the next generation of battery technology, like San Jose-based QuantumScape. Lithium is a precious input in high demand for battery production. "Building Lithium Valley" sketches out a vision for turning lithium dissolved in the water of California's Salton Sea into a reliable, responsibly managed source for lithium extraction.[96]

Manufacturing jobs are broadly recognized as good jobs worth prioritizing in economic development strategy. Jobs in manufacturing pay more than $82,600 per year on average.[97] They increasingly require technical skill sets and involve continuous learning, yet they remain accessible without expensive four-year college degrees.

There is already evidence of a direct payoff from California's policy leadership. EV manufacturing has grown in the state, nearly doubling overall direct employment in motor vehicle manufacturing compared to historical levels.

EVs have emerged as a top manufacturing export, combining with domestic demand to drive growing economic activity associated with transportation electrification.[98] This result is consistent with what is known in the economics literature as the home market effect. Rooted in decades of theory and study, the home market effect is the causal relationship between a larger domestic market and greater exports.[99] A larger home market begets more exports.

California's policymakers are trying to nurture clean energy manufacturing jobs and are generally quite active in this space. The Governor's Office of Business and Economic Development promotes EVs, clean technology, and other industries (including ones not relating to climate, energy, or innovation, such as the movie industry). Grants to scale up production are offered under the California Energy Commission's Realizing Accelerated Manufacturing and Production for Clean Energy Technologies program.[100] Innovation clusters are an explicit part of the state's approach, as evident in work to establish clean tech incubators across the state.

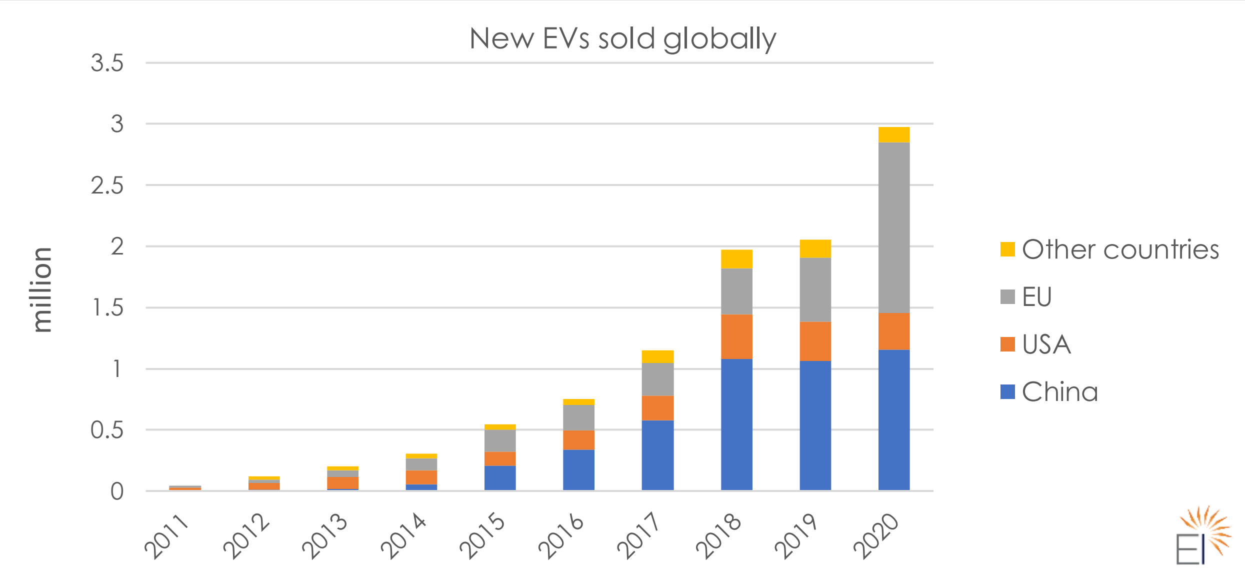
LOOKING FORWARD

This section begins with a survey of government and industry transportation electrification commitments, then turns to consider the serious hurdles ahead. Continuing challenges mean success at the necessary speed and scale will require smart public policy.

GROWING MOMENTUM FOR TRANSPORTATION ELECTRIFICATION

In addition to previously discussed trends in battery and EV innovation and cost, growth in consumer demand is robust. The share of EVs in new car sales jumped to 4.4 percent in 2020, up from 2.5 percent a year earlier. Even as overall car sales shrank because of the pandemic, EV sales grew strongly. As Figure 15 shows, new EV sales globally reached nearly 3 million in 2020, a 50 percent increase compared to 2019.

Figure 15. Annual new EV sales increased to 3 million units in 2020



Source: International Energy Agency data[101]

A wave of governmental commitments and industry support further demonstrates growing political will. In a global review, the International Council on Clean Transportation finds that 17 nations have committed to ZEV requirements for all new vehicle sales beyond a certain future date. Norway's 2025 goal is the most ambitious of any top-20 economy. Pledges keep growing in boldness. Just several weeks after California announced it would aim to transition to only ZEVs by 2035, United Kingdom Prime Minister Boris Johnson proposed a 2030 timeline to reach the same goal.

As the largest oil importer in the world, China has domestic energy security incentives to pursue transportation electrification.[102] Chinese regulations require at least 50 percent of all new light-duty vehicle sales to be electric by 2035.[103] China's ZEV requirement was inspired in concept and informed in design by California policy.

In industry as in governmental policy, ambitious pledges are made and then superseded in short order. General Motors, the largest automaker by volume, announced in early 2021 that it plans to sell only EVs by 2035. Less than two months later, the brand Volvo, owned by Chinese company Geely, announced it will completely transition from combustion technologies to ZEVs by 2030.

THE LIMITS OF THE INVISIBLE HAND

Increasingly compelling economics, growing political commitment based on mounting scientific concern and, finally, the evolution of automakers into champions are all factors contributing to the sense that the transportation sector is on the verge of a clean transportation revolution.

Despite the validity of these trends, policy complacency would be dangerous. Even if forecasts that EVs will soon cross purchase price thresholds hold true, other systemic barriers create technological inertia. Existing policy and market momentum is very likely insufficient on its own to achieve the transition quickly enough given the urgency of near-term emission reductions. The argument for why smart policy remains essential is developed first from a high-level perspective with deep roots in economic history and, second, with a focus on the transportation sector.

Adam Smith's description of the "invisible hand of the market," at 28 characters, was a stroke of concise branding genius worthy of 21st century marketing overdrive. Just as often, however, the market requires conditioning by smart policy. Nobel Prize-winning economist Joseph Stiglitz opines, "The reason that the invisible hand often seems invisible is that it is often not there. Whenever there are 'externalities'—where the action of an individual has impacts on others for which they do not pay, or for which they are not compensated—markets will not work well."[104] Stiglitz identified environmental externalities as an "important" and long understood example, adding: "Recent research has shown that externalities are pervasive, [existing] whenever there is imperfect information or imperfect risk markets—that is, always."[105]

Returning to the transportation sector specifically, the existing fuel system is a barrier—a massive convenience hurdle for any competitor. Retail gasoline stations are widespread. Government clearly needs to plan, coordinate, help finance, and to some extent fund the build-out of necessary infrastructure.

A trenchant overview of how transportation markets depart from the standard economic model is offered by Professors Sonia Yeh and Dan Sperling, the latter a California Air Resources Board member and founder of the University of California's Institute for Transportation Studies: "There are many market failures and market conditions that riddle the energy system, many of them unique to transportation, resulting in consumer and business decisions not in the best interest of society... Energy markets are particularly inefficient and ineffective at addressing end use technology efficiency and demand reduction."[106]

CONCLUSION

It is hard to overstate the importance of California's climate policy efforts in bolstering global efforts. In times when the federal government has left a void, the state has taken up the mantle. Working with like-minded "subnational" jurisdictions, California's policymakers have made the state a laboratory for policy innovation. The state's technological prowess and its can-do optimism have been essential to the willingness of other governments to act. Still, progress must come much more quickly in California as well as globally. The imperative for timely success in the ZEV transformation derives from the increasingly urgent signals coming from climate science. The unequal carnage of the health and economic crises unleashed by the COVID-19 pandemic has raised demands and hopes for increasing the equity quotient in all public policies.

California transportation policy has recognized that EV policies, transportation electrification, and decarbonization more broadly must align with statewide priorities to increase economic fairness and environmental justice. This report finds that non-luxury EVs have already begun to offer net consumer savings on total ownership cost. For used EV buyers receiving the highest incentive payments under Clean

Cars 4 All, this research finds average ownership savings of nearly 40 percent versus a comparable gas car. Furthermore, these non-luxury EV affordability benefits are very likely to grow.

EVs are not a silver bullet—in transportation, better urban design and walkable neighborhoods served by high-quality transit are needed to support greater mobility choices, reducing unchosen dependence on motor vehicle travel. And in transportation policy the state needs to match the level of ambition it has shown in other sectors. Still, the maturation and further promise of EVs as a tool for transportation decarbonization provide genuine reason for optimism in the battles against climate change and societal inequities.

APPENDIX A. SENSITIVITY ANALYSIS

Sensitivity analysis is a standard tool for testing the robustness of numerical results under varying input assumptions. If minor variations in input assumptions created large changes in outcomes, it would merit highlighting. Here, results vis-à-vis EV ownership savings remain stable across sensitivity scenarios, broadly speaking. The finding of net ownership savings for EVs remain positive across 10 of 11 sensitivity scenarios. The one outlier result is for the sensitivity for low travel demand.

Findings in the body of the paper are labeled the "Reference Scenario," indicating that it is the main set of findings against which sensitivity scenarios are compared. The Reference Scenario uses average or other measures of central tendency to enable summary insights. The specific total ownership costs for different types of vehicles for a given person will depend on the details of that person's circumstances and behavior. Some used car buyers will drive more or less than the national light-duty vehicle average of 11,400 miles driven per year. Some will own vehicles for more or less time than the five and a half years of ownership assumed in the Reference Scenario.

As a preface to sensitivity analysis, Table 10 provides numerical results, making it possible to observe the effect of the launch of the next-generation model Nissan Leaf in 2018. The introduction of this longer-range Leaf, with a new vehicle range estimated at 151 miles, means the Kia Soul EV is the the only 2018 model year BEV included with a range less than 100 miles. As a result, the depreciation cost attributed to EVs due to lower residual value at time of resale is much lower in 2018. The analysis estimates the depreciation cost component in the weighted average EV's total cost of ownership to be $120 in 2017, which is five times larger than the 2018 depreciation cost estimate of $20. The greater re-sale value for the 2018 Leaf is also observable in the vehicle purchase price trend across years. Better value retention by the Leaf leads the 2018 purchase price for BEVs to increase relatively faster than for other vehicle types. The weighted-average vehicle price for BEVs increases by 19 percent in 2018, compared to increases of 12 and 13 percent, respectively, for PHVs and gas cars.

Table 10. Breakdown of total ownership costs for different vehicle types[x]

2017	Vehicle	Fuel	Maintenance	Insurance	Charger	Depreciation	Total
Gas	$13,790	$5,990	$3,250	$4,630			$27,650
EV	$15,640	$3,290	$1,600	$5,150	$820	$50	$26,550
BEV	$14,350	$3,250	$1,540	$5,150	$1,840	$120	$26,240
PHV	$16,690	$3,330	$1,650	$5,150			$26,810
2018	Vehicle	Fuel	Maintenance	Insurance	Charger	Depreciation	Total
Gas	$15,585	$5,832	$3,250	$4,630			$29,290
EV	$17,960	$3,251	$1,600	$5,150	$820	$10	$28,790
BEV	$17,118	$3,153	$1,540	$5,150	$1,840	$20	$28,810
PHV	$18,646	$3,331	$1,650	$5,150			$28,770

Source: Energy Innovation analysis

[x] Results given in the body are rounded to the nearest hundred to avoid giving the impression of unrealistic accuracy. These results are rounded to the nearest ten to show differences that would otherwise be obscured.

Results in Table 10 also show how important installed charger cost is to total ownership cost for BEVs. However, some BEV owners opt to forego charger installation. BEV owners may do so because their driving patterns and preferences allow for slower home charging in exchange for avoiding the extra up-front investment or because of favorable workplace access. Roughly 30 percent of EV drivers principally charge at work, with most doing so free of charge, according to an Idaho National Laboratory study.[107] Several leading studies, such as frequently cited work by a Massachusetts Institute of Technology research team, exclude charger cost in the main ownership cost comparisons.[108] A sensitivity scenario is developed illustrating the ownership cost implications for BEV owners able to avoid the cost of charger installation.

A second sensitivity scenario explores the effect of BEV owners relying exclusively on the most expensive type of charging, fast charging. The charging company EVgo recently funded a study of charging behavior in the Los Angeles area. The study found 48 percent of residents of multi-unit dwellings lack access to charging at home, compared to 7 percent of others, leading to a greater reliance on fast charging: "a plurality of multi-unit dwelling resident EVgo users report using direct current fast charging as their primary charging mode."[109] The 100 percent fast charging sensitivity can be viewed as a boundary case—an unlikely or infrequent outcome—because few EV drivers are likely to solely rely on expensive, fast-charging technology.[xi]

A third sensitivity considers the implications of a larger depreciation penalty on BEVs. The depreciation sensitivity includes a residual value penalty for every vehicle except the long-range Bolt. The Reference Scenario includes such a depreciation cost for vehicles with effective ranges of less than 100 miles at the time of used car purchase, encompassing the 2017 Leaf and the Soul EV for both years. Consumer Reports' research found, as a rule, that EVs hold their value as well as gas cars, except for such short-range BEVs.[110]

Table 11 quantifies the perhaps obvious point that significant additional affordability benefits are available for BEV buyers who deem charger installation unnecessary. In the "no charger cost" sensitivity, ownership savings for BEVs are more than double those in the Reference Scenario.

The other two sensitivity scenarios profiled in Table 11 lead to smaller effects on ownership savings. The "100% fast charging" sensitivity returns a modest increase, and the "degradation" sensitivity returns a modest decrease. For brevity, Table 11 lists BEV effects exclusively, since PHVs results are unaffected, and Table 12 excludes costs unaffected by the variation in input value. The effects on the weighted-average EV may be calculated by multiplying the given results by the share of BEVs in the average EV (45 percent). For example, the $1,840 in installed charger savings for BEVs translates to additional ownership savings of $820 for the weighted-average EV.

[xi] Consistent with the assumption of barriers to home charging, this scenario also eliminates the cost of charger installation for BEVs.

Table 11. Sensitivity analyses results related to BEV depreciation and charging[xii]

Scenario and model year	Fuel	Charger	Depreciation	Total ownership cost	Savings	Change in savings
2017 model year						
Gas-reference scenario	$5,990	$0	$0	$27,650	N/A	N/A
BEV-reference scenario	$3,250	$1,840	$120	$26,240	$1,410	N/A
BEV-no charger cost	$3,250	$0	$120	$24,400	$3,250	$1,840
BEV-100% fast charging	$5,010	$0	$120	$26,160	$1,490	$80
BEV-depreciation	$3,250	$1,840	$210	$26,330	$1,330	-$90
2018 model year						
Gas-reference scenario	$5,830	$0	$0	$29,290	N/A	N/A
BEV-reference scenario	$3,150	$1,840	$20	$28,810	$480	N/A
BEV-no charger cost	$3,150	$0	$20	$26,980	$2,320	$1,840
BEV-100% fast charging	$4,960	$0	$20	$28,780	$510	$30
BEV-depreciation	$3,150	$1,840	$285	$29,080	$220	-$260

Change in savings measures the difference in savings for the sensitivity compared to the Reference Scenario.

Source: Energy Innovation analysis.

While the first set of input variations directly affected BEVs exclusively, further sensitivity analyses explored variations in other key variables affecting all vehicle types, specifically investigating the effect of different discount rates, longer ownership periods, larger effects due to battery deterioration, and differences in travel demand (i.e., how much the vehicle is driven).

A recent International Council on Clean Transportation study reported that households with income of less than $25,000 per year traveled an average of 10,300 miles per year—roughly 1,000 miles per year less than the national light-duty vehicle average used in the Reference Scenario. That value is used for the average miles traveled per year in one sensitivity, the "Moderate travel demand" scenario, while high and low vehicle-miles traveled sensitivity scenarios evaluate travel demand variations 20 percent above or below the Reference Scenario level.

The second set of sensitivity results in Table 12 cover ownership savings alone because none of the sensitivity variables affect vehicle purchase price. The eight variations are evenly split among those increasing and those decreasing ownership savings compared to the Reference Scenario. The rightmost column identifies whether the sensitivity has a positive or negative net effect on ownership savings. Most EV savings cells are shaded green, for net savings. The cell shaded red highlights the one instance in which the sign of the outcome flipped to negative, for the 2018 model year in the low-miles-traveled scenario.

[xii] Results provided in the body are rounded to the nearest hundred to avoid giving the impression of unrealistic accuracy, while results in the appendix are rounded to the nearest ten to provide greater detail.

Table 12. Sensitivity analyses of ownership period, travel demand, discount rate, and range[xiii]

	Sensitivity scenario	Reference scenario	2017 EV savings	2018 EV savings	Change in savings
Moderate travel demand (vehicle-miles traveled per year)	10,300	11,400	$690	$110	–
Higher travel demand (vehicle-miles traveled per year)	13,700	11,400	$1,970	$1,350	+
Lower travel demand (vehicle-miles traveled per year)	9,100	11,400	$230	-$340	–
Higher discount rate	15%	8%	$640	$50	–
Lower discount rate	2%	8%	$1,600	$1,000	+
Higher battery degradation (percentage reduction in range)	20%	10%	$1,000	$400	–
Longer ownership	8 years	5.5 years	$3,120	$2,470	+
Even longer ownership	10 years	5.5 years	$3,920	$3,260	+
		Reference Scenario	$1,100	$510	N/A

Sensitivity scenario results in which EV ownership savings remain net positive are shaded green. The net negative result for the 2018 model year in the lower travel demand sensitivity case is shaded red.
Source: Energy Innovation analysis.

APPENDIX B. ADDITIONAL METHODS DOCUMENTATION

This appendix explains the methodology in greater detail, starting with deeper discussion of key elements of the total cost of ownership analysis before turning to a mathematical definition of comparative cost metrics. The underlying data and analysis are open-sourced, available at this link. Table 13, below, summarizes several key inputs to the calculations.

[xiii] As stated above, results provided in the body are rounded to the nearest hundred, while results in the appendix are rounded to the nearest ten.

Table 13. Key inputs for the total-cost-of-ownership analysis

Variable	Input Value	Notes
Length of ownership	5.5 years	IHS Markit Survey data on average used car length of ownership as of 2016[111]
Travel distance	11,400 miles per year	U.S. Energy Information Administration average for light-duty vehicles[112]
Annual discount rate	8%	Miotti et al. research article in *Environmental Sciences and Technology*[113]
Installed charger cost	$1,836	Borlaug et al. journal article[114]

Several details of the total-cost-of-ownership analysis are discussed next: vehicle purchase price; maintenance; fuel; and the depreciation penalty for some BEVs. The appendix closes with a look at EV sampling choices.

Vehicle purchase prices. Vehicle price data were taken from the "car value estimator" web page of Consumer Reports.[115] Price data reflect the private party value—the higher value of the two choices, the other being trade-in value. Where pairs of the same vehicle with different powertrains were included, the vehicle price data are based on the lowest-cost trim package available in both models. For example, the Kia Optima 2017 offered the PHV option in the more expensive EX option package but not the LX. So the EX option package was chosen for both the PHV and gasoline-fueled versions of the Optima.

Maintenance. A Consumer Reports study of thousands of drivers on real-world expenses is used to set maintenance costs. The study covers both routine upkeep and unexpected repairs. It yields the results over different mileage ranges shown in Table 14, which are used to calculate maintenance costs for BEVs, PHVs, and gas vehicles for the net present value calculation.

Table 14. Maintenance costs by powertrain and mileage

Powertrain	0 – 50K miles	50K – 100K miles	100K – 200K miles	Average lifetime
BEV	$0.012	$0.028	$0.043	$0.031
PHV	$0.021	$0.031	$0.033	$0.030
Gasoline	$0.028	$0.060	$0.079	$0.061

Source: Consumer Reports[116]

Fuel costs. Fuel costs are a function of fuel economy, fuel prices, and utility factors (which determine the shares of gasoline-fueled and electricity-powered miles for PHVs).

Fuel economy and battery range are drawn from the website www.fueleconomy.gov, which bills itself as "the official U.S. government source of information on fuel economy."

The analysis assumes that wear and tear on batteries leads to a 10 percent reduction in range compared to their full capacity when originally sold. Preliminary results from a used EV survey conducted by researchers at the Plug-In Hybrid and Electric Vehicle Research Center found that "most used PEVs entered the market after only 2-3 years of usage by the original owner, still under warranty, and with 23,400 miles logged on average. Used buyers were generally aware that their batteries were no longer at full capacity, most considering them to be at 90-99% of full capacity."[117]

Real-world range depends on the mix of city and highway driving, landscape topography, how efficiently the car is driven, and other factors. In a recent test, Edmunds found the non-luxury EVs included in this study have a real-world range that exceeds the EPA-estimated range by an average of 19 percent.[118] Batteries are built for extended use but are subject to wear and tear—termed "degradation" here—like combustion engines. In California, BEVs and PHEVs have a mandated minimum 10-year/150,000-mile battery warranty.[119]

In the first year of ownership, fuel prices are set at estimated 2021 levels. For electricity, these prices are drawn from the California Energy Commission's recent Transportation Energy Demand forecast.[xiv] [120] For gasoline, the start year price is based on U.S. Energy Information Data. Specifically, drawing upon the average California gasoline price in 2020, then using the Short Term Energy Outlook to impute the 2021 price.[121] Prices in later years are imputed using the year-over-year percentage changes for each fuel in the Pacific Region forecast from the 2021 Annual Energy Outlook.[122]

The price of electricity for EVs is a weighted average of the prices for charging at different charger types. The portfolio of charging types varies for PHVs and BEVs, though in both cases home charging accounts for 81 percent of charging energy demand. Beyond home, most of the balance consists of public charging at "Level 2"-type chargers, slower than expensive "direct current" technology. The public charging category includes workplace charging as well as charging associated with household trips for school, shopping, and recreation. BEVs rely on more-expensive fast charging using direct current technology for 5 percent of total charging demand. PHVs are assumed to avoid fast charging, instead relying on their gasoline-fueled engine for longer trips.

Table 15. Home and public charging distribution

	Home	Public charging – level 2 (including workplace)	Public charging at direct current fast charger
BEV	81%	14%	5%
PHEV	81%	19%	0%

Source: Borlaug et al.[123]

Utility factors are another variable considered in calculating fuel costs. Utility factors imply a share of total travel demand, i.e., the percentage of vehicle-miles traveled, powered by electric drive for a given electric range. Recent work by Seshadri Srinivasa Raghavan and Gil Tal is used to specify utility factor values for each PHV included in the weighted average.[124] Utility factor values for each BEV draw upon an oft-cited article published in the Society for Automotive Engineers' *International Journal of Alternative Powertrains*.[125]

To estimate the utility factor levels associated with the specific electric ranges for sampled vehicles, the analysis uses scatterplot data—representing pairs of range and utility function values—listed in the source articles. A logarithmic functional form provides a good fit for scatterplot data and is used to estimate the utility factors associated with each used EV's effective all-electric range.

Depreciation. This cost category accounts for an implicit loss of market value at time of resale for the second owner. Residual value effects are approximated by an approach derived from a 2020 Consumer Reports

[xiv] Selecting rates from the "Mid-Demand" outlooks for both the residential and commercial sectors.

study, which devoted its first chapter to the topic.[126] Table 1.1 in Consumer Reports' analysis finds low-mileage BEVs have a 19 percent lower resale value than comparable gas cars.

Calculation begins with identifying the sub-100-mile BEVs—the 2017 Leaf and Soul for both model years. Standard depreciation is applied to each vehicle's used price (or second owner's purchase price) to estimate the sales price after five and a half years of second ownership; then, for sub-100-mile BEVs, the vehicle resale value is calculated using the resale value penalty for low-mileage EVs found in the Consumer Report study; and next the annual discount rate effect is factored in, consistent with the methodology's net present value approach. Finally, the estimate for the discounted resale value penalty cost is weighted by sales share to calculate each low-mileage BEV's contribution to the average EV's total cost of ownership. For example, the Leaf share of 11 percent is multiplied by the discounted resale value to calculate the contribution of this category of cost to the model year average.

EV sampling. As discussed in the body of the report, the strategy of using the same makes and models of EVs across years is meant to reduce unrelated variation. The aim is to eliminate confounding factors, assisting in efforts to detect the hypothesized temporal effect whereby increasing vehicle age at time of second owner's purchase leads to greater EV ownership savings. Therefore, the Honda Clarity PHV is excluded from sampling, even though its model year 2018 incarnation sold over 10,000 units—the Honda Clarity PHV was not available in 2017. Sampling also excluded PHVs with battery range lower than that of the Toyota Prius Prime. The intention was to provide a clearer distinction between PHVs and gas vehicle types. On this basis, at a 21-mile all-electric range for a new vehicle, the Ford Fusion Energi PHV was excluded, despite selling well.

To check whether this sampling approach introduced an unrealistic bias, the total ownership costs for the Honda Clarity and Ford Fusion Energy PHV ("Fusion-PHV") were evaluated against their gas-fueled counterparts. Results are summarized in Table 16 and reveal a pattern broadly consistent with EVs sampled for data analysis, yielding net savings on total ownership cost in all three cases. Both model year Fusion PHVs are more expensive to purchase, evidencing the expected price premium. The Clarity sells for less than the Honda Accord chosen for this comparison.

Table 16. Ownership savings and purchase price premium results for Clarity and Fusion

	EV ownership savings	EV purchase price premium
Clarity-PHV (2018)	$4,470	$(500)
Fusion-PHV (2017)	$4,992	$300
Fusion-PHV (2018)	$4,592	$700

Source: Energy Innovation analysis

Math definitions. Finally, key metrics are defined in mathematical notation to offer more precise definitions.

The total ownership cost of a generic vehicle ("x") can be defined as:

$$O_x = V_x + C_x + \sum_t (F_x + M_x + I_x + D_x) * \frac{1}{(1+r)^t}$$

With variables defined as follows:

O = ownership, total cost of
V = vehicle price
C = charger, installed cost of
F = fuel
M = maintenance
I = insurance
D = depreciation
r = discount rate
x = vehicle subscript
t = time subscript

The calculation for the average EV may be expressed as:

O_{EV} = total ownership cost calculation for the sales-weighted average EV
z = vehicle subscripts for nine EV makes and models sampled ($z = 1, \ldots, 9$)
p_z = percentage of total sales (listed by make and model in rightmost column of Table 3)

$$O_{EV} = \sum_{z=1}^{9} O_z * p_z$$

The calculation for the average gas car may be expressed as:

O_{gas} = total ownership cost calculation for the sales-weighted average gas car
y = vehicle subscripts for gas vehicles ($y = 1, \ldots, 9$)

$$O_{gas} = \sum_{y=1}^{9} O_y * p_z$$

The calculation of the average gas car retains the p_z term used in the math expression for the average ownership cost for EVs. This is because the gas counterpart retains the same values as the shares in the average EV calculation. Using the average EV and average gas car ownership results developed above, the comparative cost metric may be written as follows:

EV total ownership savings = $O_{gas} - O_{EV}$

The EV price premium is similarly the difference in the weighted average purchase price for the EV and its gas counterpart. Their respective sales-weighted average purchase prices can be written:

EV average purchase price = $V_{EV} = (\sum_{z=1}^{9} V_z * p_z)$

Gas car average purchase price = $V_{gas\ car} = (\sum_{y=1}^{9} V_y * p_x)$

And, finally, the EV purchase price premium $= V_{EV} - V_{gas\ car}$

NOTES

[1] David Reichmuth, "Inequitable Exposure to Air Pollution from Vehicles in California" (Union of Concerned Scientists, December 2018), https://www.ucsusa.org/sites/default/files/attach/2019/02/cv-air-pollution-CA-web.pdf.
[2] California Air Resources Board, "The Zero Emission Vehicle Regulation Fact Sheet," accessed April 27, 2021, https://ww2.arb.ca.gov/sites/default/files/2019-06/zev_regulation_factsheet_082418_0.pdf.
[3] Patrick Olsen, "Chevrolet Bolt Sets Consumer Reports' Electric-Vehicle Range Record," *Consumer Reports* (blog), August 13, 2017, https://www.consumerreports.org/2017-chevrolet-bolt/chevrolet-bolt-sets-electric-vehicle-range-record/.
[4] *Bloomberg New Energy Finance*, "Battery Pack Prices Cited Below $100/KWh for the First Time in 2020, While Market Average Sits at $137/KWh," December 16, 2020, https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/.
[5] Julian Spector, "Startup Sonic Energy Promises Next-Gen Battery Benefits Without the Wait," *Canary Media*, April 20, 2021, https://www.canarymedia.com/articles/startup-sionic-promises-next-gen-battery-benefits-without-the-wait/.
[6] David Roberts, "The Many Varieties of Lithium-Ion Batteries Battling for Market Share," *Canary Media*, April 21, 2021, https://www.canarymedia.com/articles/the-many-varieties-of-lithium-ion-batteries-battling-for-market-share/.
[7] Nic Lutsey, "Update on Electric Vehicle Costs in the United States Through 2030" (International Council on Clean Transportation, January 2020), https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf;
UBS Global Research, "UBS Evidence Lab Electric Car Teardown – Disruption Ahead?," Q-Series, May 18, 2017, https://neo.ubs.com/shared/d1wkuDlEbYPjF/;
Anthony Eggert and Anand Gopal, "Yes, Electric Cars Will Be Cheaper," *Forbes* (blog), accessed April 28, 2021, https://www.forbes.com/sites/anthonyeggert/2019/06/12/yes-electric-cars-will-be-cheaper/.
[8] Lutsey, "Update on Electric Vehicle Costs in the United States through 2030."
[9] Nathaniel Bullard, "Electric Car Price Tag Shrinks Along with Battery Cost" (*Bloomberg New Energy Finance*, April 12, 2020), https://www.bloomberg.com/opinion/articles/2019-04-12/electric-vehicle-battery-shrinks-and-so-does-the-total-cost.
[10] California Energy Commission, "SB 350 Low -Income Barriers Study, Part A: Overcoming Barriers to Energy Efficiency and Renewables for Low -Income Customers and Small Business Contracting Opportunities in Disadvantaged Communities," December 2016, https://efiling.energy.ca.gov/getdocument.aspx?tn=214830;
California Air Resources Board, "Low-Income Barriers Study, Part B: Overcoming Barriers to Clean Transportation Access for Low-Income Residents," February 21, 2018, https://ww2.arb.ca.gov/sites/default/files/2018-08/sb350_final_guidance_document_022118.pdf.
[11] California Air Resources Board, "Low-Income Barriers Study, Part B,"; California Energy Commission, "SB 350 Low -Income Barriers Study, Part A."
[12] California Energy Commission, "SB 350 Low -Income Barriers Study, Part A."; California Air Resources Board, "Low-Income Barriers Study, Part B."
[13] U.S. Department of Transportation, Bureau of Transportation Statistics, "2019 Trends in Average Household Transportation Spending," n.d., https://data.bts.gov/stories/s/Transportation-Economic-Trends-Transportation-Spen/ida7-k95k/.
[14] UBS Global Research, "UBS Evidence Lab Electric Car Teardown – Disruption Ahead?"
[15] Bruce Mast, Holmes Hummel, and Jeanne Clinton, "Towards an Accessible Financing Solution: A Policy Roadmap with Program Implementation Considerations for Tariffed On-Bill Programs in California" (Building Decarbonization Coalition, July 2020), https://www.buildingdecarb.org/uploads/3/0/7/3/30734489/bdc_whitepaper_final_small.pdf.
[16] Sara Baldwin, Amanda Myers, and Michael O'Boyle, "Increasing Electric Vehicle Charging Access at Multi-Unit Dwellings: Workshop Summary Report" (Energy Innovation: Policy and Technology, LLC, September 2020), https://energyinnovation.org/wp-content/uploads/2020/09/Increasing-Electric-Vehicle-Charging-at-Multi-Unit-Dwellings_FINAL3.pdf.
[17] Chris Busch, "Why Electric Vehicles Will Likely Emerge as California's Top Manufacturing Export in 2020," *Forbes* (blog), September 30, 2020, https://www.forbes.com/sites/energyinnovation/2020/09/30/why-electric-vehicles-will-likely-emerge-as-californias-top-manufacturing-export-in-2020/.
[18] Ken Alston et al., "Building Lithium Valley: Opportunities and Challenges Ahead for Developing California's Battery Manufacturing Ecosystem" (*New Energy Nexus*, September 2020), https://www.newenergynexus.com/wp-content/uploads/2020/10/New-Energy-Nexus_Building-Lithium-Valley.pdf.
[19] Sandra Wappelhorst and Hongyang Cui, "Growing Momentum: Global Overview of Government Targets for Phasing out Sales of New Internal Combustion Engine Vehicles," International Council on Clean Transportation (blog), November 11, 2020, https://theicct.org/blog/staff/global-ice-phaseout-nov2020.
[20] Climate Action Tracker, "2030 Emissions Gap- Climate Action Tracker" (Climate Action Tracker), accessed October 18, 2020, https://climateactiontracker.org/global/cat-emissions-gaps/.

[21] International Energy Agency, "World Energy Outlook 2020," accessed October 13, 2020, https://www.iea.org/reports/world-energy-outlook-2020.
[22] U.S. Department of Transportation, Bureau of Transportation Statistics, "Transportation Economic Trends."
[23] Dustin Gardiner, "Newsom's $1.5 Billion Plan for Electric Cars Shifts Rebate Money to Equity Programs," San Francisco Chronicle, January 23, 2021, sec. Politics, https://www.sfchronicle.com/politics/article/Newsom-s-1-5-billion-plan-for-electric-cars-15891774.php.
[24] National Auto Dealers Association, "2020 Mid-Year Report," 2020, https://www.nada.org/WorkArea/DownloadAsset.aspx?id=21474862016.
[25] Lutsey, "Update on Electric Vehicle Costs in the United States through 2030."
[26] Nathaniel Bullard, "Electric Car Price Tag Shrinks Along with Battery Cost" (*Bloomberg New Energy Finance*, April 12, 2020), https://www.bloomberg.com/opinion/articles/2019-04-12/electric-vehicle-battery-shrinks-and-so-does-the-total-cost.
[27] "Reaping the Wind with the Biggest Turbines Ever Made," *BBC News*, April 2, 2018, sec. Business, https://www.bbc.com/news/business-43576226.
[28] Bloomberg New Energy Finance, "Battery Pack Prices Cited Below $100/KWh for the First Time in 2020, While Market Average Sits at $137/kWh"; *Bloomberg New Energy Finance*, "Battery Pack Prices Fall as Market Ramps Up with Market Average at $156/kWh in 2019," December 3, 2019, https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/.
[29] Lutsey, "Update on Electric Vehicle Costs in the United States through 2030."
[30] Bullard, "Electric Car Price Tag Shrinks Along with Battery Cost."
[31] J. Doyne Farmer, François Lafond, "How Predictable Is Technological Progress?" *Research Policy* 45, No. 4 (April 2016): 647–65.
[32] J. Gruber and J. Johnson, Jump-Starting America: How Breakthrough Science Can Revive Economic Growth and the American Dream, 2018, https://www.publicaffairsbooks.com/titles/jonathan-gruber/jump-starting-america/9781541762503/.
[33] Gregory Nemet, How Solar Energy Became Cheap: A Model for Low Carbon Innovation, 1st ed. (Routledge, 2019), https://www.howsolargotcheap.com/;
Kelly Sims Gallagher, "Why & How Governments Support Renewable Energy," *Daedalus*, MIT Press Journals 142, no. 1 (January 2, 2013): 59–77, https://doi.org/10.1162/DAED_a_00185;
Kelly Sims Gallagher and Fang Zhang, "Innovation and Technology Transfer Across Global Value Chains: Evidence from China's PV Industry" (Tufts University, July 2013).
[34] Antoine Dechezleprêtre and Misato Sato, "The Impacts of Environmental Regulations on Competitiveness," *Review of Environmental Economics and Policy* 11, no. 2 (July 1, 2017): 183–206, https://doi.org/10.1093/reep/rex013.
[35] International Energy Agency, Experience Curves for Energy Technology Policy (OECD, 2000), https://doi.org/10.1787/9789264182165-en.
[36] International Energy Agency, "World Energy Outlook 2020 – Press Release," IEA, accessed October 13, 2020, https://www.iea.org/reports/world-energy-outlook-2020.
[37] Max Roser, "Why Did Renewables Become So Cheap So Fast? And What Can We Do to Use This Global Opportunity for Green Growth?," *Our World in Data* (blog), December 1, 2020, https://ourworldindata.org/cheap-renewables-growth.
[38] Daniel Wood, "6 Charts That Will Make You Optimistic About America's Clean Energy Future" (U.S. Department of Energy, September 28, 2016), https://www.energy.gov/articles/6-charts-will-make-you-optimistic-about-america-s-clean-energy-future.
[39] Cynthia Shahan, "California Offers up to $9,500 to Purchase Used or New Electric Vehicle, Focus on Lower-Income Motorists," CleanTechnica, January 5, 2020, https://cleantechnica.com/2020/01/05/california-offers-up-to-9500-to-purchase-a-used-or-new-electric-vehicle-focus-on-lower-income-motorists/.
[40] Chris Harto, "Electric Vehicle Ownership Costs: Today's Electric Vehicles Offer Big Savings for Consumers" (Consumer Reports, October 2020), https://advocacy.consumerreports.org/wp-content/uploads/2020/10/EV-Ownership-Cost-Final-Report-1.pdf.
[41] Harto.
[42] J. Tamerius, "Clean Vehicle Market Share Trends" (Center for Sustainable Energy, May 2020), https://energycenter.org/sites/default/files/docs/cse/CVRP_Clean_Vehicle_Market_Trends_Report_2020.pdf.
[43] Gordon Bauer, Chih-Wei Hsu, and Nic Lutsey, "When Might Lower-Income Drivers Benefit from Electric Vehicles? Quantifying the Economic Equity Implications of Electric Vehicle Adoption" (International Council on Clean Transportation, February 2021), https://theicct.org/sites/default/files/publications/EV-equity-feb2021.pdf.
[44] Tamerius.
[45] California Air Resources Board, "Appendix H. Draft Advanced Clean Trucks Total Cost of Ownership Discussion Document," February 22, 2019, https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf.
[46] IHS Markit, "Vehicles Getting Older: Average Age of Light Cars and Trucks in U.S. Rises Again in 2016," November 22, 2016, https://news.ihsmarkit.com/prviewer/release_only/slug/automotive-vehicles-getting-older-average-age-light-cars-and-trucks-us-rises-again-201.
[47] Consumer Reports, "Car Value Estimator," accessed February 26, 2021, https://www.consumerreports.org/cars/car-value-estimator/.
[48] Consumer Reports, "Car Value Estimator."

[49] Brennan Borlaug et al., "Levelized Cost of Charging Electric Vehicles in the United States," Joule 4, no. 7 (July 2020): 1470–85, https://doi.org/10.1016/j.joule.2020.05.013.
[50] IHS Markit, "Vehicles Getting Older: Average Age of Light Cars and Trucks in U.S. Rises Again in 2016."
[51] Plug-In Hybrid and Electric Vehicle Research Center, Institute for Transportation Studies, University of California Davis, "Ongoing Research," Ongoing Research, not dated, https://phev.ucdavis.edu/research/.
[52] Harto, "Electric Vehicle Ownership Costs: Today's Electric Vehicles Offer Big Savings for Consumers."
[53] Bauer, Chih-Wei Hsu, and Lutsey, "When Might Lower-Income Drivers Benefit from Electric Vehicles?"
[54] Insurance Information Institute, "Auto Insurance Facts and Statistics," accessed May 7, 2021, https://www.iii.org/customprint/fact-statistic/facts-statistics-auto-insurance.
[55] Harto, "Electric Vehicle Ownership Costs: Today's Electric Vehicles Offer Big Savings for Consumers."
[56] Harto, "Electric Vehicle Ownership Costs: Today's Electric Vehicles Offer Big Savings for Consumers."
[57] Patrick Olsen, "Chevrolet Bolt Sets Consumer Reports' Electric-Vehicle Range Record," Consumer Reports (blog), August 13, 2017, https://www.consumerreports.org/2017-chevrolet-bolt/chevrolet-bolt-sets-electric-vehicle-range-record/.
[58] California Energy Commission, "Zero Emission Vehicle and Infrastructure Statistics," August 28, 2020, https://www.energy.ca.gov/data-reports/energy-insights/zero-emission-vehicle-and-charger-statistics.
[59] California Energy Commission.
[60] Kelley Blue Book, "New and Used Car Specifications," Kbb.com, accessed May 7, 2021, https://www.kbb.com/.
[61] U.S. Department of Energy, "Compare Cars Side-by-Side," accessed May 7, 2021, https://fueleconomy.gov.
[62] Lutsey, "Update on Electric Vehicle Costs in the United States through 2030."
[63] David Roland-Holst et al., "Clean Transportation: An Economic Assessment of More Inclusive Vehicle Electrification in California," Next10 report (Berkeley Economic Advising and Research, January 2020), https://www.next10.org/sites/default/files/2020-01/clean-transportation-ev-benefits-final.pdf.
[64] Harto, "Electric Vehicle Ownership Costs: Today's Electric Vehicles Offer Big Savings for Consumers."
[65] Josh Becker, "Bill Text - SB-771 Sales and Use Tax Law: Zero Emissions Vehicle Exemption," February 19, 2021, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB771.
[66] California New Car Dealers Association, "California Auto Outlook Covering 4Q 2019 Vol. 16, No. 1," February 2020, https://www.cncda.org/wp-content/uploads/Cal-Covering-4Q-19.pdf; California New Car Dealers Association, "California Auto Outlook Covering 4Q 2020 Vol. 17, No. 1," February 2021, https://www.cncda.org/wp-content/uploads/Cal-Covering-4Q-20.pdf.
[67] California Energy Commission, "SB 350 Low -Income Barriers Study, Part A: Overcoming Barriers to Energy Efficiency and Renewables for Low -Income Customers and Small Business Contracting Opportunities in Disadvantaged Communities,"; California Air Resources Board, "Low-Income Barriers Study, Part B: Overcoming Barriers to Clean Transportation Access for Low-Income Residents."
[68] California Energy Commission, "SB 350 Low -Income Barriers Study, Part A"; California Air Resources Board, "Low-Income Barriers Study, Part B"
[69] California Energy Commission, "SB 350 Low -Income Barriers Study, Part A."; California Air Resources Board, "Low-Income Barriers Study, Part B."
[70] Bruce Mast, Holmes Hummel, and Jeanne Clinton, "Towards an Accessible Financing Solution: A Policy Roadmap with Program Implementation Considerations for Tariffed On-Bill Programs in California" (Building Decarbonization Coalition, July 2020), https://www.buildingdecarb.org/uploads/3/0/7/3/30734489/bdc_whitepaper_final_small.pdf.
[71] Baldwin, Myers, and O'Boyle, "Increasing Electric Vehicle Charging Access at Multi-Unit Dwellings."
[72] California Energy Commission, "SB 350 Low -Income Barriers Study, Part A: Overcoming Barriers to Energy Efficiency and Renewables for Low -Income Customers and Small Business Contracting Opportunities in Disadvantaged Communities"; California Air Resources Board, "Low-Income Barriers Study, Part B."
[73] U.S. Department of Transportation, Bureau of Transportation Statistics, "Transportation Economic Trends."
[74] Gil Tal and Austin Brown, "Credits and Rebates Play a Key Role in Building Consumer Market for Cleaner Electric Vehicles," Greenlight Blog (blog), undated, https://its.ucdavis.edu/wp-content/uploads/Credits-and-Rebates-Gil-Tal.pdf.
[75] UBS Global Research, "UBS Evidence Lab Electric Car Teardown – Disruption Ahead?"
[76] Mast, Hummel, and Clinton, "Towards an Accessible Financing Solution."
[77] Energy Futures Initiative, "Leveraging the DOE Loan Program: Using $39 Billion in Existing Authority to Help Modernize the Nation's Energy Infrastructure," March 2018, https://docs.house.gov/meetings/CN/CN00/20190430/109329/HHRG-116-CN00-Wstate-FosterD-20190430-SD003.pdf.
[78] Mark McCall, "Testimony of Mark A. McCall, Executive Director, Loan Programs Office, U.S. Department of Energy" (March 3, 2016), https://science.house.gov/imo/media/doc/3.3.16%20HSST%20Mark%20McCall%20Final%20Testimony.pdf.
[79] Louis Hyman, "The New Deal Wasn't What You Think: If We Are Going to Fund a Green New Deal, We Need to Acknowledge How the Original Actually Worked," *The Atlantic*, March 6, 2020, https://www.theatlantic.com/ideas/archive/2019/03/surprising-truth-about-roosevelts-new-deal/584209/.

[80] Louis Hyman, “The New Deal Wasn’t What You Think: If We Are Going to Fund a Green New Deal, We Need to Acknowledge How the Original Actually Worked,” *The Atlantic*, March 6, 2020, https://www.theatlantic.com/ideas/archive/2019/03/surprising-truth-about-roosevelts-new-deal/584209/.
[81] Leslie Aguayo, “Opening Comments of the Greenlining Institute on the Proposed Draft Transportation Electrification Framework, Chapter 6, ‘Equity,’” *California Public Utilities Commission Rulemaking R. 18-12-006*, December 13, 2018, 39.
[82] Severin Borenstein, Meredith Fowlie, and James Sallee, “Designing Electricity Rates for an Equitable Energy Transition,” Working Paper 314 (Energy Institute at the Haas School of Business, University of California, Berkeley, February 2021), https://haas.berkeley.edu/wp-content/uploads/WP314.pdf.
[83] California Air Resources Board, “Electrical Distribution Utility and Natural Gas Supplier Allowance Allocation,” undated, https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program/allowance-allocation/edu-ngs.
[84] Baldwin, Myers, and O’Boyle, “Increasing Electric Vehicle Charging Access at Multi-Unit Dwellings.”
[85] Noel Crisostomo et al., “Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment - Analyzing Charging Needs to Support Zero-Emission Vehicles in 2030” (California Energy Commission, January 2021), https://efiling.energy.ca.gov/getdocument.aspx?tn=236237.
[86] Baldwin, Myers, and O’Boyle, “Increasing Electric Vehicle Charging Access at Multi-Unit Dwellings.”
[87] Mast, Hummel, and Clinton, “Towards an Accessible Financing Solution.”
[88] Mast, Hummel, and Clinton, “Towards an Accessible Financing Solution.”
[89] Baldwin, Myers, and O’Boyle, “Increasing Electric Vehicle Charging Access at Multi-Unit Dwellings.”
[90] Tiffany Hoang, “California Electric Vehicle Infrastructure Deployment Assessment: Senate Bill 1000 Report. Increasing Access to Electric Vehicle Infrastructure for All” (California Energy Commission, December 2020), https://efiling.energy.ca.gov/GetDocument.aspx?tn=236189.
[91] Adam Beam, “California Is Ready to Pull the Plug on Gas Vehicles,” *AP NEWS*, September 24, 2020, sec. AP Top News, https://apnews.com/article/technology-gavin-newsom-california-4956d87b72b000a917eed27392d16d8b.
[92] Sacha Pfeiffer, "California Gov. Newsom Calls Transition to Electric Cars an ‘Economic Imperative,’” *National Public Radio*, September 24, 2020, https://www.npr.org/2020/09/24/916625380/california-governor-on-his-order-to-ban-sale-of-new-gasoline-vehicles-by-2035.
[93] Busch, “Why Electric Vehicles Will Likely Emerge as California’s Top Manufacturing Export in 2020.”
[94] Busch, “Why Electric Vehicles Will Likely Emerge as California’s Top Manufacturing Export in 2020.”
[95] US Census Bureau, “USA Trade Online - The Official Source of Trade Statistics,” Database, accessed May 10, 2021, https://usatrade.census.gov/.
[96] Alston et al., “Building Lithium Valley:”
[97] California Manufacturers and Technology Association, “Industry Job Growth and Average Wages Since 2010” (California Manufacturers and Technology Association, August 4, 2016), https://www.cmta.net/multimedia/20160804_industry_job_growth_since_2010_w_wages.pdf.
[98] Busch, “Why Electric Vehicles Will Likely Emerge as California’s Top Manufacturing Export in 2020.”
[99] S.B. Linder, An Essay on Trade and Transformation (Uppsala: Almqvist and Wiksells, 1961), https://pdfs.semanticscholar.org/3e37/a898256b1601cd88059607ab53b27b87cbdd.pdf;
Paul Krugman, “Scale Economies, Product Differentiation, and the Pattern of Trade,” *American Economic Review* 70, no. 5 (1980): 950–59;
Arnaud Costinot et al., “The More We Die, The More We Sell? A Simple Test of the Home-Market Effect,” *The Quarterly Journal* of *Economics* 134, no. 2 (May 2009): 843–94.
[100] California Energy Commission, “GFO-20-302: Realizing Accelerated Manufacturing and Production for Clean Energy Technologies (RAMP) 2020,” undated, https://www.energy.ca.gov/solicitations/2020-07/gfo-20-302-realizing-accelerated-manufacturing-and-production-clean-energy.
[101] International Energy Agency, “Global EV Outlook 2021,” April 2021, https://www.iea.org/reports/global-ev-outlook-2021.
[102] U.S. Energy Information Administration (EIA), “China’s Crude Oil Imports Surpassed 10 Million Barrels per Day in 2019,” Today in Energy (blog), March 23, 2020, https://www.eia.gov/todayinenergy/detail.php?id=43216.
[103] Society of Automotive Engineers (China), “Energy-Saving and New Energy Vehicle Technology Roadmap 2.0,” October 27, 2020, http://en.sae-china.org/a3967.html.
[104] Daniel Altman, “Economist’s View: Q & A Joseph Stiglitz,” *International Herald Tribune*, October 11, 2006, Web edition, https://www8.gsb.columbia.edu/faculty/jstiglitz/sites/jstiglitz/files/Economist%27s%20View_%20Joseph%20Stiglitz%20Q%20%26%20A.pdf.
[105] Daniel Altman, “Economist’s View: Q & A Joseph Stiglitz,” *International Herald Tribune*, October 11, 2006, Web edition, https://www8.gsb.columbia.edu/faculty/jstiglitz/sites/jstiglitz/files/Economist%27s%20View_%20Joseph%20Stiglitz%20Q%20%26%20A.pdf.
[106] Sonia Yeh and Daniel Sperling, “Low Carbon Fuel Policy and Analysis,” *Energy Policy* 56 (May 1, 2013): 1–4, https://doi.org/10.1016/j.enpol.2013.01.008.
[107] John Galloway, “Plugged In: How Americans Charge Their Electric Vehicles” (Idaho National Laboratory, July 1, 2015), https://doi.org/10.2172/1369632.

[108] Marco Miotti et al., “Personal Vehicles Evaluated against Climate Change Mitigation Targets,” *Environmental Science & Technology* 50, no. 20 (October 18, 2016): 10795–804, https://doi.org/10.1021/acs.est.6b00177.
[109] J.R. DeShazo and James Di Filippo, “Evaluating Multi-Unit Resident Charging Behavior at Direct Current Fast Chargers” (Luskin Center for Innovation, University of California, Los Angeles, February 2021), https://innovation.luskin.ucla.edu/wp-content/uploads/2021/03/Evaluating-Multi-Unit-Resident-Charging-Behavior-at-Direct-Charging-Behavior-at-Direct-Current-Fast-ChargersCurrent-Fast-Chargers.pdf.
[110] Harto, “Electric Vehicle Ownership Costs: Today’s Electric Vehicles Offer Big Savings for Consumers.”
[111] IHS Markit, “Vehicles Getting Older: Average Age of Light Cars and Trucks in U.S. Rises Again in 2016.”
[112] U.S. Energy Information Administration, “Annual Energy Outlook 2021,” Database, Annual Energy Outlook, February 3, 2021, https://www.eia.gov/outlooks/aeo/.
[113] Miotti et al., “Personal Vehicles Evaluated against Climate Change Mitigation Targets.”
[114] Borlaug et al., “Levelized Cost of Charging Electric Vehicles in the United States.”
[115] Consumer Reports, “Car Value Estimator: Trade In & Market Value.”
[116] Harto, “Electric Vehicle Ownership Costs: Today’s Electric Vehicles Offer Big Savings for Consumers.”
[117] Plug-In Hybrid and Electric Vehicle Research Center, Institute for Transportation Studies, University of California Davis, “Ongoing Research,” not dated, https://phev.ucdavis.edu/research/.
[118] Jonathan Elfalan, “Edmunds Tested: Electric Car Range and Consumption,” February 9, 2021, https://www.edmunds.com/car-news/electric-car-range-and-consumption-epa-vs-edmunds.html.
[119] California Air Resources Board, “California Vehicle and Emissions Warranty Periods,” April 13, 2018, https://ww2.arb.ca.gov/resources/fact-sheets/california-vehicle-and-emissions-warranty-periods.
[120] Aniss Bahreinian, “Transportation Energy Demand Forecast - 2020 Independent Energy Policy Report Update” (California Energy Commission, December 3, 2020), https://efiling.energy.ca.gov/getdocument.aspx?tn=235841.”
[121] U.S. Energy Information Administration, “Short-Term Energy Outlook -Summer Fuels Outlook,” 2021, https://www.eia.gov/outlooks/steo/special/summer/2021_summer_fuels.pdf.
[122] U.S. Energy Information Administration, “Annual Energy Outlook 2021.”
[123] Borlaug et al., “Levelized Cost of Charging Electric Vehicles in the United States.”
[124] Seshadri Srinivasa Raghavan and Gil Tal, “Plug-in Hybrid Electric Vehicle Observed Utility Factor: Why the Observed Electrification Performance Differ from Expectations,” *International Journal of Sustainable Transportation*, December 31, 2020, https://doi.org/10.1080/15568318.2020.1849469.
[125] Michael Duoba, “Developing a Utility Factor for Battery Electric Vehicles,” *SAE International Journal of Alternative Powertrains* 2, no. 2 (April 8, 2013): 362–68, https://doi.org/10.4271/2013-01-1474.
[126] Harto, “Electric Vehicle Ownership Costs: Today’s Electric Vehicles Offer Big Savings for Consumers.”