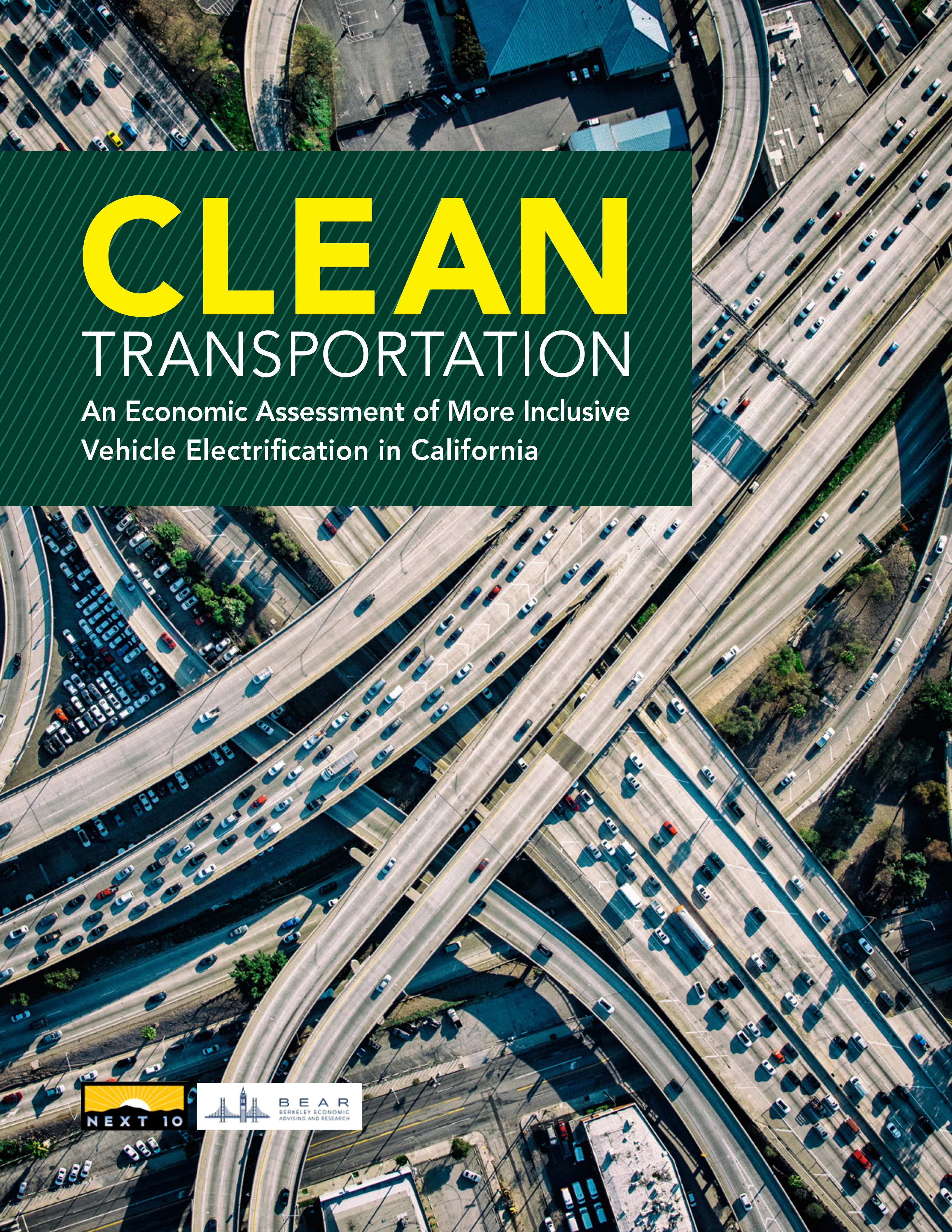
CLEAN TRANSPORTATION

An Economic Assessment of More Inclusive Vehicle Electrification in California



NEXT 10

BEAR BERKELEY ECONOMIC ADVISING AND RESEARCH

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NEXT 10 is an independent nonpartisan organization that educates, engages and empowers Californians to improve the state's future.

Next 10 is focused on innovation and the intersection between the economy, the environment, and quality of life issues for all Californians. We provide critical data to help inform the state's efforts to grow the economy and reduce greenhouse gas emissions. Next 10 was founded in 2003 by businessman and philanthropist F. Noel Perry.

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Abbreviations

AB32	California Assembly Bill 32 – the Global Warming Solutions Act
ARB	California Air Resources Board
BEV	Battery electric vehicle
BLS	U.S. Bureau of Labor Statistics
CalEPA	California Environmental Protection Agency
CARB	California Air Resources Board
CEC	California Energy Commission
CGE	Computable General Equilibrium
CI	Carbon intensity
DAC	Disadvantaged Community
DOF	Department of Finance
EV	Electric vehicle
GHG	Greenhouse gases
GSP	Gross state product
GWh	Gigawatt hours
HFC	Hydrogen fuel cell
ICE	Internal combustion engine
IVC	Incremental vehicle cost
kWh	Kilowatt hours
LTES	Long-term Energy Scenarios
LCFS	Low Carbon Fuel Standard
LRT	LCFS Reporting Tool
LTES	Long-term Energy Scenarios
$MMTCO_2e$	Million metric tons carbon dioxide-equivalent
MW	Megawatts
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
RPS	Renewable Portfolio Standard
ZEV	Zero-emission vehicle

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Executive Summary

Executive Summary

California's transportation sector is the largest contributor of greenhouse gas emissions in the state, accounting for 41 percent of statewide emissions.[1] Electrification of the light vehicle fleet is an essential component of the state's ambitious plans to reduce global warming pollution. While adoption of plug-in electric vehicles (PEVs) has been relatively gradual and unequally distributed across the population, overall adoption is likely to accelerate as prices continue to drop, technology continues to improve, and more mass market vehicles become competitive. To promote more inclusive access to these innovative vehicle technologies, the state is considering more targeted incentives.

To help elucidate some of the potential impacts and benefits of broader PEV adoption, this study assesses the economic implications of the projected increase in electric vehicle use with a long-term economic forecasting model. Four scenarios were considered in order to illustrate the consequences of different pathways for large-scale electrification of the light vehicle fleet (Table ES.1), with two key factors informing the variations between each scenario: (1) electric vehicle adoption patterns and (2) Incremental Vehicle Costs (IVC)—or the incremental cost of purchasing a higher-priced PEV instead of an otherwise comparable conventional internal combustion engine (ICE) vehicle. The adoption patterns vary among the scenarios, with the Baseline assuming current adoption patterns—meaning greater adoption at higher-income levels—while the other scenarios assume the adoption patterns converge by 2030 or 2050.

The study found that vehicle electrification under the scenario with relatively more conservative cost assumptions would confer significant economic benefits by both 2030 and 2050—resulting in increases to Gross State Product (GSP), employment, real household incomes, and state revenue. These results indicate that wider and more rapid PEV adoption will benefit most Californians—whether they buy a PEV or not—by stimulating the overall economy and reducing harmful criteria pollution. The study also finds that promoting PEV adoption in lower-income communities improves both economic and health benefits to them without significantly reducing benefits to others.

KEY FINDINGS INCLUDE:

- **Light-duty vehicle electrification** can be a potent catalyst for California's economic growth between 2020 and 2030, stimulating job growth directly and indirectly across the economy.
  - By 2030, vehicle electrification will increase California's GSP by between $82 billion to $142 billion, depending on the scenario.
  - Real income is projected to increase substantially—ranging from between $311 billion to $357 billion in 2030, depending on the scenario.
  - Study authors calculated an estimated increase of 394,000 new jobs in 2030 under the relatively more conservative scenario (LTES)—and more than half a million new jobs under the scenarios that account

1 2019 California Green Innovation Index. Next 10. October 8, 2019. Available at: https://www.next10.org/publications/2019-gii

for declining costs and increasing availability of PEVs. These do not include the substantial employment gains that exceed direct job creation.

 » This overall economic expansion has significant fiscal benefits–generating billions in additional revenue per year from existing tax instruments.

- Looking out to 2050, **the economic benefits increase by seven to eight times,** depending on the scenario, over those in 2030 as the growth dividends from more efficient mobility are amplified.

 » Money that would otherwise go to out-of-state energy companies is instead spent on largely in-state goods and services. Even in the conservative LTES scenario, vehicle electrification increases California's GSP by about five percent by 2050.

 » In the scenarios (Innovation and Equity) that reflect more realistic vehicle cost reductions, the gains are almost twice as large.

- **Individual Californians gain from increased economic growth** associated with fuel cost savings due to vehicle electrification, whether they buy a new car or not.
- Because households and enterprises spend their fuel savings primarily on services, employment and income benefits are proportionately higher among Disadvantaged Communities (DACs).

 » DACs will experience relatively higher job growth and larger per capita economic benefits from reduced mortality.

 » Air pollution reductions from large-scale electric vehicle adoption also benefit DAC households more than higher-income groups due to decreased health costs.

POLICY CONSIDERATIONS

- Most of the benefits of PEV adoption occur regardless of who adopts the vehicles, but if policies can accelerate adoption in DACs, these groups will benefit more from direct savings and local pollution reduction, and California will come much closer to achieving its long-term pollution reduction goals.
- Creating a market to incubate the next generation of fuel-efficient vehicles could promote job growth across California's economy while capturing national and global market opportunities for technology development.
- Benefits to GSP and income dwarf the amounts accruing to other policies, such as California's cap-and-trade program and the budgets thus far committed to clean vehicle incentive programs. Under any of the alternative scenarios considered, increased vehicle fleet electrification could be very lucrative for the state.
- While the current federal administration's approach toward California's authority to regulate vehicles provides some uncertainty, the fiscal authority to offer economic incentives is much more secure. The state could consider pursuing and expanding incentives more aggressively to optimize net benefits, such as reduced GHG emissions and a variety of economic and health co-benefits that are discussed in this study.

ANALYSIS APPROACH & RESULTS

To review the initial evidence, the study begins with a summary of the latest research on emerging PEV technology. A set of scenarios (detailed in Table ES.1) are established that reflect the current policy dialogue on how to advance California vehicle electrification, and in particular, how to do so more inclusively. Included in the analysis is an evaluation of the challenges for Disadvantaged Communities (DACs) to adopt and benefit from innovative vehicle technologies that have heretofore been out of reach. A more detailed description of scenario assumptions is provided below, including visual representations of adoption patterns that drive each

TABLE ES.1 Scenarios Evaluated in the Present Study

	SCENARIO	DESCRIPTION	ADOPTION	INCREMENTAL VEHICLE COST
1	**Baseline**	A reference Scenario with existing policies in force to 2050. Baseline policies are complemented by revised adoption and use cost estimates commissioned by CEC from E3. Vehicle technology costs are assumed to remain constant at current levels.	Constant adoption shares among income groups	High
2	**LTES**	Incorporates E3 technology cost estimates for vehicles, declining over time.	Equal shares by 2050	Medium
3	**Innovation**	LTES policies to 2030 and 2050, taking account of more recent vehicle technology cost estimates.[2]	Equal shares by 2050	Low
4	**Equity**	The LTES scenario with PEV purchase shares equalizing across California income groups by 2030.	Equal shares by 2030	Low

Source: Authors' Analysis

scenario (Figure ES.1). Results for the macroeconomic assessment and DAC assessment are then presented for the two milestone years 2030 and 2050.

The scenarios analyzed differentiate the pattern of PEV adoption over time, using the state's aggregate GHG reduction commitment as the reference. This study assumes that the light-duty vehicle fleet will reduce its aggregate GHG emissions 40 percent below the 1990 level by 2030 and 80 percent below the same level by 2050. It is also assumed that these goals are achieved with a fleet that blends four categories of vehicles: ICE, PHEV, BEV, and HFC. The adoption scenarios do not mandate full electrification by 2050, but assume BEV and HFC vehicles have zero emissions (including electric power source emissions) and PHEVs have half of the emissions of ICE vehicles. Finally, ICE vehicles are assumed to deliver efficiency improvements as mandated by the state over the same period.

Having specified the composition of the aggregate vehicle fleet, what remains is to determine who owns the vehicle types and what are their comparative costs. As already indicated, IVC profiles for PEVs are evaluated that are relatively High (Baseline), Medium (LTES), and Low (Innovation and Equity). In terms of ownership, the first three scenarios assume that the income group shares of the vehicle fleet remain at today's levels until 2030, but then converge to the same shares of vehicle types as the aggregate fleet by 2050. In the Equity scenario, it is assumed that all income groups converge by 2030. In other words, the incremental costs and benefits of the aggregate fleet are shared equally by all households by 2050 in the first three scenarios, but 20 years earlier in the Equity scenario.

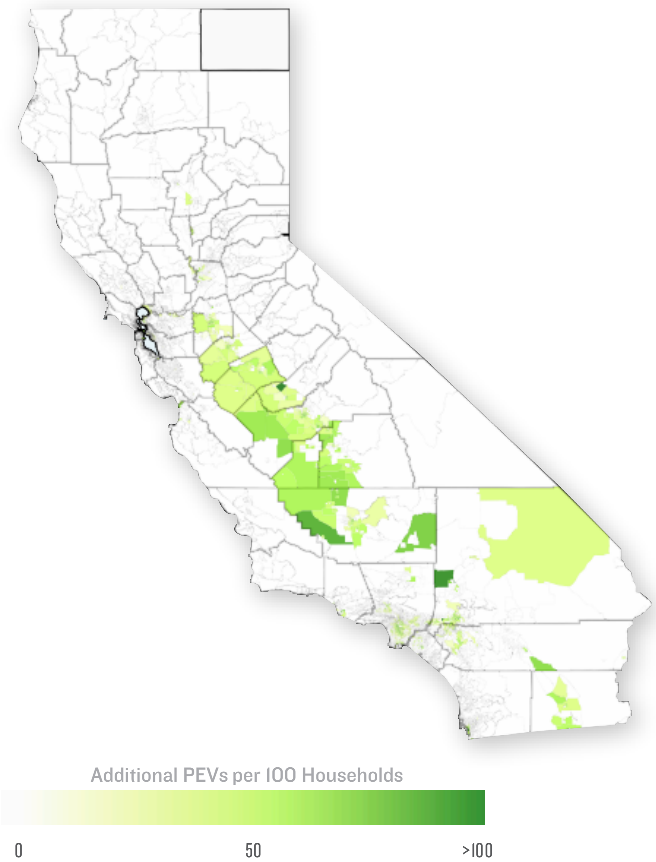
This assessment does not explicitly model vehicle consumer behavior, only the consequences of alternative adoption patterns that can be envisioned by policy makers. The goal of this study is to illustrate economic benefits of these alternative adoption pathways across the state as a whole in an effort to strengthen evidence supporting the choice of policy objectives—not to prescribe interventions that would induce a given adoption pathway.

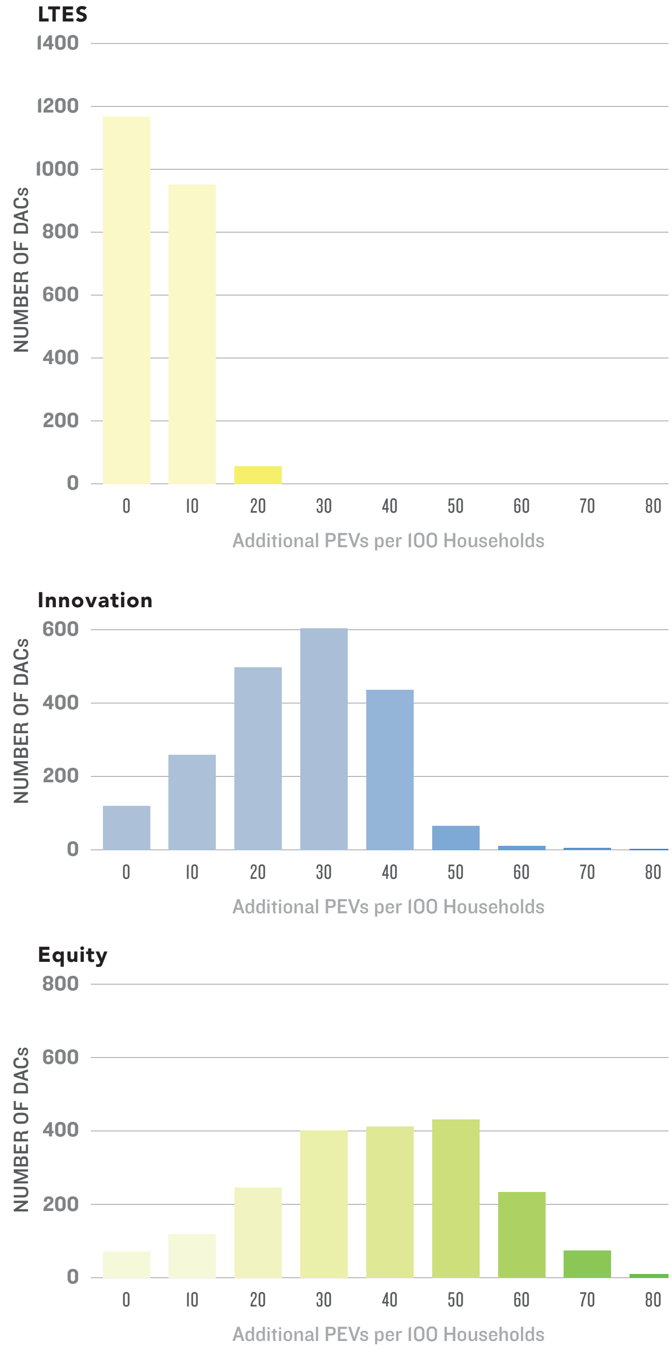
Macroeconomic Impacts in 2030

The study finds that vehicle electrification under LTES cost assumptions would confer significant economic benefits from direct and indirect demand stimulus, and that these combine to increase Gross State Product (GSP), employment, real household incomes, and state revenue. The Innovation scenario incorporates more recent and significantly lower vehicle cost estimates from the International

2 Lutsey, Nic, et. al. "Update on electric vehicle costs in the United States through 2030." The International Council on Clean Transportation. April 2, 2019. Available at: https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

FIG ES.1 PEV Adoption Patterns in DACs by Scenario, 2030





Source: Authors' Analysis

Council on Clean Transportation[3] and significantly improves the aggregate economic stimulus. Finally, more equitable vehicle adoption pathways yield essentially the same overall benefit, but the composition differs in important ways. Once again, it should be emphasized that the threefold stimulus from accelerated PEV deployment creates growth and jobs broadly across the economy, with many Californians benefitting whether they by a PEV or not.

Percent changes are useful in comparing the relative impacts between different scenarios, but do not give a clear idea to the magnitude of these effects. Indeed, the fiscal dimensions of California climate policy has great significance for many public programs and private parties who bear costs and benefits of policies.

Table ES.3 presents the estimated macroeconomic impacts in inflation-adjusted 2016 dollars.

These results illustrate the size of the impacts with GSP increasing some $82 to $142 billion in 2030, de-

3 Lutsey, Nic, et. al. "Update on electric vehicle costs in the United States through 2030." The International Council on Clean Transportation. April 2, 2019. Available at: https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

pending on the scenario. Real income is projected to increase substantially—ranging between $311 billion to $357 billion in 2030, depending on the scenario. Perhaps the most arresting feature of these numbers is how they dwarf the amounts accruing to (e.g.) California's cap-and-trade mechanism, as well as the budgets thus far committed to clean vehicle incentive programs. If more vehicle fleet electrification can deliver even a fraction of the estimated revenue for any of the alternative scenarios considered, it could be very lucrative for the state. The disparity in program and impact numbers is hardly surprising, even before considering multiplier effects. Energy program revenues are based on marginal fuel and other user taxes, while large-scale PEV adoption recycles household and enterprise savings from cutting back between 40 to 80 percent of what Californians traditionally spend on gas for vehicles.[4]

This finding points to another important policy issue for California—reliance on incentives over standards. Currently, there are persistent uncertainties regarding the state's authority to regulate vehicles and other energy use technologies. Fiscal authority to offer economic incentives is much more secure, and our results suggest the state could pursue this much more aggressively, reaping net benefits in terms GHG emissions and a variety of economic and health co-benefits discussed in this study. The scope for incentives can also be significantly expanded, to include purchaser prices, financing, vehicle sharing, dealer and manufacturer incentives, infrastructure (e.g. charging) and component technology subsidies.

With regard to jobs, the study found an estimated increase of 394,000 new jobs in 2030 with higher-cost PEVs, to over half a million new jobs with more recent, lower vehicle purchase and operating cost projections. It should be noted that overall employment gains significantly exceed direct job creation that can be expected from increased PEV sales.

TABLE ES.2 Macroeconomic Impacts in 2030 - Percentages (Change from Baseline in 2030)

	LTES	INNOVATION	EQUITY
Gross State Product ($B)	1.48%	2.55%	2.54%
Real Output	2.18%	3.10%	3.08%
Employment	1.44%	1.95%	1.94%
Real Income	2.92%	3.99%	4.16%
In State Revenue	1.45%	2.51%	2.50%

Source: Authors' Analysis

TABLE ES.3 Macroeconomic Impacts in 2030 - Absolute Levels (Difference from Baseline in 2030; 2016 $ Billions Unless Noted)

	LTES	INNOVATION	EQUITY
Gross State Product ($B)	82	142	141
Real Output	179	256	254
Employment	394	532	530
Real Income	311	351	357
In State Revenue	4	7	7

Source: Authors' Analysis

Finally, it should also be noted that overall economic expansion has significant fiscal benefits, generating billions in additional revenue per year from existing tax instruments. Much larger than California's anticipated cap-and-trade revenue, it is a reminder that pro-growth aspects of new vehicle adoption policy can yield substantial new resources for reinvestment in public goods and services.

4 Annual gasoline demand in California is currently about 15 billion gallons, the retail value of which is about $60 billion.

Macroeconomic Impacts in 2050

Extending this analysis to 2050 significantly amplifies the growth dividends associated with more efficient mobility (Tables ES.4 and ES.5). Like interest, energy and other use savings from more efficient technology compound over time, where the multiplier in this case comes from the expenditures diverted from (largely imported) energy fuels to in-state goods and (predominately) services. The result is that extending the scenario horizon threefold (from 10 years in the future to 30 years) increases economic benefits (real GSP) by seven to eight times, depending on the scenario. Even in the relatively conservative LTES scenario, vehicle electrification increases California GSP by about five percent by 2050, assuming the state meets its adoption goals under a relatively high-cost scenario. With a greater reduction in vehicle costs, the gains are almost twice as large. Because adoption patterns between 2030 and 2050 are essentially the same for the Innovation and Equity scenarios, they differ little by the final year. Having said this, it should be emphasized that these two scenarios have very different effects on economic inequality.

The macroeconomic drivers of these three scenarios are simply described. As was already established by in the independent assessment of CEC's Long-Term Energy Strategy (LTES), investments in new and more efficient clean energy provide significant net stimulus to the California economy.[5] Decomposing the PEV component of this in the LTES scenario shows how important vehicle electrification is to statewide efficiency gains and growth. When more recent estimated improvements in vehicle cost effectiveness are taken into account with the Innovation scenario, the growth stimulus is even greater. Finally, promoting PEV adoption among lower-income households distributes these household economic benefits more inclusively.

TABLE ES.4 Macroeconomic Impacts in 2050 - Percentages (Change from Baseline in 2050)

	LTES	INNOVATION	EQUITY
Gross State Product ($B)	4.94%	9.24%	9.22%
Real Output	6.00%	10.51%	10.48%
Employment	2.86%	4.03%	4.02%
Real Income	7.80%	12.74%	12.81%
In State Revenue	4.70%	8.81%	8.79%

Source: Authors' Analysis

TABLE ES.5 Macroeconomic Impacts in 2050 - Absolute Levels (Difference from Baseline in 2050; 2016 $ Billions Unless Noted)

	LTES	INNOVATION	EQUITY
Gross State Product ($B)	614	1,150	1,147
Real Output	1118	1,956	1,952
Employment (,000)	1290	1,816	1,812
Real Income	1,216	1,489	1,494
In State Revenue	29	55	54

Source: Authors' Analysis

HOUSEHOLD IMPACTS BY INCOME GROUP

To assess prospects for inclusive vehicle adoption, the BEAR model—which has the ability to forecast results for each state income tax bracket—was used to examine scenario impacts across different California income groups. Given that the benefits from transitioning to electric and other zero-emission vehicles will not be

5 Roland-Host, D., D. Behnke, S. Evans, C. H. Springer, S. Heft-Neal. Senate Bill 350 Study, Volume VIII: Economic Impact Analysis. California State Senate, 2016.

uniformly distributed across the population, this feature of the model is particularly relevant. The results for income impacts by decile are illustrated in Figure ES.2. Here the essential macroeconomic drivers of vehicle electrification can be seen—both in terms of aggregate income growth and its distribution. Simply put, more efficient vehicles confer income benefits on their owners, and these propagate across multiplier linkages to the rest of the state economy. Even when lower-income households capture larger benefits from accelerated adoption rates, these indirect linkages protect most of the gains for higher-income groups.

FIG ES.2 Household Real Income Changes by Tax Bracket (Percent Change from Baseline Scenario in 2030)

Source: Authors' Analysis

The LTES scenario assumes the state would progress toward uniform PEV adoption by 2050. The Innovation scenario adhered to the same adoption pathway but offered greater PEV owner savings via more optimistic vehicle cost trajectories. Finally, the Equity scenario shifted PEV purchasing to achieve equal ownership rates across income groups by 2030, meaning the same overall PEV deployment, but more rapid adoption among lower-income groups. The primary difference between these scenarios was the consequent distribution of PEV purchase costs and use savings. The economy and all income groups gained from lower cost vehicle deployment (LTES) and gained more when costs were even lower (Innovation). When lower-income groups experienced more rapid adoption, their gains were even larger than those of higher-income groups, exactly as would be expected.

Less obvious, but very welcome for policy makers, is the finding that higher-income groups would be nearly unaffected by the redistribution of vehicles. This is because, while fewer people may benefit directly from PEV ownership, many more can benefit indirectly from adoption by others, via emission reductions and the economic spillovers from an expanding technology sector.

Any discussion of the economic impacts from large-scale technology adoption also needs to take account of three component impacts: investment in technology production, technology purchasing, and more indirect technology adoption costs/benefits. The first, like building and operating an automobile factory, represents so-called "shovel-ready" investment and is usually an unambiguous economic stimulus. Technology purchase and use costs can have mixed effects on the economy, depending on their so-called opportunity cost. In other words, technology adoption will stimulate the economy if it leads to higher productivity, lower resource costs, or both. If it reduces productivity (e.g. online gaming or shopping during working hours) or increases resource costs, it will be detrimental to economic growth.

But it is worth noting that, as with the example of Tesla, every time California establishes standards or incentives for adoption of new technology, it creates an incubator the size of the world's fifth-largest economy. Firms know that establishing marketable innovations here can prepare them for global export competitiveness. All of this underscores a central tenet of California's knowledge-intensive growth model—induced growth from technology innovation benefits the overall economy, rewarding even those people who neither develop nor adopt it. For PEVs, this conclusion applies with comparable force to economic and environmental benefits, although PEVs in lower-income communities might displace less efficient vehicles, amplifying these benefits.

DISADVANTAGED COMMUNITY RESULTS

Disadvantaged Communities (DACs), comprised mainly of households in the lower quartile of California incomes and facing higher-than-average pollution burdens, are a primary target for the state's emission mitigation and economic stimulus efforts. From the lower-income perspective, the most important finding of this assessment is that large-scale California vehicle electrification benefits these groups regardless of which patterns of adoption are analyzed. As long as the state accelerates PEV deployment, the savings from this will expand service-intensive household demand, creating jobs across the economy that are more likely to benefit lower-wage, less-skilled workers. It should also be emphasized that these multiplier benefits may not be directly observable as links to higher-income groups adopting efficient vehicles, yet the indirect expenditure linkages are inexorable. Of course, it would also be desirable for lower-income communities to enjoy the direct efficiency and local pollution benefits of PEVs, but these impacts are additional to the overall job-intensive stimulus resulting from expansion of a more fuel-efficient light vehicle fleet. These indirect employment gains are also far greater than direct income and job creation from the PEV sector itself. These comparisons are summarized in Table ES.6 for 2030. Noting first that DACs comprise 25 percent of the California population, this group's job growth significantly exceeds this share (36%) in all scenarios.

TABLE ES.6 Macroeconomic Impacts of PEV Deployment in 2030

IMPACT	SCENARIO	DAC_ SHARE	NONDAC_ SHARE
Jobs	LTES	36%	64%
	Innovation	36%	64%
	Equity	36%	64%
PEVs	LTES	11%	89%
	Innovation	40%	60%
	Equity	45%	55%
Avoided Health Costs	LTES	33%	67%
	Innovation	34%	66%
	Equity	34%	66%

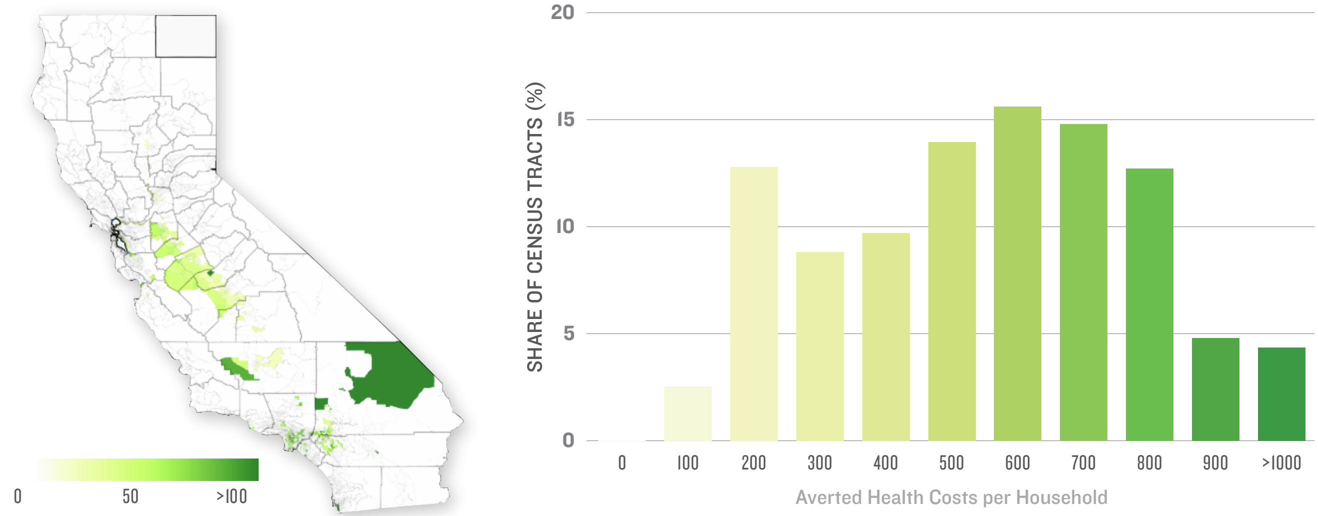
Source: Authors' Analysis

DAC Job Impacts

Job growth statewide is driven by new jobs in service industries and these sectors happen to be sectors that disproportionately employ DAC workers. As Los Angeles County and the Central Valley comprise 75 percent of the disadvantaged communities in the state, these two regions were analyzed for this study. Approximately 25 percent of the state population lives in a DAC.

- In Los Angeles County, 45 percent of the population lives in a DAC community and DAC workers are 55 percent more likely to be employed in service industries. In the Innovation Scenario, more than half of the 161,000 forecasted jobs by 2030 in that county in are forecast to be created in DACs.
- More than 32,000 of the 59,000 jobs created in the Central Valley by 2030 in the Innovation Scenario are forecast to be created in DACs.
- By 2050, the Innovation Scenario gives rise to 1.812 million additional jobs across the state, with 36 percent generated for DAC households.
  - » Los Angeles County (192 jobs created per DAC) and the Central Valley (216 jobs created per DAC) enjoy substantial incremental employment benefits.

FIG ES.3 Estimated DAC Health Cost Savings, Equity Scenario, 2030



Source: Authors' Analysis

DAC Health Impacts

In terms of averted health costs from reduced vehicular criteria pollution, DACs again enjoy relatively greater benefits that Non-DAC communities, regardless of the which of the three PEV adoption patterns prevails. Study estimates represent health benefits associated with reductions in criteria pollutant (NOx, SOx, and PM2.5) emissions in the vehicle sector alone but do not quantify many of the other expected benefits that are known to be substantial. However, assuming uniform statewide emission reductions, **these benefits are higher for households in disadvantaged communities.** Moreover, it is likely underestimating the total benefits to DACs of these policies as cannot fully account for the potential benefits to DACs because they are often located closer to high-traffic roads and highways.[6]

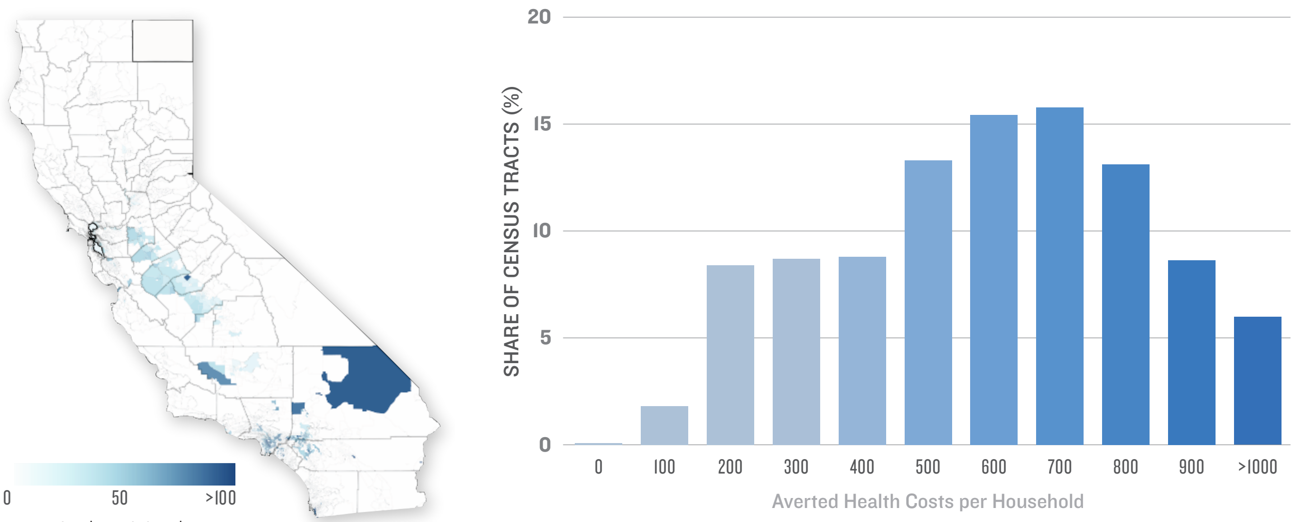
- Under the Equity Scenario, the economic value of health benefits from reductions in criteria pollutants in the energy and fuel sector will be $2.0 billion by 2030—$800 million from averted mortality and $1.2 billion from averted medical costs.
- The benefits are higher for DAC households than non-DAC households—with $581 averted per DAC household and $494 averted per non-DAC household—and the savings represent a greater proportion of household income for DACs.

Because DAC households have lower incomes, their economic gains are even more dramatic in relative terms. However, more targeted policies could produce even larger gains. By 2030, forecasts from this study indicate that health benefits across California DACs could be substantial, even in the more technology-pessimistic LTES scenario (Figure ES.5), but even greater with higher rates of PEV innovation (Figure ES.4) and lower-income household vehicle adoption (Figure ES.3).

To summarize—for all scenarios evaluated, compared to the rest of the state's population, Disadvantaged Communities (DACs) will experience higher job growth and larger per capita economic benefits from reduced mortality and morbidity than in the baseline case.

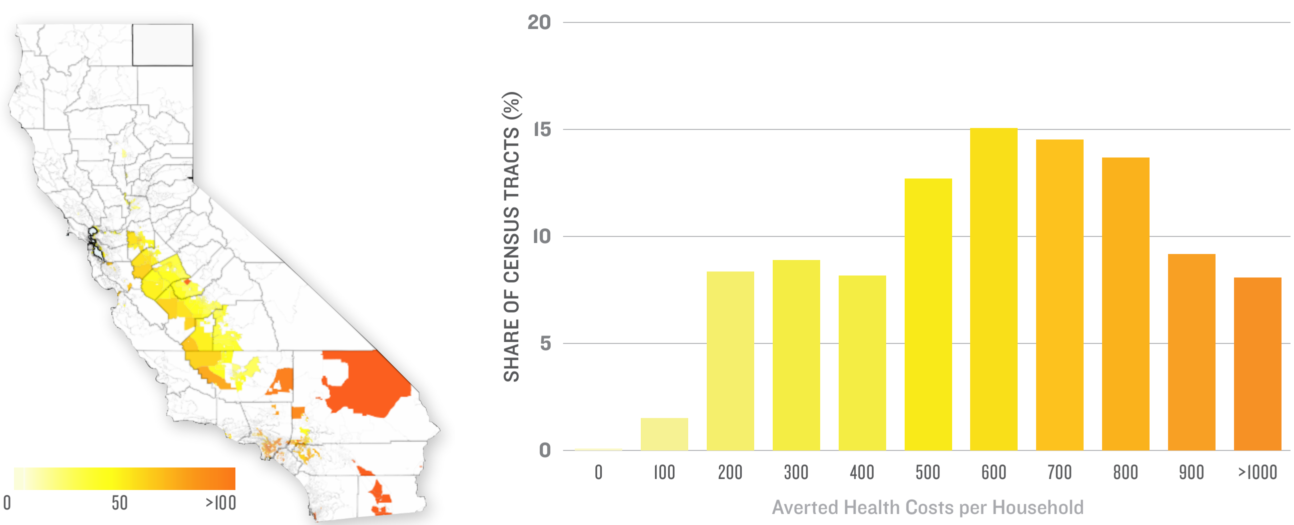
6 CHAPTER 10: Climate Adaptation and Resiliency, section 6: in "Increasing Climate Resilience in Disadvantaged Communities" includes a detailed description of how DAC exposure to poor air quality correlates with proximity to transportation networks. Available at: http://www.energy.ca.gov/2017_energypolicy/

FIG ES.4 Estimated DAC Health Cost Savings, Innovation Scenario, 2030



Source: Authors' Analysis

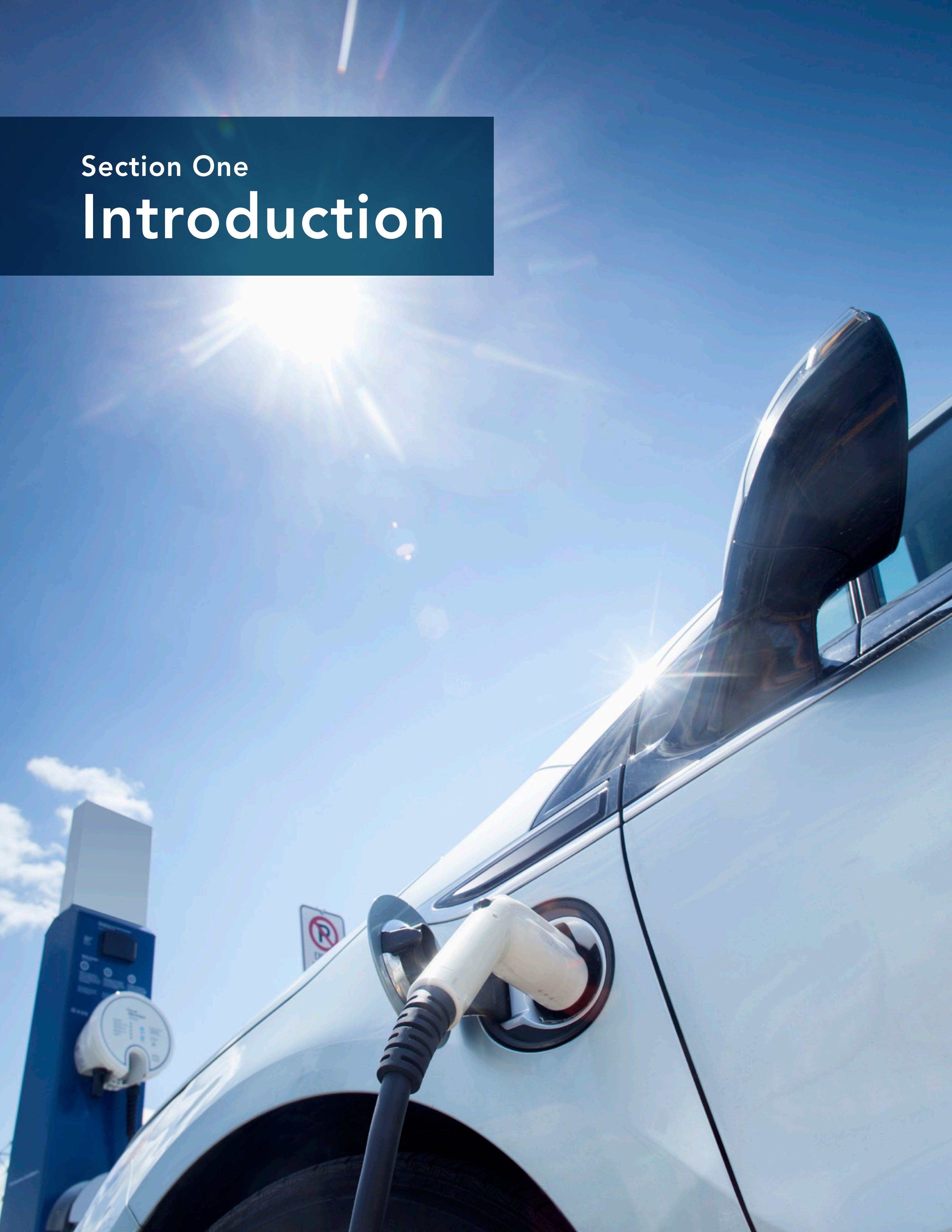
FIG ES.5 Estimated DAC Health Cost Savings, LTES Scenario, 2030



Source: Authors' Analysis

Section One

Introduction



Introduction

If California is to achieve its overall pollution reduction goals, including a reduction of greenhouse gas (GHG) emissions to 80 percent below 1990 levels by the year 2050, a dramatic shift towards electric vehicles (EVs) will be essential. State policies such as the Zero Emission Vehicle (ZEV) program, the Low Carbon Fuel Standard (LCFS), and GHG emissions regulations are already driving vehicle electrification,[7] but progress to date has been uneven.

In particular, average EV adoption rates will need to accelerate significantly, meaning these vehicles have to become more affordable and desirable across California's diverse population. Fortunately, aggressive renewable energy commitments by the state, combined with dramatic vehicle technology improvements, are rapidly improving the financial and environmental characteristics of EVs. At the same time, the automotive industry is preparing a new generation of more affordable and versatile vehicles that will expand this category dramatically, while the conventional energy sector is scrambling to join low carbon electricity supply chains.

This study examines the economic impacts of large-scale EV adoption in the California light vehicle sector, including long-term projections that would contribute to achieving the goals of reducing GHG emissions by 40 percent and 80 percent below 1990 levels, in 2030 and 2050, respectively. Scenarios incorporate the most up-to-date technical information on emerging vehicle technologies, as well as a variety of incentives targeting EV adoption statewide and among economically disadvantaged groups.

Results indicate that, while consistent with long-term climate goals, policies that encourage large-scale plug-in electric vehicle (PEV) deployment can be a potent catalyst for medium-term economic growth, benefitting millions of Californians over the next decade and beyond. In all of the scenarios evaluated, large-scale carbon fuel savings translate into billions of dollars of new in-state consumption, income, and tax revenue, creating thousands of new jobs across the state economy. Because growth is concentrated in service sectors, lower-income workers see relatively greater income and job growth. The study also includes an assessment of the economic impacts of another important co-benefit—better public health via air quality improvements—and finds these benefits operate in exactly the same direction. Up to one-third of the total economic gains from decarbonizing the transportation sector and its supporting electric power supply come from increased public health.

Climate action generally, but especially bottom-up policies that have extensive impacts on consumption patterns, have complex behavioral properties and pervasive economic impacts. A general equilibrium forecasting tool like the Berkeley Energy and Resources (BEAR) model is well suited to capture such interactions, and can elucidate the detailed incidence of these policies. BEAR has an explicit inter-temporal structure and sector detail that maps out patterns of adjustment and the distribution of economic benefits and costs.[8]

7 "Transportation Electrification Activities Pursuant to Senate Bill 350." California Public Utilities Commission. Available at: https://www.cpuc.ca.gov/sb350te/

8 The BEAR model is fully documented in the following study and the overall structure is summarized in section 5 of this report with additional information in the Appendix. Roland-Holst, David. 2018. "Berkeley Energy and Resources (BEAR) Model: Documentation for a Dynamic California CGE Model for Energy and Environmental Policy Analysis," Version 3, Department of Agricultural and Resource Economics, University of California, Berkeley, Processed.

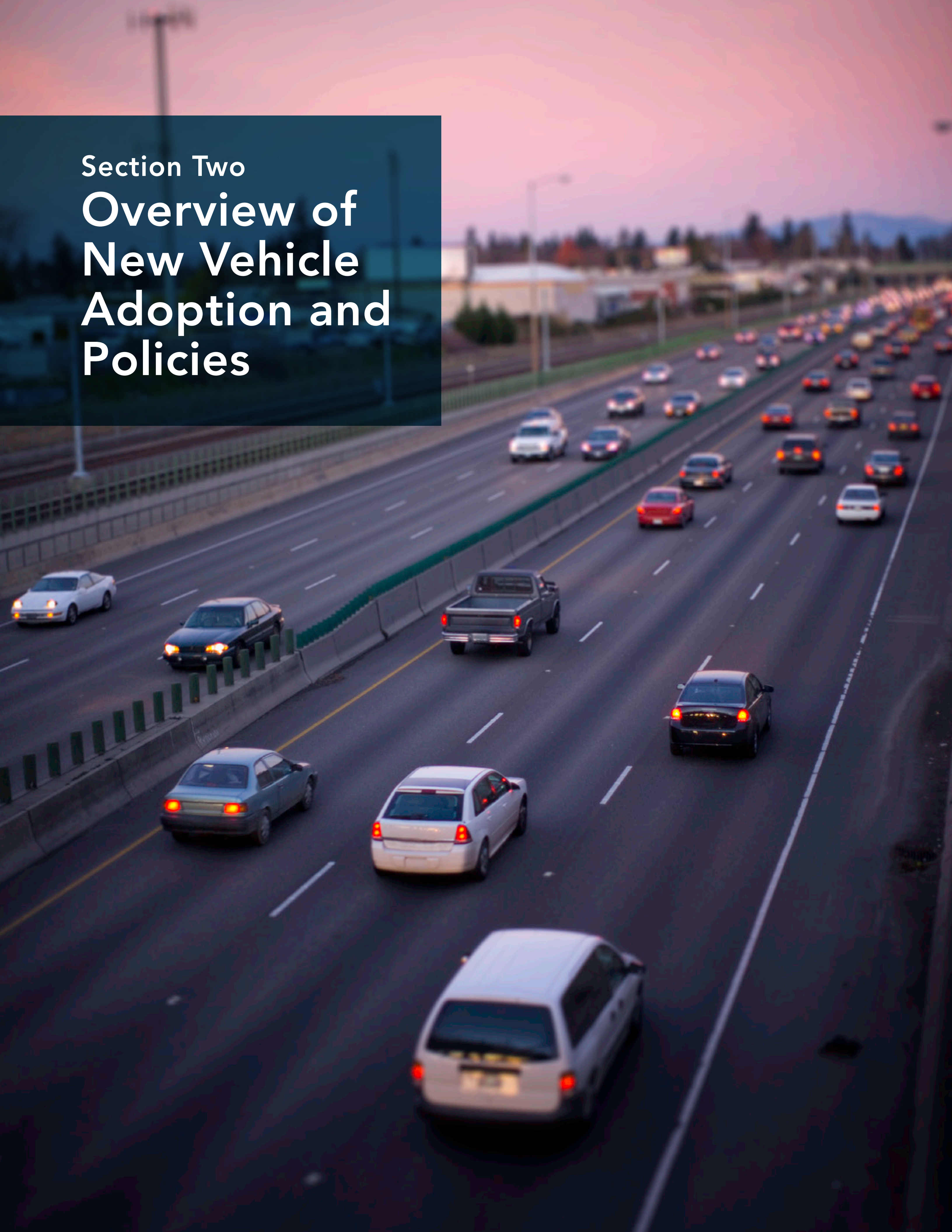
For more effective policy dialogue, design, and implementation, public and private stakeholders need more reliable information on the direct and indirect economic impacts of policy options before they are implemented. To support this, the present study evaluates the economic significance of such factors as:

- Costs of electric vehicles relative to petroleum-fueled vehicles
- Scenarios evaluating more inclusive patterns of PEV adoption across the state
- Localized (county-level) employment, income, and public health effects due to new vehicle technology adoption and fuel shifting

This analysis models annual results over the next three decades, emphasizing outcomes for the policy milestone years of 2030 and 2050. The policy scenarios analyzed will include vehicle penetration on a trajectory sufficient to support California's policy goals of 40 percent and 80 percent reduction in GHG emissions with respect to 1990 levels in 2030 and 2050, respectively.

Section Two

Overview of New Vehicle Adoption and Policies



Overview of New Vehicle Adoption and Policies

The transportation sector is a primary driver of global warming pollution in California, comprising more than 40 percent of the state's overall GHG emissions inventory in recent years. In 2017, on-road vehicles constituted 68 percent of transportation sector emissions.[9] Transportation emissions have varied over the last decade, with the greatest decrease occurring during the last recession, but are trending upward as the economy has recovered.

This section focuses on the demand side of California's new vehicle market, offering a brief overview of existing and emerging patterns of new vehicle technology adoption.

Electric vehicle adoption to date has been quite uneven and well below the potential suggested by the prospective use and financial characteristics of these vehicles. The authors of this report do not attempt to explain or model adoption behavior in this section or this study as a whole, but intensive and innovative research literature has been emerging on this subject for over a decade and continues to offer insights for policy design and marketing.

2.1 DEMOGRAPHICS OF EV CONSUMERS

The state of California presently comprises nearly 47 percent of the U.S. electric vehicle fleet as of 2018.[10] A recent detailed study from Muehlegger and Rapson analyzed 400,000 vehicle purchases in California.[11] From this evidence, Figure 1 illustrates the demographic breakdown of EV consumers with a comparison of purchases from consumers of different income brackets. In particular, for ICEVs and HEVs, consumers with annual incomes below $100,000 comprise 72 percent and 63 percent of purchases, respectively. In comparison, most alternative fuel vehicles are purchased by buyers in income brackets above $100,000. This is consistent with the international evidence cited below—higher-income groups account for a disproportionate share of alternative fuel vehicle purchases in the state of California.

Another dimension explored in this section compares vehicle purchases by consumer ethnicity. Figure 2 displays the results of this analysis. Notably, Asian buyers and non-Hispanic whites display similar purchase patterns in terms of accounting for a relatively higher fraction of alternative technology vehicle purchases relative to their share of ICEV and HEV purchases. These social disparities in adoption patterns have many implications and this concern is the target of significant state policies, as well as a primary subject of this study.

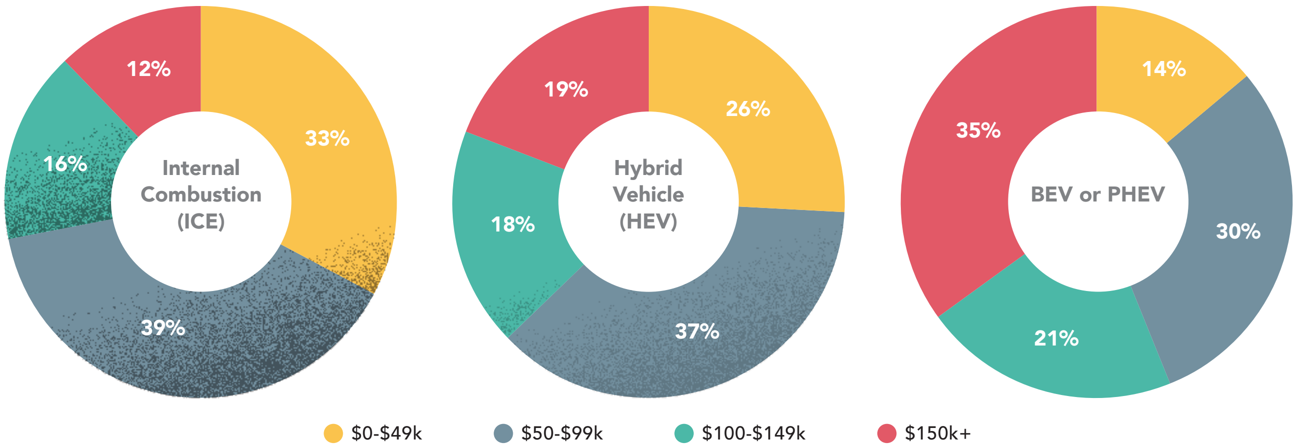
Furthermore, some interesting trends are observed when looking at consumer trends concerning used car purchases. Roughly two-thirds of EV sales within the Muehlegger & Rapson study period occurred in 2015. In this year, in particular, used vehicle sales comprised approximately 15 percent of all vehicle sales. In other words, the vast majority of alternative fuel vehicle

9 *2019 California Green Innovation Index.* Next 10. October 8, 2019. Available at: https://www.next10.org/publications/2019-gii

10 Share of U.S. electric vehicles in California available at: https://evadoption.com/ev-market-share/ev-market-share-california/

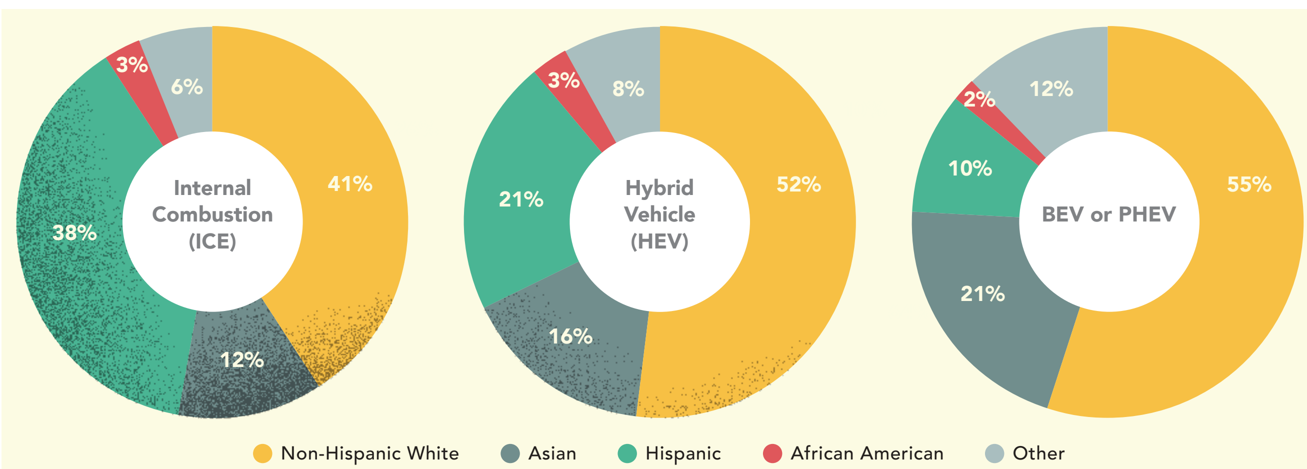
11 Muehlegger, E. & Rapson, D. (2018a). *Distributional Impacts of Vehicle Policy: Who Buys New and Used Alternative Vehicles.* UC Davis, National Center for Sustainable Transportation. Available at: https://escholarship.org/uc/item/0tn4m2tx

FIG 1 Fraction of Vehicle Sales in California by Income Bracket



Source: National Center for Sustainable Transportation[12]

FIG 2 Fraction of Vehicle Sales in California by Ethnicity



Source: National Center for Sustainable Transportation[13]

sales in California during the study period were new vehicles. These data analyzed by income bracket strata are displayed in Figure 3.

When looking at similar used-car purchase decisions for different ethnic groups, the results show unsurprisingly that non-Hispanic white consumers are the largest group of purchasers by population. In addition, Hispanic and African American consumers tend to be relatively more likely to buy used EVs compared to the other ethnic groups.

These results are derived from a very detailed California analysis, but are in line with similar international research. Hopefully, what they reveal about the links between demographic heterogeneity and adoption patterns can be interpreted to yield deeper insights about real behavioral drivers, information availability,

12 Ibid.

13 Ibid.

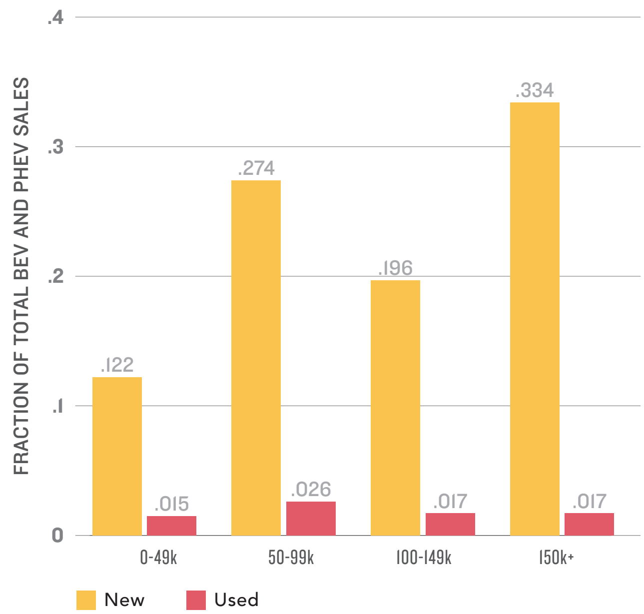
financial, and other constraints that might be mitigated by policy so that PEV adoption can reach its potential.

In the same California context, a valuable analysis based on representative survey data for 1,604 low- and moderate-income households helps to identify effective policy strategies to promote the retirement of ICEVs and the adoption of alternative fuel vehicles within California.[16] First, some general characteristics of the vehicle search process within this sample population are analyzed. In terms of the time spent searching for a new car, the results show that the average consumer spends 5.7 months on this activity, although there are significant differences by gender (Table 1).

Further breaking down this decision-making characteristic by income groups, the highest-income households are found to spend nearly double the amount of time searching than the sample average while the lowest-income group spent the second-most time searching. For the lowest-income group (<$25,000), this makes sense as their decisions on car purchases are most likely financially constrained, making it more difficult to find a vehicle within their price range that still meets their needs. Higher-income groups, on the other hand, are more likely to spend more time finding vehicles that fit their personal preferences, without the similar urgency of time constraints that may be present in other groups.

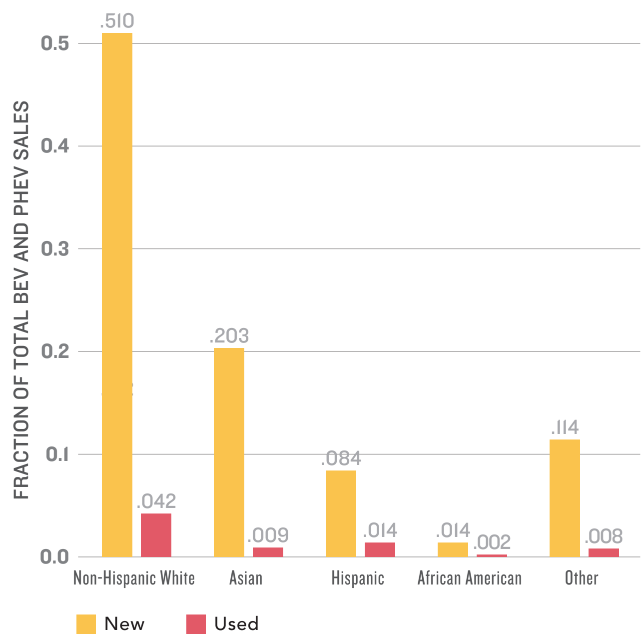
Further breaking down this decision-making characteristic by income groups, the highest-income households are found to spend nearly double the amount of time searching than the sample average while the lowest-income group spent the second-most time searching. For the lowest-income group (<$25,000), this makes sense as their decisions on car purchases are most likely financially constrained, making it more difficult to

FIG 3 Fraction of New and Used BEV and PHEV Sales, by Income



Source: National Center for Sustainable Transportation[14]

FIG 4 Fraction of New and Used BEV and PHEV sales, by Ethnicity



Source: National Center for Sustainable Transportation[15]

14 Ibid.

15 Ibid.

16 Pierce, G., DeShazo, J. R., Sheldon, T., McOmber, B., & Blumenberg, E. Designing Light-Duty Vehicle Incentives for Low- and Moderate-Income Households. UCLA Luskin Center for Innovation. March 12, 2019. Available at: https://ww3.arb.ca.gov/research/apr/past/15rd011.pdf

find a vehicle within their price range that still meets their needs. Higher-income groups, on the other hand, are more likely to spend more time finding vehicles that fit their personal preferences, without the similar urgency of time constraints that may be present in other groups.[18]

Households in urban and suburban areas were much more likely to spend significantly longer on their search than rural households. This could possibly be due to the time-sensitive nature of car purchases in rural areas where public transportation is not as well-established.

With all these adoption characteristics in mind, the results of surveys of households responding to two hypothetical public programs to incentivize lower carbon vehicle adoption presented in the UCLA study were reviewed. The first policy option provided rebate purchase incentives to households that make less than 225 percent and between 225 and 300 percent of the Federal Poverty Limit (FPL), respectively, when adopting a cleaner vehicle. The second policy option offered guaranteed financing to households willing to purchase cleaner vehicles. Across all vehicle types, rebates of $2,500, $5,000 and $9,500 value increased purchase rates from the baseline by about 20 percent, 40 percent and 60 to 80 percent, respectively (Table 3).[21]

Interesting to note is that a higher share of moderate-income consumers would purchase PHEVs, while a slightly higher share of low-income consumers would purchase a BEV, indicating a stronger preference by the moderate- and low-income groups towards PHEVs and BEVs, respectively. Results of this analysis turned out to be quite similar across the different levels of geographic urbanization, as can be seen in Table 4. Presumably, this

17 Ibid.

18 Ibid.

19 Ibid.

20 Ibid.

21 Ibid.

TABLE 1 Number of Months Spent Searching for Past Purchase of Vehicles, by Gender

	N.	MEAN	S.D.
Male	797	5.0	6.8
Female	683	6.5	14.6
Sample Avg.	**1,480**	**5.7**	**10.5**

Source: UCLA Luskin Center for Innovation[17]

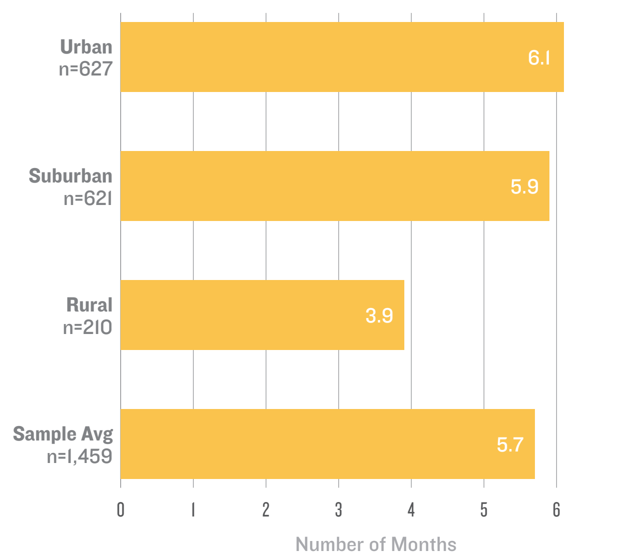
TABLE 2 Number of Months Spent Searching for Past Purchase of Vehicles, by Past Income

	N.	MEAN[1]	S.D.
< $25,000	440	6.9	11.2
$25K - $50K	548	4.5	9.8
$25K - $50K	353	4.4	6.1
> $75,000	139	10.2	12.8
Sample Avg.	**1,480**	**5.7**	**10.5**

[1] The difference in mean months spent searching is statistically significant at $P < 0.05$ between < $25K and $25 - $50K, and $25K and $50K - $75K.

Source: UCLA Luskin Center for Innovation[19]

FIG 5 Number of Months Spent Searching for Past Purchases, by Urbanized Geography



Source: UCLA Luskin Center for Innovation[20]

TABLE 3 Effect of Rebate Levels on Purchase Rate, by Income by Vehicle Type

BY INCOME: PERCENT OF WEIGHTED SAMPLE CHOOSING HEV/PHEV/BEV BY SUBSIDY				
HEV	**$0**	**$2,500**	**$5,000**	**$9,500**
Below 225% FPL	25.5%	30.5%	35.8%	43.9%
Above 225% FPL	25.9%	30.2%	34.8%	41.9%
PHEV	**$0**	**$2,500**	**$5,000**	**$9,500**
Below 225% FPL	3.7%	4.5%	5.2%	6.8%
Above 225% FPL	5.4%	6.3%	7.3%	9.1%
BEV	**$0**	**$2,500**	**$5,000**	**$9,500**
Below 225% FPL	5.4%	6.5%	7.6%	8.3%
Above 225% FPL	5.1%	5.9%	6.8%	7.6%

Source: Source: UCLA Luskin Center for Innovation[22]

TABLE 4 Effect of Rebate Levels on Purchase Rate, by Geography, Subsidy and Vehicle Type

BY GEOGRAPHY: PERCENT OF WEIGHTED SAMPLE CHOOSING HEV/PHEV/BEV BY SUBSIDY				
HEV	**$0**	**$2,500**	**$5,000**	**$9,500**
Urban	25.7%	30.5%	35.6%	43.4%
Suburban	25.6%	30.4%	35.4%	43.2%
Rural	25.7%	30.5%	35.5%	43.4%
PHEV	**$0**	**$2,500**	**$5,000**	**$9,500**
Urban	4.2%	5.0%	5.8%	7.4%
Suburban	4.3%	5.1%	5.9%	7.5%
Rural	4.3%	5.1%	6.0%	7.6%
BEV	**$0**	**$2,500**	**$5,000**	**$9,500**
Urban	5.4%	6.4%	7.4%	8.1%
Suburban	5.4%	6.4%	7.4%	8.1%
Rural	5.2%	6.1%	7.1%	7.9%

Source: Source: UCLA Luskin Center for Innovation[23]

22 Ibid.

23 Ibid.

TABLE 5 Effect of Financing Alternatives on Purchase Rate, by Income and Vehicle Type

BY INCOME: PERCENT OF WEIGHTED SAMPLE CHOOSING HEV/PHEV/BEV BY FINANCING/INTEREST RATE				
HEV	**NONE**	**15.0%**	**7.5%**	**5.0%**
Below 225% FPL	25.7%	26.3%	26.9%	27.0%
Above 225% FPL	25.9%	27.9%	28.7%	29.0%
PHEV	**NONE**	**15.0%**	**7.5%**	**5.0%**
Below 225% FPL	3.7%	4.1%	4.2%	4.3%
Above 225% FPL	5.4%	6.0%	6.3%	6.3%
BEV	**NONE**	**15.0%**	**7.5%**	**5.0%**
Below 225% FPL	5.4%	5.4%	5.4%	5.4%
Above 225% FPL	5.1%	5.3%	5.4%	5.4%

Source: Source: UCLA Luskin Center for Innovation[24]

implies relative homogeneity of vehicle use patterns by location of residence and model type. In contrast, results demonstrate predictable heterogeneity with respect to income, i.e. lower-income groups are more responsive to subsidies, regardless of where they live.

For the second hypothetical policy, the paper focused on guaranteed loans with a maximum interest of 15 percent. It was discovered that financing with interest rates of 15 percent, 7.5 percent, and 5 percent increased the lower-income population's probability of PHEV purchase by 10 percent, 13 percent, and 14 percent, respectively, and the moderate-income population's probability of PHEV purchase by 11 percent, 15 percent, and 17 percent, respectively (Table 5). The results of this analysis were able to elucidate price elasticities of demand as with financing—upfront payments go down while monthly payments go up. For the lower-income groups, decrease in utility from higher monthly payments outweighs the increase utility from a lower upfront payment. In comparison, rebates represented a reduction in upfront price, lowering both the down payment and monthly financing payments, thereby increasing overall utility.

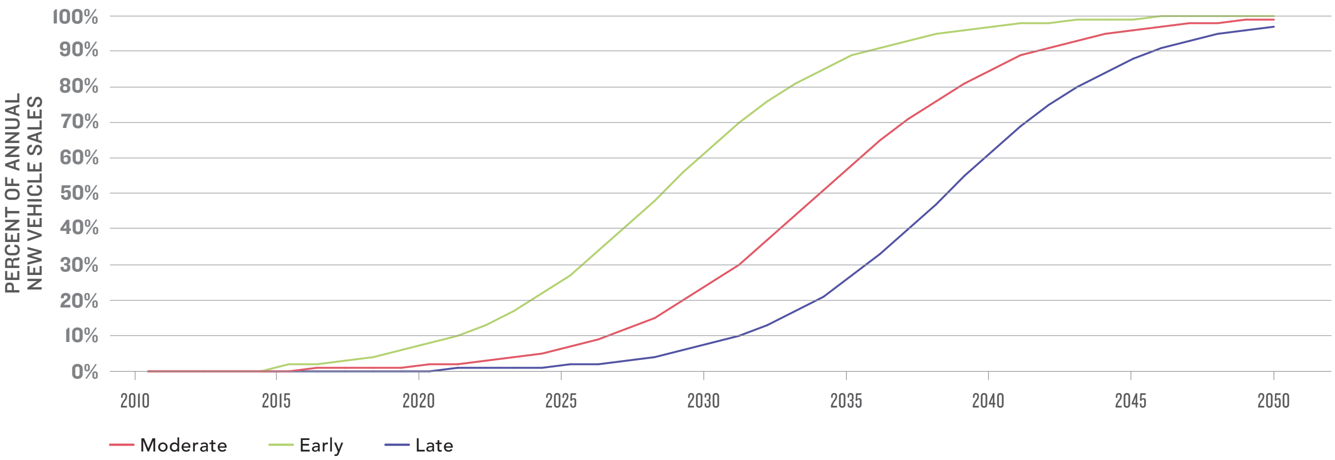
Overall, the results from this study conclude that all incentive levels create a positive and significant impact on consumer propensity to purchase alternative fuel vehicles in California. Respondents considering BEVs were not as influenced by the presence of a subsidized loan. However, within the subpopulation of PHEV consumers, financing at a 15 percent interest rate level resulted in adoption rate increases equivalent to those of receiving a $2,500 subsidy. In general, rebates had a larger impact than did offering guaranteed alternatives for financing due to the Californian population's preference for financing and the price elasticities of demand explored previously.

2.2 HYPOTHETICAL CALIFORNIA PEV ADOPTION PATTERNS

Taking account of these behavioral considerations and the technical trends to be further discussed in Section 3, the task of California policymakers is to determine the conditions necessary to facilitate electrification of the light-duty vehicle fleet. Even assuming the same ultimate (2050) goal of full electrification is achieved, the pathway there will have important implications for total vehicle emissions, as well as the economic impacts of changing ownership and use patterns. In this economic assessment, the authors do not model adoption behavior per se, but specify hypothetical pathways of adoption to

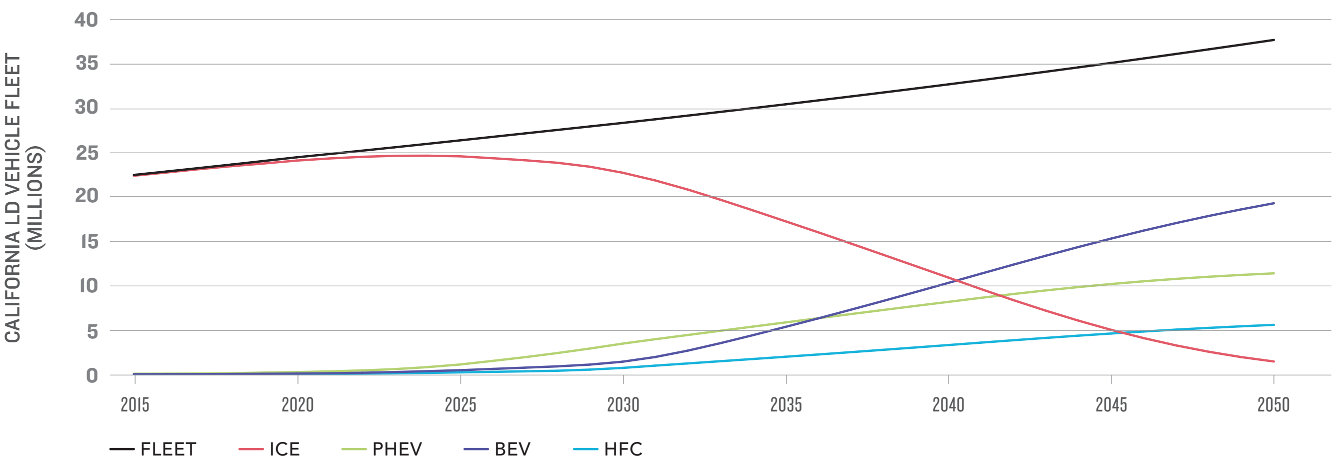
24 Ibid.

FIG 6 Figure 6. Scenarios for Plug-in Electric Vehicle Adoption



Source: Author's estimates

FIG 7 California Vehicle Fleet – Moderate BEV Adoption Profile



Source: E3 estimates from the PATHWAYS model[25]

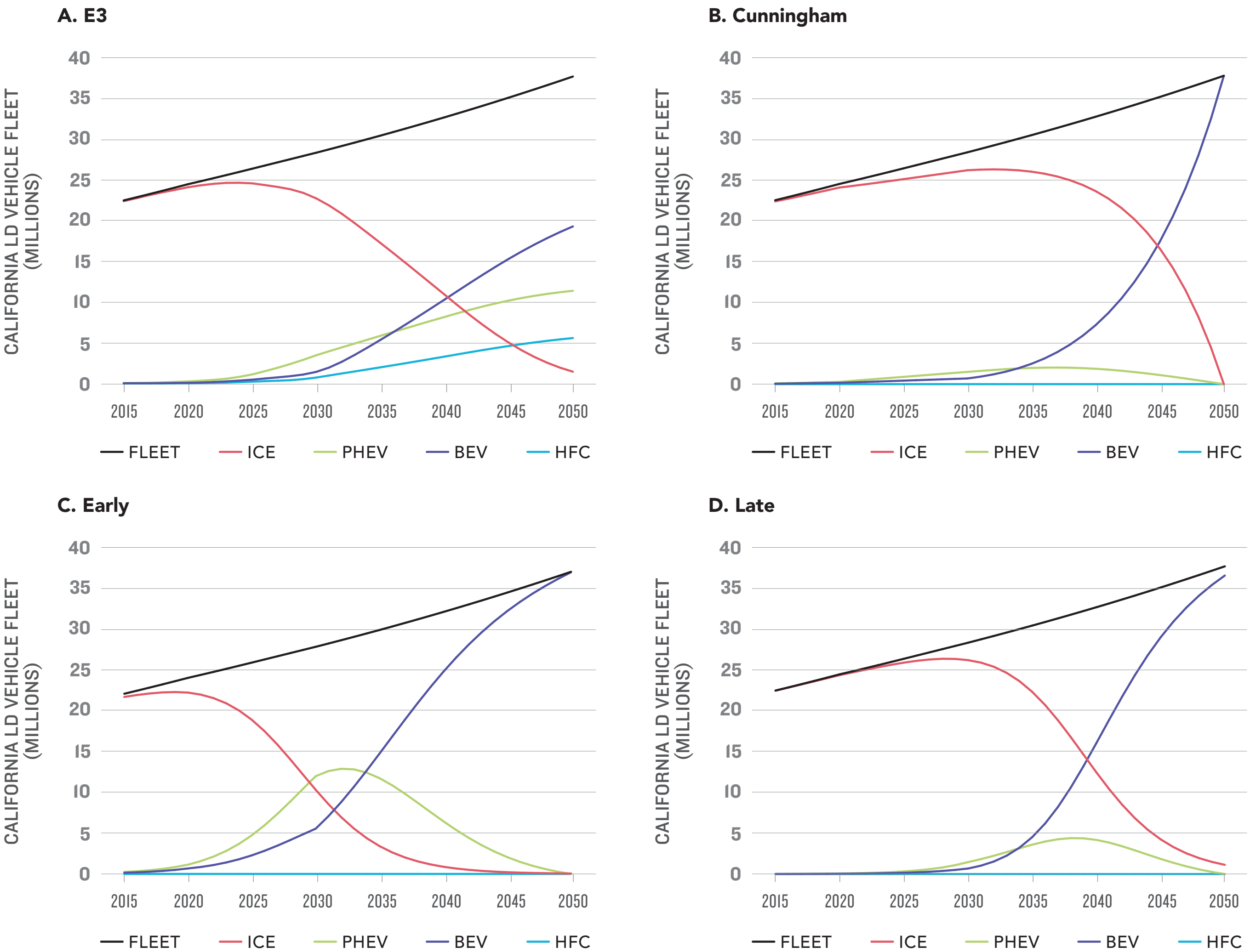
Note: Vehicle classes are Internal Combustion Engine (ICE), Plug-in Hybrid Electric Vehicles (PHEV), 100% electric or Battery Electric Vehicles (BEV), and Hydrogen Fuel Cell (HFC).

2050, forecasting the economic consequences of each. Four generic adoption scenarios illustrated in Figure 6 reflect different expectations regarding emergent PEV demand. The Early and Late pathways can be seen as essentially bracketing the new vehicle technology adoption trend between extreme optimism and pessimism.[25]

Within these, a so-called Moderate adoption profile represents reasonable optimism about accelerating adoption during the 2025-2035 decade, as the market passes through incremental vehicle cost (IVC) parity to substantial unit cost advantages, followed by sustained growth of the market with more widespread consumer information and experience. For the present study, the Moderate adoption

25 E3. 2015. " PATHWAYS Project: Long-term Greenhouse Gas Reduction Scenarios," Report to the California Air Resources Board, California Energy Commission, California Public Utilities Commission, and the California Independent System Operator. Available at: https://ethree.com/public_projects/energy_principals_study.php

FIG 8 California Vehicle Fleet – Moderate BEV Adoption Profile



Source: Authors' analysis; E3 estimates from the PATHWAYS model[26]

pathway is based on estimates from E3, as implemented by Roland-Holst for the CEC.[27] Illustrated in Figure 7, this pathway includes ICEV, PHEV, and BEV. For its own study, E3 included market share forecasts for Hydrogen Fuel Cell (HFC) vehicles.[28] The present study lumps HFCVs together with BEVs as both are zero-emission vehicles. Alternative adoption pathways mentioned in the literature are compared to Moderate/E3 in Figure 8.

As the results of the macroeconomic analysis demonstrate, should the Moderate adoption pathway be achieved, both the economic and mitigation benefits to California drivers would be substantial. Via the expenditure shifting that vehicle use savings enable, this would combine an important source of pollution mitigation with potential growth stimulus for the state economy.

26 Ibid.

27 Roland-Holst, David, Samuel Evans, Samuel Heft-Neal, Drew Behnke, and Myung Lucy Shim. 2018. *Exploring Economic Impacts in Long-Term California Energy Scenarios*. California Energy Commission. Publication Number: CEC-500-2018-013.

28 For background information: Yang, C. and J. Ogden, "Determining the lowest-cost hydrogen delivery mode," International Journal of Hydrogen Energy. 2007.

Section Three

Innovation Trends in the Light Vehicle Sector

Innovation Trends in the Light Vehicle Sector

3.1 GENERAL TRENDS

The importance of technological change in the vehicle sector cannot be overstated. It is unlikely for California to achieve 80 percent decarbonization or carbon neutrality without a fundamental transition of its transportation system to a combination of electric power and net-zero carbon fuels like hydrogen. Alternative fuels can be important sources of mitigation in the near-term, but they cannot displace enough conventional fuel emissions to meet the 2050 target given current population growth trends, known technologies for biofuel production and distribution, and a limited supply of biomass.

This section focuses on the demand side of California's new vehicle market, offering a brief overview of existing and emerging patterns of new vehicle technology adoption.

Electric vehicle adoption to date has been quite uneven and well below the potential suggested by the prospective use and financial characteristics of these vehicles. The authors of this report do not attempt to explain or model adoption behavior in this section or this study as a whole, but intensive and innovative research literature has been emerging on this subject for over a decade and continues to offer insights for policy design and marketing.

Fortunately, pervasive and sustained technical innovation is changing the landscape of the EV market in California, and assessments only a few years old are already quite out-of-date. To support public and private decisions about low-carbon mobility more effectively, more timely evidence is needed on the economic characteristics of these innovations, including adoption and use costs, as well as expected economic benefits including energy cost savings, public health benefits, and the employment and income effects of the vehicle fleet transition.

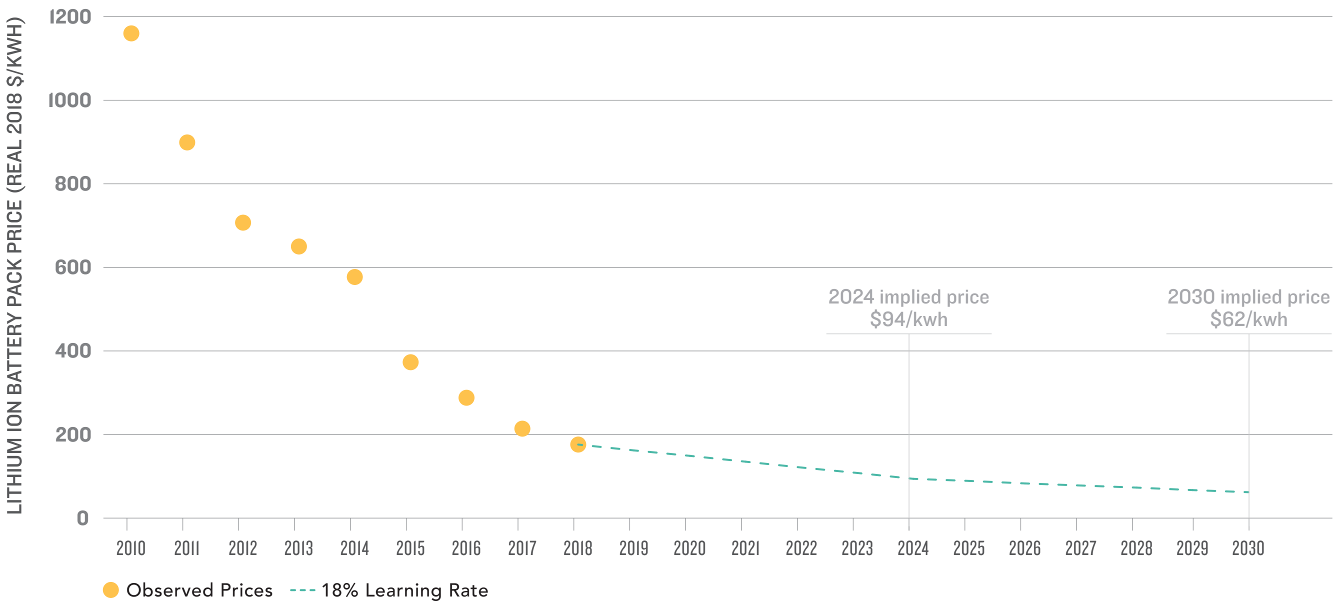
This assessment provides such an update. This new technical information is also incorporated in the study's economic assessment, revealing substantial benefits across the economy and communities in California from vehicle innovation. The following section is a review the four primary channels for innovation in this sector: battery technology and energy storage, power train technology, autonomous control, and vehicle design. The section closes with a synthesis of this information into "incremental costs" of operation and ownership for these new vehicle technologies, by comparison to more conventional substitutes. All of this cost information is later incorporated into the economic modeling and scenario assessment presented in Section 5.

3.2 BATTERY TECHNOLOGY

Thanks to determined scientific and engineering effort around the world, the costs of battery energy storage have been plummeting (Figure 9).

The most intensive research frontier for EV energy storage is in solid-state batteries. This technology provides many benefits in terms of critical characteristics such as safety, energy density, and lifecycle. Neverthe-

FIG 9 Battery Cost and Efficiency



Source: Bloomberg New Energy Finance[29]

less, viable solid-state batteries have yet to reach market despite massive levels of investment from entities such as Toyota,[30] VW,[31] the U.S. federal government,[32] and more.[33] While it seems certain that solid-state batteries will be the next major innovation for electric vehicles, the timing of their introduction is still very uncertain, as many issues of reliability and cost-effective manufacturing remain unsolved.[34] Meanwhile, the prices of Lithium-ion (Li-ion) batteries have fallen continuously and dramatically over the last decade, with further improvements already in the production pipeline.[35] Much of the price decrease arises from oversupply and strong competition among battery manufacturers. Nevertheless, the Li-ion supply chain faces significant bottlenecks to the supply of nickel, cobalt, and rare-earth metals that would limit further price decreases barring additional innovation.[36] In the case of cobalt, specifically, some like Caspar Rawles of Benchmark Mineral Intel-

29 Goldie-Scot, Logan. "A Behind the Scenes Take on Lithium-ion Battery Prices," BloombergNEF. March 5, 2019. Available at: https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

30 "Toyota and Panasonic to jointly make electric-car batteries, explore solid-state tech," Nikkei Asian Review. January 20, 2019. Available at: https://asia.nikkei.com/Business/Business-deals/Toyota-and-Panasonic-to-build-electric-car-batteries-together?fbclid=IwAR0StBv8BIO2MOdf27eDJB0s250q1AtuTBPQ3hWNYSDRfbHstWxLZyhyEFs

31 "Volkswagen plugs $100M into solid-state battery development," CNET Roadshow. September 13, 2018. Available at: https://www.cnet.com/roadshow/news/volkswagen-invests-100-million-to-develop-solid-state-battery-tech/

32 "US government awards General Motors $2M for solid-state battery research," CNET Roadshow. August 16, 2019. Available at: https://www.cnet.com/roadshow/news/general-motors-solid-state-battery/

33 "Ford invests in 'breakthrough' solid-state battery startup already backed by BMW and Hyundai," electrek. April 11, 2019. Available at: https://electrek.co/2019/04/11/ford-solid-power-state-battery/

34 "Why lithium-ion may rule batteries for a long time to come," MIT Technology Review. September 12, 2018. Available at: https://www.technologyreview.com/s/611982/why-lithium-ion-may-rule-storage-technology-for-a-long-time-to-come/

35 "Lithium-ion Battery Costs and Market," BloombergNEF. July 5, 2017. Available at: https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf

36 "Risks and Opportunities in the Battery Supply Chain," Massif Capital. May 2019. Available at: https://www.dropbox.com/home/Rapid%20EV%20Study/2.%20Technology/Storage?preview=Risks+and+Opportunities+in+the+Battery+Supply+Chain.pdf

ligence, forecast the price minimum to be hit as early as 2022.[37] Optimistically, battery manufacturers have already made substantial investments in cobalt-free Li-ion technology,[38] and current Teslas already have batteries containing significantly less cobalt than competitors.[39]

3.3 POWERTRAIN TECHNOLOGY

Development in the powertrains of electric vehicles largely mirrors that of the batteries, though with more diverging trends. There is a constant push to reduce usage of rare-earth metals and socially-problematic supply chains. But at the same time, both Tesla and Chevy have switched from AC induction motors to permanent-magnet motors for the Model 3[40] and Bolt,[41] a move that offers benefits in terms of efficiency and manufacturing cost, but also has fewer pathways toward reducing the usage of rare-earth metals.

In terms of thermal management strategies for cooling batteries, there is little consensus at the moment from EV manufacturers.[42] Higher-end vehicles like Tesla Models S, X, and 3 use fully-integrated battery/engine cooling systems with interconnections between the powertrain and the battery system. By comparison, the Chevrolet Bolt uses a less expensive system without interconnection between battery pack and powertrain.

3.4 AUTONOMOUS DRIVING

Autonomous light-duty vehicle technologies can deliver significantly greater fuel efficiency and lower operating, maintenance, and insurance costs. The resulting more efficient road usage and reductions in congestion have benefits not only for the autonomous cars themselves, but for any road user. Autonomous technology could also improve adoption rates by enabling a faster payback and lower costs for larger light-duty vehicle users, like taxi services or vehicle fleets.[43] Some analysis even finds autonomous taxi services could support reductions in energy usage—even if miles traveled, speed, and vehicle size increased.[44]

However, recent reports have given indications that autonomous driving is not a near-term technology. Accidents involving autonomous test vehicles prompted the early termination of pilots, the scaling back of investments, and delays to multiple programs.[45] Industry leaders like Alphabet's newly-acquired Waymo have struggled with common real-world challenges like unprotected left turns.[46] Nonetheless, even the deployment of lower levels of automation, at most Level 2 (240V), can produce reductions in energy usage.[47]

37 "Elon Musk wants cobalt out of his batteries – here's why that's a challenge," *The Verge*. June 21, 2018. Available at: https://www.theverge.com/2018/6/21/17488626/elon-musk-cobalt-electric-vehicle-battery-science

38 "Panasonic plans to develop cobalt-free car batteries," *Reuters*. May 30, 2018. Available at: https://www.reuters.com/article/us-panasonic-battery/panasonic-plans-to-develop-cobalt-free-car-batteries-idUSKCN1IV14Y

39 "VWs Batterien enthalten viermal so viel Kobalt wie Tesla-Batterien," *WirtschaftsWoche*. March 29, 2019. Available at: https://www.wiwo.de/unternehmen/auto/volkswagen-elektroautos-vws-batterien-enthalten-viermal-so-viel-kobalt-wie-tesla-batterien/24156880.html

40 "Tesla motor designer explains Model 3's transition to permanent magnet motor," *electrek*. February 27, 2018. Available at: https://electrek.co/2018/02/27/tesla-model-3-motor-designer-permanent-magnet-motor/

41 "Electric Motor Design of General Motors' Chevrolet Bolt Electric Vehicle," *SAE International*. April 5, 2016. Available at: https://www.sae.org/publications/technical-papers/content/2016-01-1228/

42 "Trends in electric-vehicle design," *McKinsey & Company*. October 2017. Available at: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/trends-in-electric-vehicle-design

43 "Autonomous Vehicles: Uncertainties and Energy Implications," *U.S. Energy Information Administration*. May 2018. Available at: https://www.eia.gov/outlooks/aeo/pdf/AV.pdf

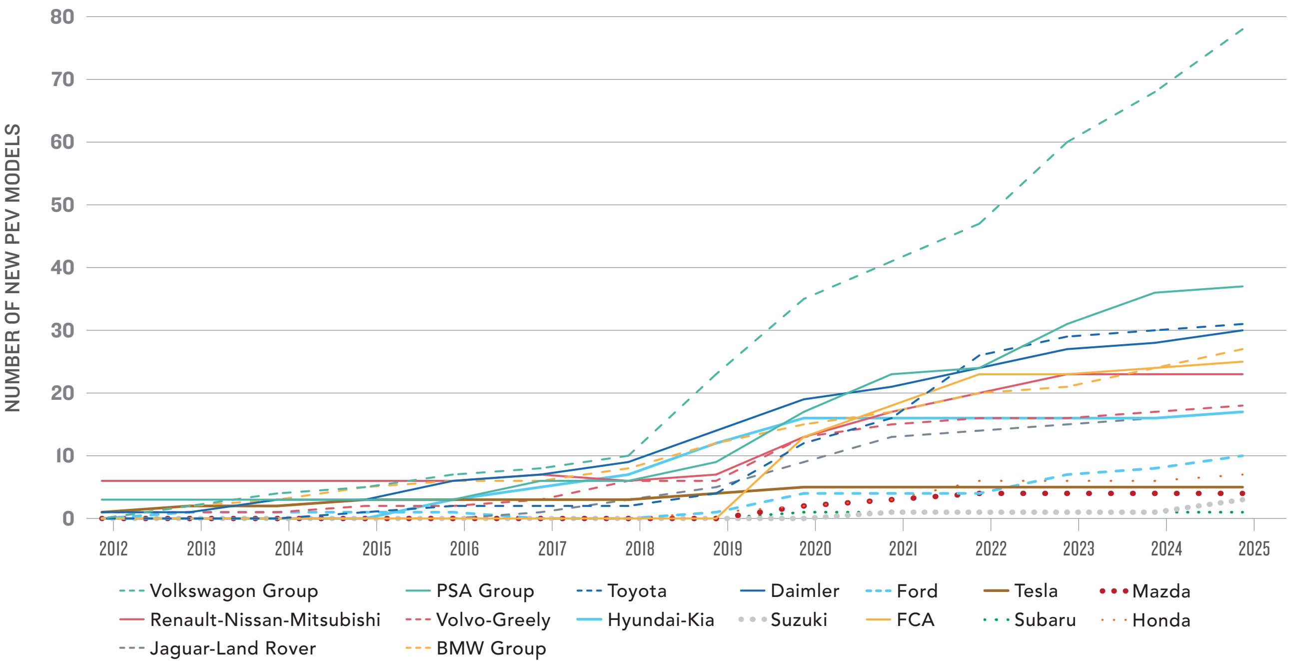
44 "Autonomous taxis could greatly reduce greenhouse-gas emissions of US light-duty vehicles," *Nature Climate Change*. 2015. Available at: https://www-nature-com.libproxy.berkeley.edu/articles/nclimate2685

45 "2018 Was a Hard Reality Check for Autonomous Cars," *Jalopnik*. December 19, 2018. Available at: https://jalopnik.com/2018-was-a-hard-reality-check-for-autonomous-cars-1831182272

46 "Waymo's big Ambitions Slowed by Tech Trouble," *The Information*. August 28, 2018. Available at: https://www.theinformation.com/articles/waymos-big-ambitions-slowed-by-tech-trouble

47 "Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles," Transportation Research Policy and Practice. April 2016. Available at: https://www.sciencedirect.com/science/article/pii/S0965856415002694

FIG 10 Number of New PEV Models Manufactured in Europe by Company, 2012-2025



Source: Transport & Environment[48]

3.5 VEHICLE DESIGN

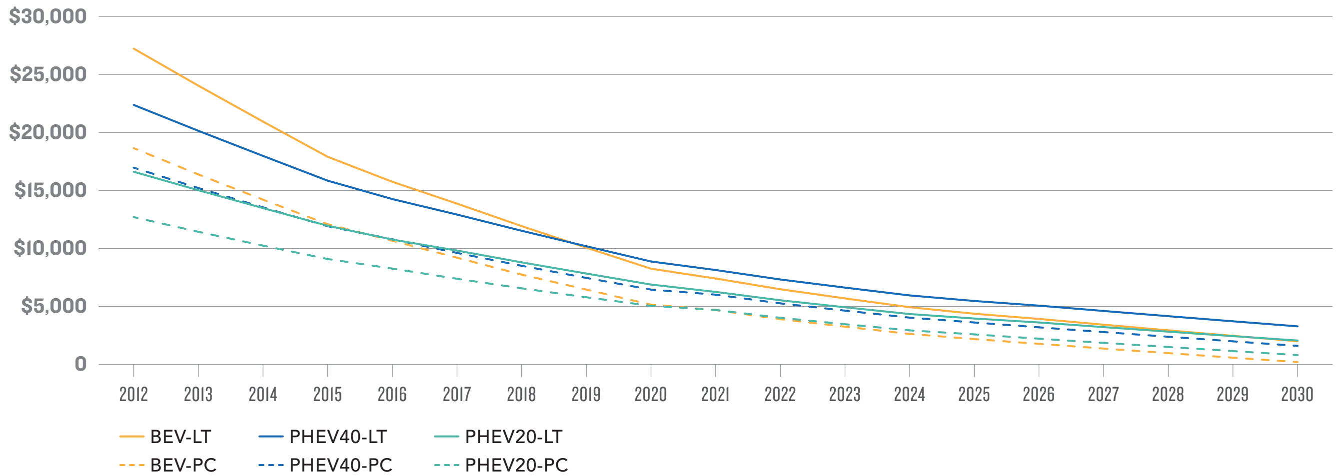
Many present-day electric vehicle models are merely electrified versions of existing models: Ford Focus Electric, Honda Clarity Electric, and so on. Building an electric vehicle on an ICE platform requires forcing an electric powertrain and battery packs into a non-optimized design. As manufacturers develop newer, electric-native chassis, the resultant models will be more efficient, and have better comfort and performance characteristics. European manufacturers have embraced this transition, and original PEV model varieties are proliferating rapidly in this market.

A common drawback of current electric vehicles is the weight of the battery packs required for the range customers desire. The 2017 Ford Focus Electric, for example, features a curb weight of 3,640 lbs., almost 600 lbs. (20%) heavier than its ICE cousin (3,055 lbs. at its heaviest), and a heavier vehicle has obvious drawbacks in terms of efficiency and range. This weight differential can, at the very least, be offset by trends in vehicle design.[49] However, the incentives toward weight-reduction in electric vehicles are limited at the moment: newer powertrains yield their own weight reductions which can allow lower-cost materials; more powerful, and heavier, battery packs do more for

48 "Electric Surge: Carmakers' electric car plans across Europe 2019-2025." *Transport & Environment.* July 18, 2019. Available at: https://www.transportenvironment.org/publications/electric-surge-carmakers-electric-car-plans-across-europe-2019-2025

49 Other important sources of *efficiency potential:* Vehicle aerodynamics are also an important source of efficiency potential. Drag reductions typically derive from a reduction in a vehicle's "drag coefficient," a value dependent on its general shape and design elements like spoilers, mirrors, inlets, etc. Previous studies have identified a historical trend of about 1 percent to 2.5 percent annual reductions in aerodynamic drag. However, with many light-duty vehicles already achieving a drag coefficient of less than 0.30, there is skepticism about the ability of newer cars, especially on the lower-end of the price spectrum, to attain significant further reductions below 0.25. Such innovations would require changes like the addition of an integrated front spoiler, the removal of exterior mirrors, the enclosure of the underbody, and other changes. A final source of efficiency innovation in vehicle design is in tire technology. Reductions in rolling-resistance for standard tires have historically been achieved. However, these reductions come at the cost of tire wear, stopping distance, cornering grip, etc. that affect consumer costs and safety. There is constant research into new tire materials that could achieve efficiency improvements without such sacrifices, but it has yet to prove fruitful.

FIG 11 Incremental Vehicle Purchase Costs, by Vehicle Type



Source: McKinsey, Environmental Protection Agency, California Air Resources Board, Electric Power Research Institute; Authors' analysis

range improvements at current costs; and the electric power means EVs are not subject to the same efficiency incentives as ICE vehicles.[50]

Taking account of technical analysis and evidence up to 2016, incremental vehicle costs (the incremental cost of purchasing a higher priced PEV instead of an otherwise comparable conventional internal combustion engine vehicle) for PEVs were expected to improve by about 80 percent over the next two decades (more than twice the expected improvement for ICE vehicles, see Figure 11). In analysis conducted for the California Energy Commission, BEAR found that these cost improvements, combined with widespread PEV adoption, would confer substantial growth dividends on the state's economy. Benefits included both vehicle use/fuel savings and air quality improvements—both of which contributed to higher employment and income—regardless of who purchased new vehicle technologies. The same forces can be found at work in the current scenario analysis. IVC estimates do not include operating cost advantages, which are a major contributor to the economic advantages of PEV ownership and the economic impacts estimated in this study. Declining IVC makes these vehicles competitive in terms of initial adoption cost, their long term energy cost savings offer much greater economic returns to ownership.

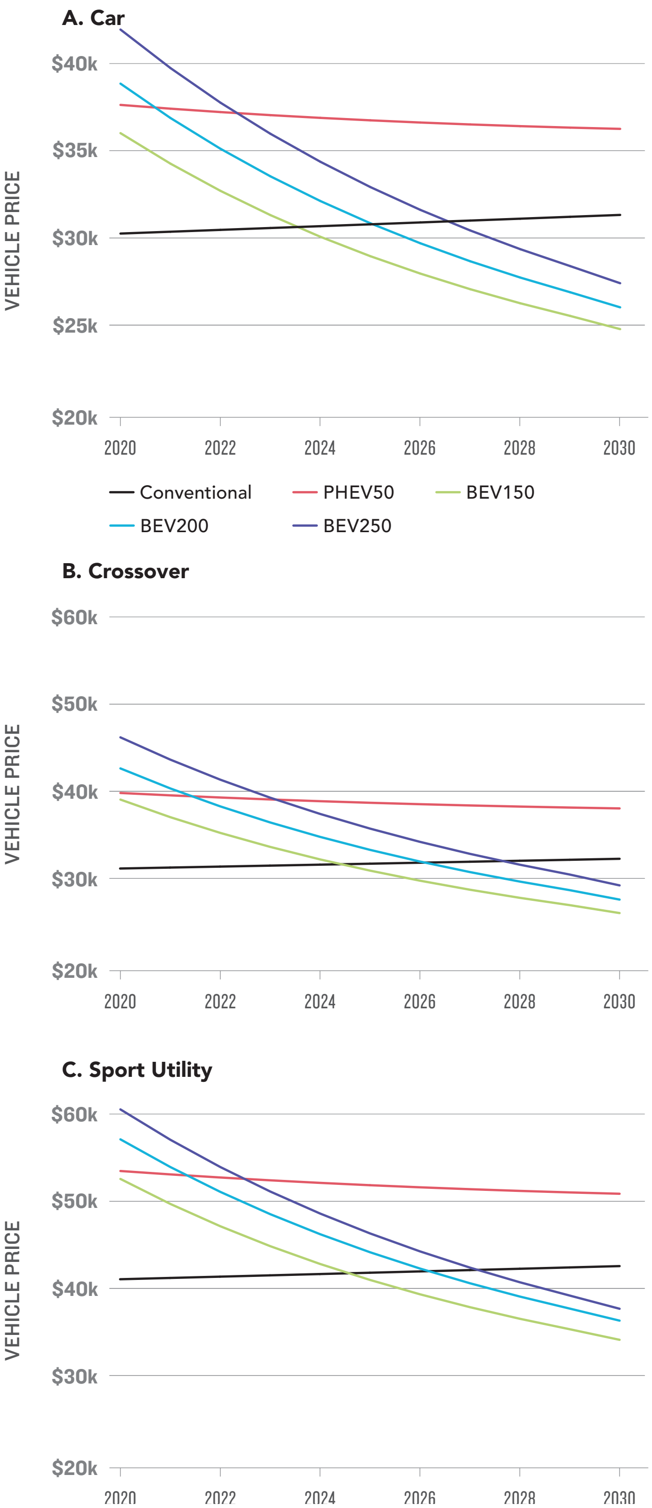
This study examines the implications of more inclusive PEV adoption patterns, passing on more cost-saving and local air quality benefits directly to lower-income households. Meanwhile, as the technical side of the vehicle industry is changing so rapidly, technical cost information has also been revised. In particular, a recent vehicle technology assessment published by the nonpartisan NGO International Council on Clean Transportation (ICCT) provides a rigorous and comprehensive review of emerging light-vehicle technologies was utilized. Based on actual teardowns of existing and new models, as well as objective engineering evidence on existing and proven technologies, the authors are seeing significantly accelerated progress to PEV cost parity, both for vehicle purchase (Figure 12) and operation (Figure 13).[52]

50 "Trends in electric-vehicle design," McKinsey & Company. October 2017.
Available at: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/trends-in-electric-vehicle-design

51 Lutsey, Nic, et. al. Update on electric vehicle costs in the United States through 2030. The International Council on Clean Transportation. April 2, 2019. Available at: https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

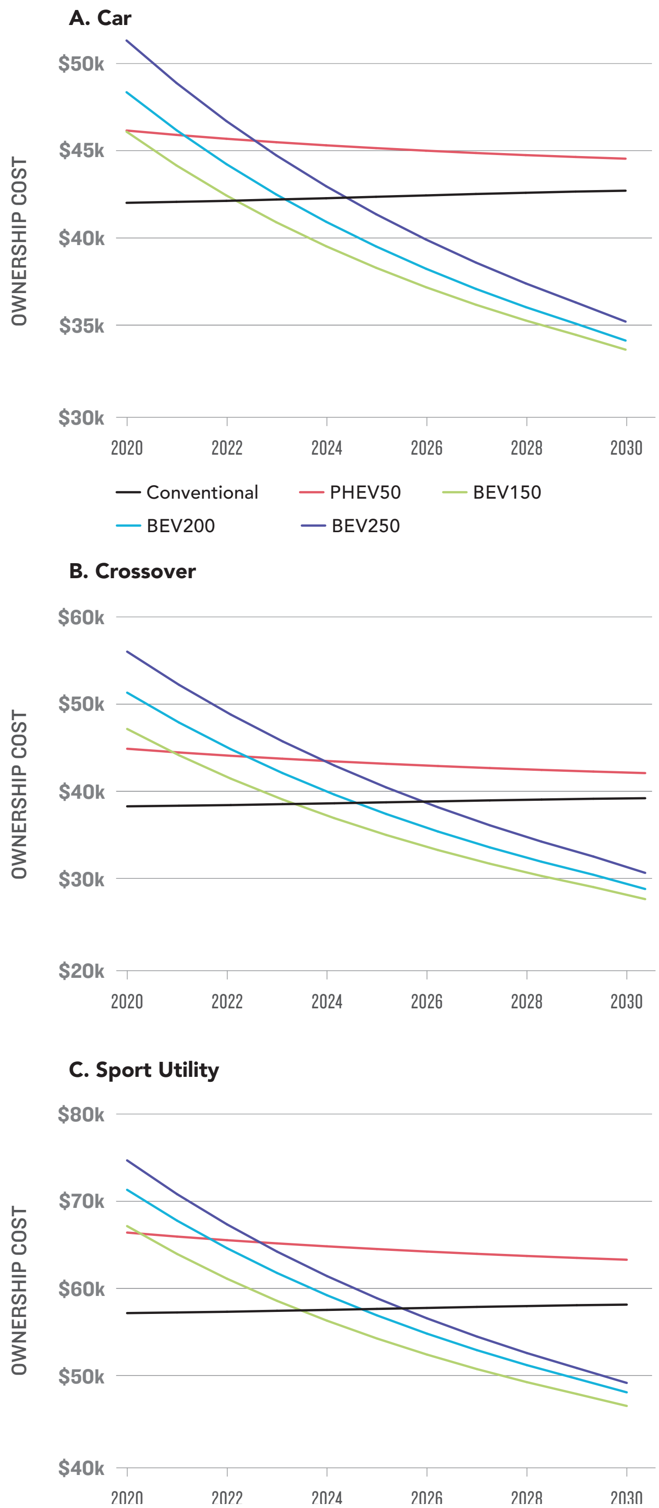
52 For operating costs, fuel and electricity prices are taken from the U.S. Energy Information. Administration, where gasoline increases from $2.90 to $3.48 per gallon from 2018 to 2035 and electricity increases from $0.12/kWh to $0.13/ kWh from 2018 to 2035. See U.S. Energy Information Administration, Annual Energy Outlook 2019. U.S. Department of Energy. January 24, 2018.
Available at: https://www.eia.gov/outlooks/aeo/index.php

FIG 12 Initial Purchase Price of Conventional Vehicles and Electric Vehicles for Cars, Crossovers, and SUVs for 2020–2030



Source: The International Council on Clean Transportation[53]

FIG 13 Ownership Cost[54] of Conventional Vehicles and Electric Vehicles for Cars, Crossovers, and SUVs for 2020–2030

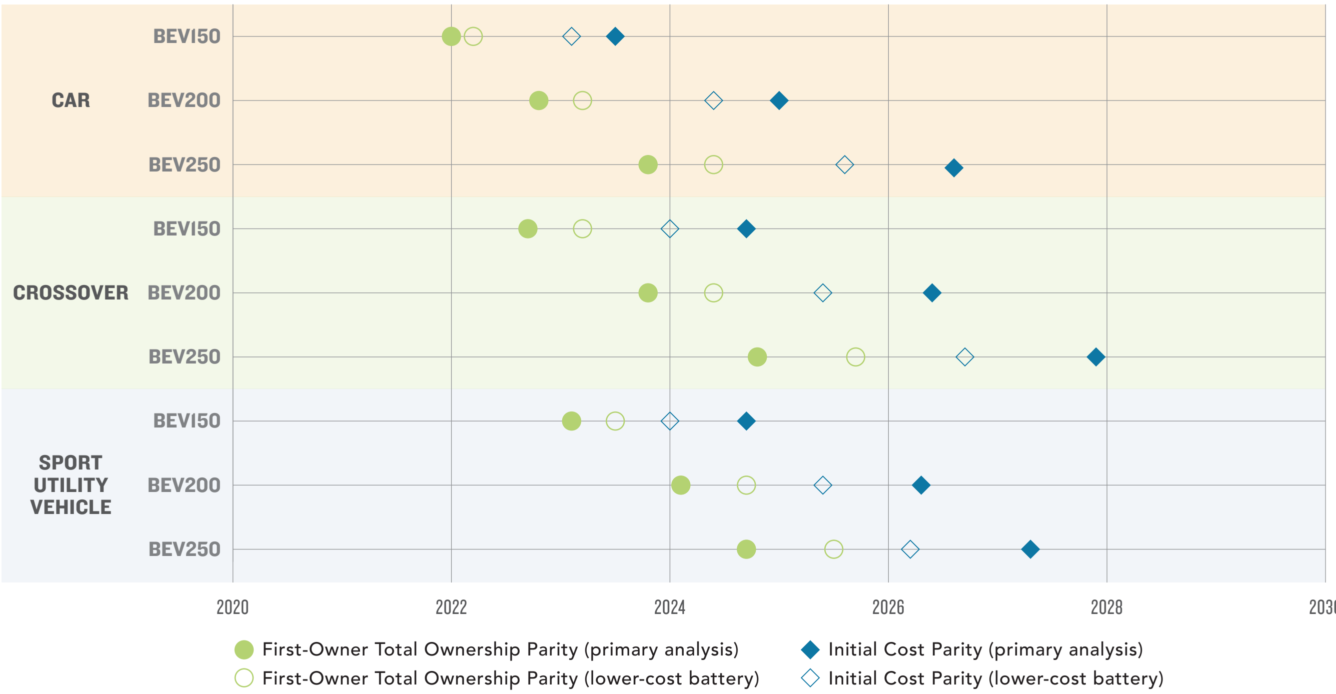


Source: The International Council on Clean Transportation[53]

53 Lutsey, Nic, et. al. "Update on electric vehicle costs in the United States through 2030." The International Council on Clean Transportation. April 2, 2019. Available at: https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

54 Ownership costs are presented as cumulative, undiscounted, current dollar savings over the average term of vehicle ownership.

FIG 14 Year of Cost Parity Based on First-Owner Total Cost of Ownership and Initial Vehicle Cost, Shown as the Primary Analysis and a Lower-Cost Battery Scenario



Source: The International Council on Clean Transportation[53]

This detailed evidence demonstrates that, in two short years, the industry has innovated to the point where it promises ICE cost parity up to five years earlier, by the mid-2020s rather than after 2030 (Figure 14). In the context of this economic assessment, there are two main implications of this recent evidence:

- Electric vehicle initial cost parity is coming within five to 10 years
- Cost-competitiveness approaches even faster than initial cost parity based on fuel savings, where energy prices are assumed to follow EIA median trends

The implications of ICCT's evidence for voluntary PEV adoption, in both quantity and demographic scope, are quite profound. Also essential is the implication that substantially less public money may be required to promote adoption, at least in the form of direct subsidies.

To evaluate the wider economic impacts of this technological change, the modeling approach and assumptions for this study were for recalibrated to explicitly recognize innovation processes and vehicle cost improvements over the 2018-2050 time period assessed. For PEV vehicles, incremental vehicle costs (IVC) estimates were built from the bottom up. After a review of the vehicle engineering literature and consultation with experts in this field, the authors estimated incremental vehicle cost for PEVs using the median ICCT cost profiles. For batteries, drive trains, and other primary PEV cost components discussed above, the authors assumed steady progress or "learning" in this technology, as documented by ICCT. Internal combustion engine (ICE) vehicles were also assumed to attain higher average mpg in accordance with state and federal regulations, conferring modestly higher costs—reaching a $2,000 premium over average 2012 prices by 2030 (less than 0.5% annual price appreciation).

Section Four

New Vehicles and Job Creation in California

New Vehicles and Job Creation in California

One of the most important findings of this assessment is that PEV deployment stimulates economic growth, increasing employment and incomes around the state, with many people benefiting whether they buy a PEV or not. Much of this growth is due to indirect market linkages captured by the economic forecasting model, including consumer expenditures diverted from transport fuel and other savings associated with electric and innovative vehicle adoption. In addition to this general stimulus, the PEV sector itself is responsible for job creation today, and increasingly as adoption widens, through several channels. The first of these is direct—new jobs making new vehicles and components for them. The other two channels are indirect—employment associated with delivering vehicle charging infrastructure and maintenance services, as well as new jobs expanding the electric power sector to supply energy for new vehicles. Much more research is needed to fully assess the magnitude of each channel's contribution to new employment and income as the PEV sector expands, but some indicative results are already available.

4.1 DIRECT EMPLOYMENT

In terms of current jobs, the manufacturing of fuel-efficient vehicles is associated with 14,776 jobs in California alone, as increasing standards on fuel economy have prompted increased investment by auto manufacturers in development of new technologies, the retooling of old factories, and the building of new ones.[55] The U.S. Department of Energy also estimates about 259,468 jobs nationally are associated with the manufacturing of alternative fuel vehicles. Of these, 41,991 (~16.2%) are in the production of battery-electric vehicles and 198,354 (~76.4%) are in the production of hybrid electric, plug-in hybrid, or battery-electric vehicles.[56] However, some analysts have argued that electric vehicle production would reduce total employment in auto manufacturing as electric powertrain production requires fewer higher-skilled employees, greater imports such as lithium-ion batteries, and is—in general—a more labor-efficient and automated process.[57, 58]

55 "Supplying Ingenuity II: U.S. Suppliers of Key Clean, Fuel-Efficient Vehicle Technologies," NRDC and Blue Green Alliance. May 2017. Available at: https://www.nrdc.org/sites/default/files/supplying-ingenuity-clean-vehicle-technologies-report.pdf

56 "U.S. Energy and Employment Report," U.S. Department of Energy. January 2017. Available at: https://www.energy.gov/sites/prod/files/2017/01/f34/2017%20US%20Energy%20and%20Jobs%20Report_0.pdf

57 "Electrification May Disrupt the Automotive Supply Chain," Congressional Research Service. February 8, 2019. Available at: https://fas.org/sgp/crs/misc/IF11101.pdf

58 "ELAB 2.0 Wirkungen der Fahrzeugelektrifizierung auf die Beschaeftigung am standort Deutschland (Effects of Vehicle Electrification on On-Site Employment in Germany)," Fraunhofer-Institut fuer Arbeitswirtschaft und Organisation IAO. June 4, 2018. Available at: https://www.euractiv.com/wp-content/uploads/sites/2/2018/08/ELAB2.0.pdf

4.2 INDIRECT EMPLOYMENT

4.2.1 Charging Infrastructure

Scarcity of infrastructure to charge PEVs appears to be a serious constraint on perceived usability and actual adoption of these vehicles. In terms of aggregate national growth, a study of the 100 most populous U.S. metropolitan areas projected a need for 82,000 workplace charging stations, 103,000 public Level 2 (240V) stations, and 10,000 DC fast stations in 2025. Compared with what was in place at the end of 2017, these 2025 charging estimates are seven times, three times, and three times, respectively, the amount currently available for each type.[59] Combining these three types of non-home charging, the 195,000 charge points are 4.3 times as many charge points as were available at the end of 2017.[60] These estimates do not include home charging, corridor fast charging between metropolitan areas, or other stations in rural areas.

To date, there has been a lack of research and reliable figures on California employment from charging infrastructure installation. However, study authors have been able to find some information on charging infrastructure demand from the ICCT, Edison Electric Institute, and the CEC; information on the costs associated with the installation of non-residential charging infrastructure; and relatively detailed information on the costs and employment related to charging infrastructure installation in the EU.[61, 62]

4.2.2 Utility Load

The adoption of electric vehicles will increase California's energy demand. The CEC expects a significant increase in electricity consumption, perhaps an increase of over 15,000 GWh by 2030 (~4% of total demand).[63] To date, study authors have been unable to find data pertaining to employment effects or the investment needed to meet this increased demand.

59 "Quantifying the Electric Vehicle Charging Infrastructure Gap Across U.S. Markets," *ICCT.* January 2019. Available at: https://theicct.org/sites/default/files/publications/US_charging_Gap_20190124.pdf

60 "Plug-in Electric Vehicle Sales Forecast Through 2025 and the Charging Infrastructure Required," *Edison Electric Institute*. June 2017. Available at: https://assets.documentcloud.org/documents/4756558/IEI-EEI-PEV-Sales-and-Infrastructure-Thru-2025.pdf

61 "Powering a New Value Chain in the Automotive Sector," *The European Association of Electric Contractors.* No date provided. Available at: https://download.dalicloud.com/fis/download/66a8abe211271fa0ec3e2b07/c572c686-f52f-4c0d-88fc-51f9061126c5/Powering_a_new_value_chain_in_the_automotive_sector_-_the_job_potential_of_transport_electrification.pdf

62 "California Plug-In Electric Vehicle Infrastructure Projections: 2017-2025," *California Energy Commission*. March 2018. Available at: https://www.nrel.gov/docs/fy18osti/70893.pdf
"Costs Associated With Non-Residential Electric Vehicle Supply Equipment," *U.S. Department of Energy.* November 2015. Available at: https://afdc.energy.gov/files/u/publication/evse_cost_report_2015.pdf

63 "The California Energy Demand 2018-2030 Revised Forecast," California Energy Commission. January 22, 2018. Available at: https://efiling.energy.ca.gov/getdocument.aspx?tn=222287 Comparable numbers for 2050 have yet to be published.

Section Five

Macroeconomic Analysis

Macroeconomic Analysis

As was emphasized in the Introduction, this study assesses the economic costs and benefits of achieving the California's goals of light vehicle fleet electrification. The authors use a general equilibrium framework to elucidate how individual vehicle technology adoption would affect household incomes—net of vehicle adoption and operating costs. These estimates pair the latest technology cost data with existing and hypothetical future use patterns and show how net savings will accrue to new vehicle users and be recycled into other expenditures. The study's basic finding is that the economy-wide "multiplier" effects of these savings will be a potent catalyst for income and employment growth across the state. The study also shows that the allied air quality improvements have similar economic benefits for California, quite apart from other co-benefits like mitigating climate risk.

These benefits would certainly justify more determined public efforts to promote PEV adoption, but the present study does not offer guidance on this important issue. In particular, report authors did not model vehicle adoption behavior or PEV incentive programs in this study, but do assume that certain adoption patterns are achieved and calculate their economic consequences. A significant amount of original research is under way to improve collective understanding of PEV adoption and policies that can facilitate it, but much remains to be done. Suffice to say for the moment that results from this study suggest that the potential economic benefits far exceed current expenses for research and adoption programs.

5.1 BEAR MODEL DESCRIPTION

The BEAR model is a dynamic economic forecasting model for evaluating long-term growth prospects for California.[64] The model is an advanced policy simulation tool that models demand, supply, and resource allocation across the California economy, estimating economic outcomes annually over the period of 2018 to 2030. This kind of Computable General Equilibrium (CGE) model is a state-of-the-art economic forecasting tool, using a system of equations and detailed economic data that simulate price directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also included, with varying degrees of detail, to close the model and account for economy-wide resource allocation, production, & income determination. Additional information on the BEAR model is available in Appendix A1.

BEAR is calibrated to a 2018 dataset of the California economy and it includes highly disaggregated representation of firm, household, employment, government, and trade behavior. The model's 2018 – 2050 baseline is calibrated to the California Department of Finance (DOF) economic and demographic projections. The model's baseline is recalibrated to incorporate the new data whenever new projections are released.

For the EV assessment, the BEAR model was aggregated to 60 economic sectors (Table 7). To more fully

64 Roland-Holst, David. 2018. "Berkeley Energy and Resources (BEAR) Model: Documentation for a Dynamic California CGE Model for Energy and Environmental Policy Analysis," Version 3, Department of Agricultural and Resource Economics, University of California, Berkeley, Processed.

capture linkages between vehicle electrification and more determined commitments to renewable energy development, electric power sector was disaggregated by eight generation types in order to be consistent with the detailed energy framework put forward by E3.

5.2 SCENARIOS

The goal of this assessment to estimate the economic impacts of more extensive EV adoption across the state by 2050. The Baseline scenario assumes that the California economy sustains its baseline growth rate as reflected in its latest official forecasts.[65] From an energy policy perspective, it is also assumed that the state follows its Long-Term Energy Strategy, as agreed by the CEC, CARB, and allied agencies.[66] These commitments entail widespread adoption of new energy use technologies, of which vehicles comprise only one category. The others include:

- Commercial Building Durable Goods
- Residential Durable Goods
- Industrial Sectors
- Transportation other than Light Duty Vehicles
- Electric Power Sector Investment

To take account of uncertainty in future technology costs, E3 used its PATHWAYS energy system model to develop detailed cost estimates in three generic scenarios of innovation to 2050, assuming high, low, and intermediate costs for adoption and use of new energy technologies in each category. These cost data are used as technical inputs for the energy system components of BEAR in scenarios for this study.[67] For all of scenarios and non-vehicle energy technologies, E3's intermediate cost estimates were used in the Baseline scenario.

TABLE 6 The Current Structure of BEAR Model, 2018

CURRENT STRUCTURE
60 production activities
60 commodities (includes trade and transport margins)
3 non-labor factors of production, Capital, Land, and Water
22 labor categories
Capital
Land
Natural capital
9 Household types, defined by income tax bracket
Enterprises
Federal Government (7 fiscal accounts)
State Government (27 fiscal accounts)
Local Government (11 fiscal accounts)
Consolidated capital account
External Trade Account

Source: Authors' Analysis

To elucidate the consequences of different pathways for large scale electrification of the light vehicle fleet, four scenarios were considered: (1) For vehicles in the Baseline scenario, authors assumed constant costs. (2) Another, more realistic Long-term Energy Scenario (LTES) assumes vehicle costs follow a downward trajectory as estimated in research for the CEC.[68] (3) A third Innovation scenario specifically addresses the economic impacts of more affordable electric vehicles, using more recent projections of EV costs. These are closer to the optimistic LTES scenario from E3 for vehicles, but incorporate more up-to-date information. (4) Finally, a

65 The BEAR model is always calibrated to the quarterly forecasts from the California Department of Finance.

66 See e.g. California Energy Commission Energy Innovation Showcase at http://innovation.energy.ca.gov/SearchResults.aspx?tks=637034607087928821

67 See Roland-Holst, David, Samuel Evans, Samuel Heft-Neal, Drew Behnke, and Myung Lucy Shim. 2018. *Exploring Economic Impacts in Long-Term California Energy Scenarios*. California Energy Commission. Publication Number: CEC-500-2018-013 for an application of BEAR directly to LTES.

68 Mahone, A., Z. Subin, J. Kahn-Lang, D. Allen, V. Li, G. De Moor, N. Ryan, and S. Price. Deep Carbonization in a *High Renewables Future: Updated Results from the California PATHWAYS Model*. Publication Number: CEC-500-2018-012. California Energy Commission, 2018. http://innovation.energy.ca.gov/SearchResultProject.aspx?p=30124&tks=637034620375287955

TABLE 7 BEAR Sector Aggregation

LABEL	DESCRIPTION	LABEL	DESCRIPTION
A01Agric	Agriculture	**A31Aluminm**	Aluminum production and related manufacturing
A02Cattle	Livestock	**A32Machnry**	Machinery manufacturing
A03Dairy	Dairy cattle and milk production	**A33AirCon**	Major appliance manufacturing
A04Forest	Forestry, forest products, and timber tract production	**A34MfgComp**	Computer and related component manufacturing
A05OilGas	Oil and gas extraction	**A35SemiCon**	Semiconductor and related component manufacturing
A06OthPrim	Other mining activities	**A36ElecApp**	Electrical appliance manufacturing
A07EleHyd	Electric power generation - Hydro	**A37Autos**	Automobile manufacturing
A08EleFF	Electric power generation - Fossil	**A38OthVeh**	Other vehicle and component manufacturing
A09EleNuc	Electric power generation - Nuclear	**A39AeroMfg**	Aerospace, railroad, ship, and related component manufacturing
A10EleSol	Electric power generation - Solar	**A40OthInd**	Other manufacturings
A11EleWind	Electric power generation - Wind	**A41WhlTrad**	Wholesale trade
A12EleGeo	Electric power generation - Geothermal	**A42RetVeh**	Retail - vehicles
A13EleBio	Electric power generation - Biomass	**A43AirTrans**	Air transportation
A14EleOth	Electric power generation - All other	**A44GndTrans**	Rail and pipeline transportation
A15DistElec	Electric power transmission and distrubution	**A45WatTrns**	Water transportation
A16DistGas	Natural gas distribution	**A46TrkTrns**	Truck transportation
A17DistOth	Other utilities	**A47PubTrns**	Transit and ground passenger transportation
A18ConRes	Construction - Residential	**A48RetAppl**	Apparel and other related retail
A19ConNRes	Construction - NonResidential	**A49RetGen**	Other retail
A20ConPow	Construction - Power and communications	**A50InfCom**	Information and communication services
A21ConRd	Construction - Highways and roads	**A51FinServ**	Financial services
A22FoodPrc	Food processing	**A52OthProf**	Other professional services
A23TxtAprl	Textile and apparel manufacturing	**A53BusServ**	Business services
A24WoodPip	Wood product manufacturing	**A54WstServ**	Waste services
A25PapPrnt	Paper manufacturing and printing	**A55Educatn**	Education services
A26OilRef	Petroleum products manufacturing	**A56Medicin**	Medical services
A27Chemicl	Chemical manufacturing	**A57Recratn**	Recreation services
A28Pharma	Pharmaceutical and medicine manufacturing	**A58HotRest**	Hotels and restaurants
A29Cement	Cement and concrete product manufacturing	**A59OthPrSv**	Other private services
A30Metal	Ferrous and nonferrous metal production and metal fabrication	**A60GovtSv**	Government services

Source: Authors' Analysis

TABLE 8 Scenarios Evaluated in the Present Study

	SCENARIO	ADOPTION	IVC
1	**Baseline** A reference Scenario with existing policies in force to 2050. Baseline policies are complemented by revised adoption and use cost estimates commissioned by CEC from E3. Vehicle technology costs are assumed to remain constant at current levels.	Constant adoption shares among income groups	High
2	**LTES** Incorporates E3 technology cost estimates for vehicles, declining over time.	Equal shares by 2050	Medium
3	**Innovation** LTES policies to 2030 and 2050, taking account of more recent vehicle technology cost estimates[69]	Equal shares by 2050	Low
4	**Equity** The LTES scenario with PEV purchase shares equalizing across California income groups by 2030.	Equal shares by 2030	Low

Source: Authors' Analysis

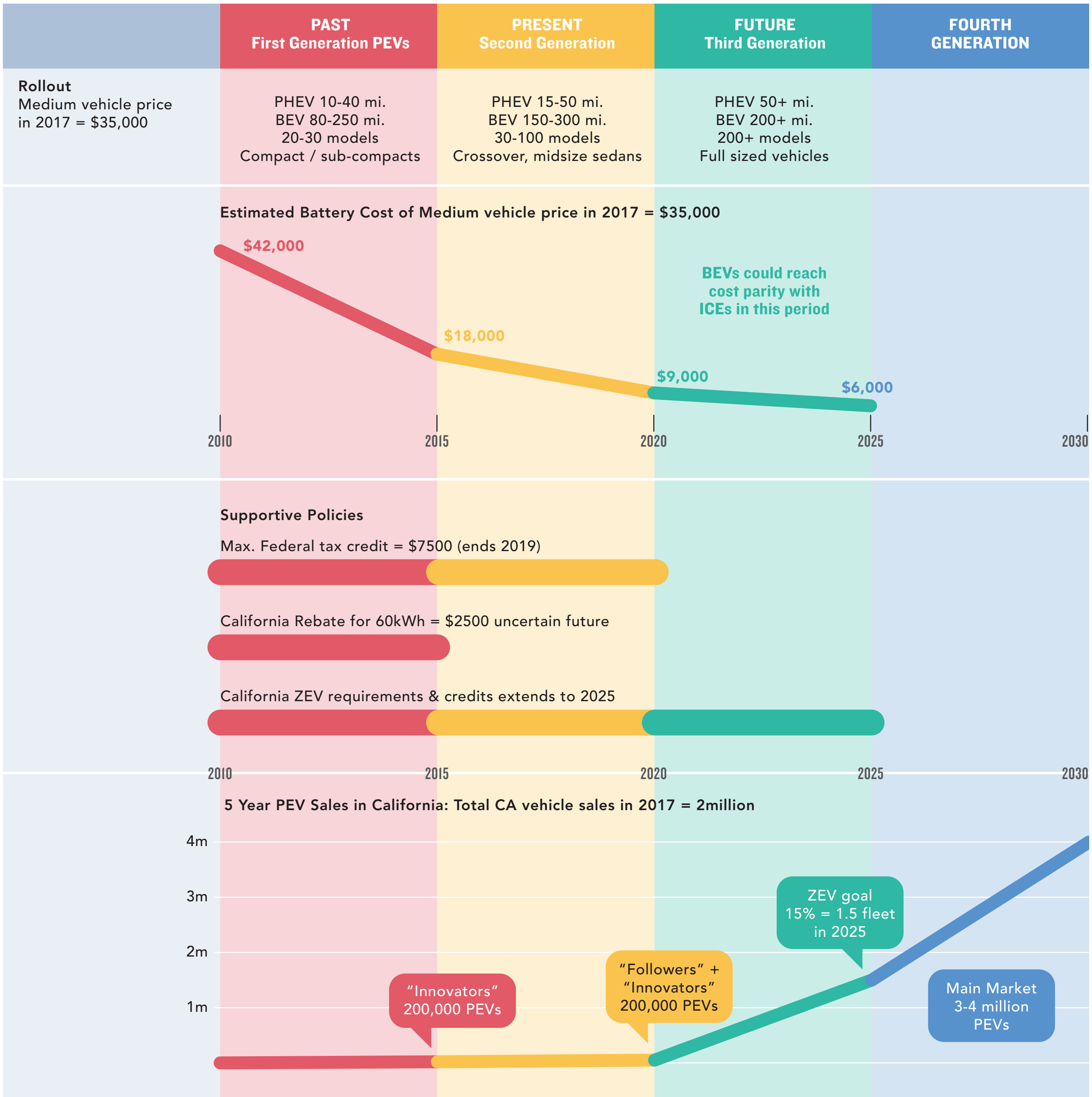
fourth Equity scenario explicitly incorporates a more inclusive electric vehicle adoption pattern—one that would achieve relatively uniform PEV penetration across all California income groups, and do so more rapidly than current trends. In the first three scenarios (Baseline, LTES, and Innovation), it is assumed that shares of EV purchases among income groups remain at current levels (about 90% purchased by higher-income groups). The Equity scenario assumes that EV purchases converge to equal shares across all income groups by 2030. It should again be emphasized that this study neither proposes nor evaluates incentives or other policies that might achieve this goal, although they would likely be needed. Results from this analysis do make clear, however, that there would be very substantial economic benefits if such policies fulfilled the Equity scenario objective of clean vehicle access for all. All four scenarios are summarized in Table 8.

Note that these scenarios differentiate the pattern of PEV adoption over time, using the state's aggregate GHG emissions reduction commitment as a reference. In particular, the light-duty vehicle fleet is assumed to reduce its aggregate GHG emissions 40 percent below the 1990 level by 2030 and 80 percent below the same level by 2050. The authors further assume this goal is achieved with a fleet that blends four categories of vehicles: ICEV, PHEV, BEV, and HFC, as indicated in Figure 7 in Section 2. This "Moderate" adoption scenario does not mandate full electrification by 2050, but it assumes BEV and HFC vehicles have zero emissions (including electric power source emissions) and PHEVs have half of the emissions of ICE vehicles. Finally, ICE vehicles are assumed to deliver efficiency improvements as mandated by the state over the same period.

Having externally specified the composition of the aggregate vehicle fleet, what remains is to determine who owns the vehicle types and what are their comparative costs. As already indicated, IVC profiles were evaluated for PEVs that are relatively High (Baseline), Medium (LTES), and Low (Innovation and Equity). In terms of ownership, the first three scenarios assume[69] that the income group shares of the vehicle fleet remain at today's levels until 2030, but then converge to the same shares of vehicle types as the aggregate fleet by 2050. In the Equity scenario, it is assumed that all

69 Lutsey, Nic, et. al. "Update on electric vehicle costs in the United States through 2030." *The International Council on Clean Transportation.* April 2, 2019. Available at: https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

FIG 15 Schematic of California's Ongoing PEV Programs and Adoption Trends



Source: The International Council on Clean Transportation[70]

70 Turrentine, T., Hardman, S., & Garas, D. (2018). Steering the Electric Vehicle Transition to Sustainability. UC Davis, National Center for Sustainable Transportation. Available at: https://escholarship.org/uc/item/1w3836d3

income groups converge by 2030. In other words, the incremental costs and benefits of the aggregate fleet are shared equally by all households by 2050 in the first three scenarios, but 20 years earlier in the Equity scenario. As the results indicate, the Equity scenario confers very substantial economic benefits on lower-income households.

In particular, this assessment does not explicitly model vehicle consumer behavior—only the consequences of alternative adoption patterns that can be envisioned by policy makers. The goal of this study is to demonstrate the economic benefits of these alternative adoption pathways across the state as a whole in order to strengthen evidence supporting the choice of policy objectives, not to prescribe interventions that would induce a given adoption pathway.

Many PEV incentives and other policies have already been adopted, some continue, and others are being contemplated. Recent evidence on both autonomous innovation and estimated incentive responses support optimism that these programs can significantly influence adoption behavior.[71] Of course, once goals are agreed upon (like the desirability of more socially inclusive adoption), economic and statistical models can support the search for effective policy interventions. Due to the principle of additionality, public funds should be used to foster PEV buying among groups who would not otherwise adopt. It might also be appropriate to scale back individual subsidies as private cost disadvantages for publicly beneficial technology choices decline or reverse themselves, allowing scarce public funds to be used to promote more extensive PEV diffusion.

Fortunately, early research in this area is encouraging. For example, quite ingenious and potentially valuable work indicates that lower-income groups can be quite responsive to graduated subsidies for PEV adoption.[72] Further strengthening this behavioral evidence can help CARB and other agencies more effectively target public resources to advance both environmental and social objectives.

5.3 OTHER POLICY ISSUES

5.3.1 Air Quality Improvement

Much of the debate about vehicle electrification focuses on costs and benefits of energy use technologies, while many societal benefits of reduced environmental pollution receive less attention. This study attempts to quantify reduced health costs from improved air quality, a real co-benefit of clean vehicle electrification that would be directly added to other economic impacts. Building on a rapidly growing body of public health research on climate policy, this study estimates the economic benefits (i.e., avoided health costs) of reducing hazardous co-pollutants—PM2.5, Ozone, nitrogen oxide (NOx), and sulfur oxide (SOx)—associated with carbon fuel consumption. These pollutants are not only associated with electric power and industry, but present a serious health risk in transportation corridors and densely-populated urban environments.

In order to estimate health benefits from the proposed policies, recently published research that uses a meteorological model to model the spatial relationship between emissions and criteria pollutants in 50km x 50km grid cells across the United States was leveraged.[73] Using this model and scaling modeled changes to emissions in California to reflect the proposed vehicle incentive policies allows authors to estimate changes in criteria pollutants across the state under each policy scenario. The EPA's BenMAP model

71 See e.g. Muehlegger, E. & Rapson, D. (2018a). Distributional Impacts of Vehicle Policy: Who Buys New and Used Alternative Vehicles. National Center for Sustainable Transportation for recent and innovative work in this area.

72 Muehlegger, E. & Rapson, D. (2018a). "Distributional Impacts of Vehicle Policy: Who Buys New and Used Alternative Vehicles." And (2018b): "Subsidizing Mass Adoption of Electric Vehicles: Quasi-Experimental Evidence from California." *National Center for Sustainable Transportation.*

73 Zhang, Yuqiang et al, 2017. "Co-Benefits of global, domestic, and sectoral greenhouse gas mitigation for US air quality and human health in 2050." *Environmental Research Letters.* 12. 114033.

is then used to relate changes in criteria pollutants to changes in the number of excess deaths from pollution. differentiating incidence by source of emissions (e.g. vehicles, coal fired generation, industrial process, etc.).[74] Excess deaths are valued according to the EPA's Value of a Statistical Life (VSL) and EPA estimates of the relationship between mortality and morbidity health costs are used to approximate the magnitude of total health benefits.

Using this approach, the authors estimate that the added public health benefits are substantial, comprising up to one third of total economic benefits from the proposed policies. Thus, while public health benefits are an addition to social wellbeing, including or excluding them from the analysis does not fundamentally change the cost-benefit calculation. These estimates are intended only to be indicative of the magnitude of potential health benefits from the proposed policies. A detailed description of the methods used to estimate health benefits is given in Section 6.

5.3.2 Trade

Lower expenditures on conventional energy (i.e. gasoline and diesel fuel) reduce California's dependence on imports of energy fuels from other states and overseas. It is possible that reduced California fuel imports could negatively impact the state's opportunities to export goods to trade partners. However, conventional energy fuel imports can increase state employment as long as it results from improved efficiency that frees up consumer dollars for other spending. It has already been observed that the carbon fuel supply chain has extremely low employment potential. For example, a dollar spent on California gasoline generates less than 5 percent as many jobs as the average dollar of consumer spending ($0.70 of which go to services). Even if California's exports fell by an amount equal to the reduction in conventional energy fuel imports, the net job creation effect would be strongly positive.

Three other effects of fuel savings on households and enterprises are also likely to have an impact:

- Spending fuel savings creates its own import demand. This would offset about half the mercantile effect of reduced energy imports.
- Service spending has larger in-state multipliers than energy fuel spending.
- Innovation benefits of new fuel and vehicle technologies increase state employment and income.

5.3.3 Market Failure

Sometimes findings of economic benefits due to climate policies encounter skepticism, based on a presumption of market efficiency. Simply put, this perspective holds that to justify intervention, one must identify specific market failures that are inhibiting otherwise voluntary mitigation efforts and/or technology adoption. Otherwise, markets know best and society is already using or pursuing the most cost-effective solutions.

In reality, of course, there are many market imperfections in the climate change context generally and with respect to transportation in particular. Of course, the most important one is the global GHG emissions externality, an inconvenient disconnect between the private benefit of using energy services and the public cost of the greatest environmental risk in human history. If this isn't enough to justify intervention in today's energy systems, it is also worth acknowledging universal subsidies to conventional modes of transport, as well as oligopolies and/or local monopolies in vehicle, conventional fuel, and electric power sectors.

5.3.4 Estimating Employment Effects

The positive job creation resulting from the scenarios analyzed requires that supply conditions are conducive to new hiring. To be clear, BEAR is not a "full employment" model because California historically has had an elastic supply of labor. Coming out of an adverse national macro cycle, the state had some structural unemployment, and like most economies, this will likely revisit the

74 BenMAP model documentation, Environmental Protection Agency. 2018. Available at: https://www.epa.gov/benmap

economy intermittently. Over the long term, however, California has a higher-than-average elasticity of labor supply, sustained by a long-term trend of net immigration to the state. This study takes explicit account of this and, while it may not yield net job creation for the national economy, this kind of new job and income creation has always benefitted California.[75]

5.4 MACROECONOMIC RESULTS

The macroeconomic assessment results are presented in Tables 9 through 12 for two time horizons (2030 and 2050). In the first case, it was found that vehicle electrification under LTES cost assumptions would confer significant economic benefits from combined PEV production, infrastructure, and vehicle savings stimulus and these combine to increase state GSP, employment, real household incomes, and state revenue. Incorporating more recent vehicle cost data from ICCT's sources significantly improves the aggregate economic stimulus, and more equitable vehicle adoption yield essentially the same overall benefit. Once again, it should be emphasized that the threefold stimulus from accelerated PEV deployment creates growth and jobs broadly across the economy, with many Californians benefitting whether they buy a PEV or not.

Percent changes are useful in comparing the relative impacts between different scenarios, but do not give a clear idea to the magnitude of these effects. To complement this, macroeconomic findings in level form are also reported in Table 10. These results illustrate the size of the impacts with Gross State Product increasing some $82 to $142 billion in 2030, depending on the scenario. Real income is projected to increase substantially, ranging between an additional $311 to $357 billion in 2030, depending on scenario. With regard to jobs, this analysis finds an estimated increase of 394,000 new jobs in 2030 with higher cost PEVs to over half a million

TABLE 9 Macroeconomic Impacts in 2030 - Percentages (Change from Baseline in 2030)

	LTES	INNOVATION	EQUITY
Gross State Product ($B)	1.48%	2.55%	2.54%
Real Output	2.18%	3.10%	3.08%
Employment	1.44%	1.95%	1.94%
Real Income	2.92%	3.99%	4.16%
In State Revenue	1.45%	2.51%	2.50%

Source: Authors' Analysis

TABLE 10 Macroeconomic Impacts in 2030 - Absolute Levels (Difference from Baseline in 2030; 2016 $ Billions Unless Noted)

	LTES	INNOVATION	EQUITY
Gross State Product ($B)	82	142	141
Real Output	179	256	254
Employment	394	532	530
Real Income	311	351	357
In State Revenue	4	7	7

Source: Authors' Analysis

new jobs with more recent, lower vehicle purchase and operating cost projections. Finally, it should be noted that overall economic expansion has significant fiscal benefits, generating billions in additional revenue per year from existing tax instruments. Much larger than anticipated cap-and-trade revenue, this serves as

75 Borenstein, Severin. 2015. "The Job Creation Shuffle," Haas School of Business, University of California, Berkeley. February, 2015. Available at: https://energyathaas.wordpress.com/2015/02/17/the-job-creation-shuffle/. Borenstein is among prominent experts who caution about the risk of overestimating national benefits from state-specific job creation. This skepticism is certainly well founded, but states tend to place self-interest first when it comes to jobs and income growth.

a reminder that pro-growth aspects of climate policy can yield substantial new resources for reinvestment in public goods and services. It can also be noted that overall employment gains significantly exceed direct job creation that can be expected from increased PEV sales.

Incorporating more recent vehicle cost data from ICCT's sources significantly improves the aggregate economic stimulus, and more equitable vehicle adoption yields essentially the same overall benefit. Once again, it should be emphasized that the threefold stimulus from accelerated PEV deployment creates growth and jobs broadly across the economy, with many Californians benefitting whether they buy a PEV or not.

Extending the analysis to 2050 significantly amplifies the growth dividends associated with more energy efficient mobility (Tables 11 and 12). Like interest, energy and other use savings from more efficient technology compound over time, where the multiplier in this case is coming from expenditure diverted from (largely imported) energy fuels to in-state goods and (predominately) services. The result is that extending the scenario horizon threefold (from 10 to 30 years in the future) increases economic benefits (real GSP) by seven to eight times, depending on the scenario. Even in the relatively conservative LTES scenario, vehicle electrification increases California's GSP about five percent by 2050—assuming the state meets its adoption goals under a relatively high cost scenario. With more progress in vehicle cost reduction, the gains are almost twice as large. Because adoption patterns between 2030 and 2050 are essentially the same for the Innovation and Equity scenarios, they differ little by the final year. Having said that, it should be emphasized that these two scenarios have very different effects on economic inequality.

The macroeconomic drivers of these three scenarios are simply described. As was already established by in the independent assessment of CEC's Long-Term Energy Strategy, investments in new and more efficient clean energy provide significant net stimulus to the California economy.[76] Decomposing the PEV component of this in the LTES scenario shows how important vehicle electrification is to statewide efficiency gains and growth. When more recent estimated improvements in vehicle cost effectiveness are considered for the Innovation scenario, the growth stimulus is even more positive. The resulting benefit estimates remain conservative,

TABLE 11 Macroeconomic Impacts in 2050 - Percentages (Change from Baseline scenario)

	LTES	INNOVATION	EQUITY
Gross State Product ($B)	4.94%	9.24%	9.22%
Real Output	6.00%	10.51%	10.48%
Employment	2.86%	4.03%	4.02%
Real Income	7.80%	12.74%	12.81%
In State Revenue	4.70%	8.81%	8.79%

Source: Authors' Analysis

TABLE 12 Macroeconomic Impacts in 2050 - Absolute Levels (Difference from Baseline in 2050; 2016 $ Billions Unless Noted)

	LTES	INNOVATION	EQUITY
Gross State Product ($B)	614	1,150	1,147
Real Output	1118	1,956	1,952
Employment (,000)	1290	1,816	1,812
Real Income	1,216	1,489	1,494
State Revenue	29	55	54

Source: Authors' Analysis

76 Roland-Holst, David, Samuel Evans, Samuel Heft-Neal, Drew Behnke, and Myung Lucy Shim. 2018. *Exploring Economic Impacts in Long-Term California Energy Scenarios*. California Energy Commission. Publication Number: CEC-500-2018-013.

however, since no incremental innovation from the base year (2018) forward is assumed. Finally, promoting PEV adoption among lower-income households accelerates overall electrification and distributes the economic benefits more equitably.

5.5 HOUSEHOLD IMPACTS BY INCOME GROUP

Both of the arguments for inclusive vehicle adoption and the virtuous growth cycle discussed in the previous section can be clearly understood by examining scenario impacts across different California income groups. The BEAR model has the ability to forecast results for each state income tax bracket. Given that the benefits from transitioning to electric and other zero-emission vehicles will not be uniformly distributed across the population, this feature of the model is particularly relevant. The results for income impacts-by-decile are illustrated in Figure 16, demonstrating the essential macroeconomic drivers of vehicle electrification, both in terms of aggregate income growth and its distribution. Simply put, more efficient vehicles confer income benefits on their owners, and these propagate across multiplier linkages to the rest of the state economy. Even when lower-income households capture larger benefits from accelerated adoption rates, these indirect linkages protect most of the gains for higher-income groups.

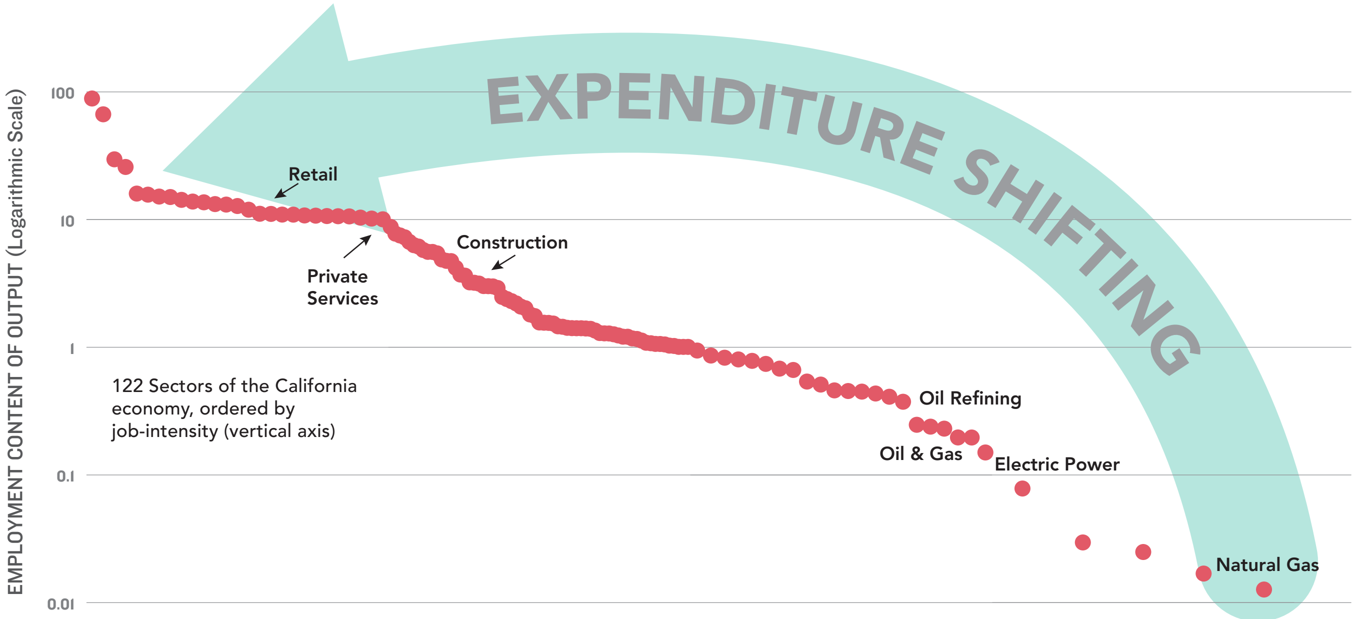
FIG 16 Household Real Income Changes by Tax Bracket, Percent Change from Baseline Scenario in 2030

Source: Authors' Analysis

The LTES scenario assumes the state would progress toward uniform PEV adoption by 2050. The Innovation scenario adhered to the same adoption pathway but offered greater PEV owner savings via more optimistic vehicle cost trajectories. Finally, the Equity scenario shifted PEV purchasing to achieve equal ownership rates across income groups by 2030, meaning the same overall PEV deployment, but more rapid adoption among lower-income groups. The primary difference between these scenarios was the consequent distribution of PEV purchase costs and use savings. The economy and all income groups gained from lower cost vehicle deployment (LTES) and gained more when costs were even lower (Innovation). When lower-income groups experienced more rapid adoption, their gains were even larger than those of higher-income groups, exactly as would be expected.

Less obvious, but very welcome for policy makers, is the finding that higher-income groups would be nearly unaffected by the redistribution of vehicles. This is because, while fewer people may benefit directly from PEV ownership, many more can benefit indirectly from adoption by others, via emission reductions and the economic spillovers from an expanding technology sec-

FIG 17 Job Creation Through Expenditure Shifting



Source: Authors calculations based on data from the US Bureau of Economic Analysis, US Bureau of Labor Statistics, and California Department of Finance[79]

tor. As with the example of Tesla, every time California establishes standards or incentives for adoption of new technology, it creates an incubator the size of the world's fifth-largest economy. Firms know that establishing marketable innovations here can prepare them for global export competitiveness. All this reminds us of a central tenet of California's knowledge-intensive growth model—induced growth from technology innovation benefits the overall economy, rewarding even those people who neither develop nor adopt it. For PEVs, this conclusion applies with comparable force to economic and environmental benefits, although PEVs in lower-income communities might displace less efficient vehicles, amplifying these benefits.

Any discussion of the economic impacts from large-scale technology adoption needs to take account three component impacts: investment in technology production, technology purchasing, and more indirect technology adoption cost. The first, like building and operating an automobile factory, represents so-called "shovel-ready" investment and is usually an unambiguous economic stimulus. Technology purchase and use costs can have mixed effects on the economy, depending on their so-called opportunity cost. In other words, technology adoption will stimulate the economy if it leads to higher productivity, lower resource costs, or both. If it reduces productivity (e.g. online gaming or shopping during working hours) or increase resource costs, it will be detrimental to economic growth.

This report has already argued that current trends in PEV technology will lower vehicle costs, so this provides direct stimulus (through consumer savings) in California whether the state make the cars or not. Growth stimulus from energy fuel saving is subtler, but also more pervasive. Promoting energy efficiency (in vehicles, appliances, or any durable goods) saves

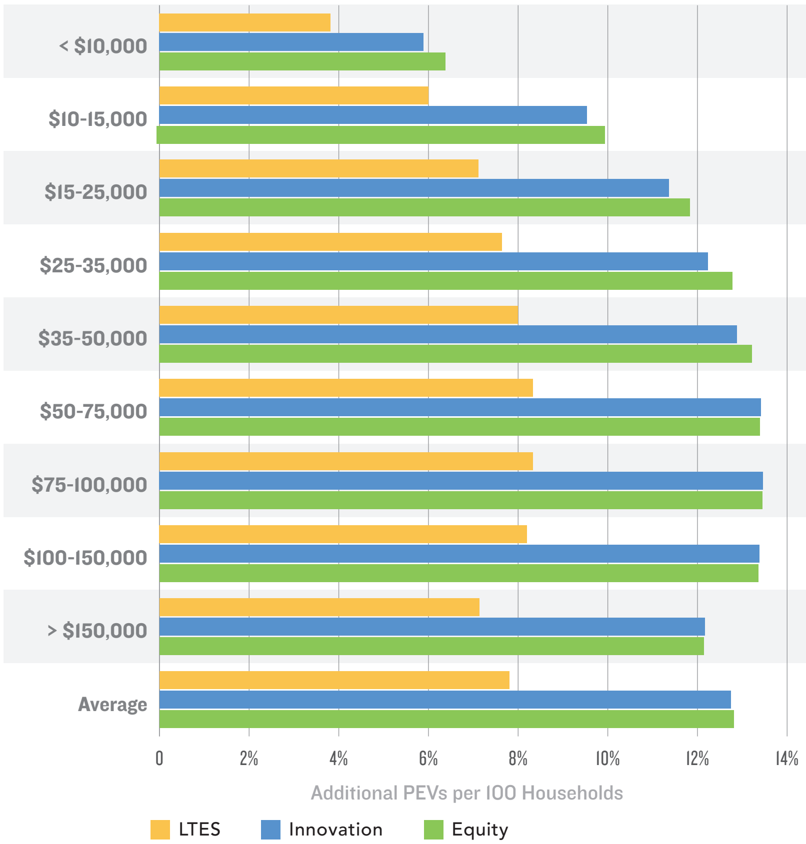
77 "Exploring Economic Impacts in Long-Term California Energy Scenarios." California Energy Commission. June 2018. Available at: https://ww2.energy.ca.gov/2018publications/CEC-500-2018-013/CEC-500-2018-013.pdf

money for households and enterprises. These savings will be diverted toward other expenditures, the majority of which (in California) go to in-state services that

- employ workers from all skill levels and demographics
- are non-tradable, meaning these new jobs cannot be outsourced.

To understand how potent this driver is, note that 70 percent of California aggregate demand (GSP) is household consumption and 70 percent of this goes to services. Thus, about half of incremental income or diverted expenditure can be expected to go to the service category of employment—the most labor-intensive and skill-diverse in the economy. As Figure 17 makes clear, the carbon fuel supply chain is among the least employment intensive, and this after deducting a significant import cost share. Jobs per million of revenue in the service sector are one to 10 times greater than the same metric in the carbon fuel supply chain, and the difference is far too large to be offset by wage inequality. Simply put, if you save a dollar at the gas pump, you will spend about two-thirds of it on services, stimulating much stronger in-state job growth.

FIG 18 Household Real Income Changes by Tax Bracket, Percent Change from Baseline Scenario in 2050



Source: Authors' Analysis

Figure 18 shows real gains by household income group in 2050, which have converged along with assumed vehicle adoption patterns. Despite the "level playing field" since 2030 when the Equity scenario assumes PEV adoption rates are equalized, a residual growth benefit of early (2018 to 2030) accelerated adoption persists for lower-income households. Moreover, higher-income groups still capture the full benefit of the Innovation scenario's superior efficiency assumptions. This suggests the state can achieve its goals of more inclusive PEV economic and environmental benefits without long-term disadvantage to any group.

Section Six

Disadvantaged Community Analysis

Disadvantaged Community Analysis

6.1 BACKGROUND

Statewide models of the economy are useful tools for evaluating the costs and benefits of proposed policies in California. However, state-level results provide little information about how policies will affect individual communities. In particular, the distributional component of costs and benefits will have broad implications with respect to policy impacts and must be considered in order to ensure that vulnerable communities do not bear more than their share of the costs. Examples of past studies that directly considered policy impacts on disadvantaged communities include the Economic Assessment of SB350 commissioned by the California ISO[78] and the Economic Analysis of the 2017 Scoping Plan developed by the California Air Resources Board.[79]

Here, the above-described BenMAP approach to downscaling statewide economic impacts at the census tract level is used. Moreover, in addition to income and employment effects, the authors also rely on detailed vehicle registration data from the Department of Motor Vehicles (DMV) along with rebate data to examine adoption patterns of electric vehicles in both disadvantaged and non-disadvantaged communities. Lastly, these methods are further refined by drawing on CalEnviroScreen 3.0 to identify Disadvantaged Communities (DACs) and to utilize updated census level data to calibrate community shares. The authors hope this approach will further develop the template for future analysis of environmental policy impacts on disadvantaged communities in California.

6.2 IDENTIFYING DISADVANTAGED COMMUNITIES

In order to identify communities that are disadvantaged with respect to environmental policies, the California Environmental Protection Agency (CalEPA) worked with the Office of Environmental Health Hazard Assessment (OEHHA) to develop a tool called CalEnviroScreen (CES) that evaluates economic and environmental conditions of every census tract in California. The most recent version, CalEnviroScreen 3.0, was last updated in January 2018 and it considers factors such as environmental conditions, health outcomes, and socioeconomic status to construct a score for each census tract, which can then be used to identify vulnerable communities likely to be sensitive to changing policies.[80] Disadvantaged Communities (DACs) are commonly defined using this tool as

78 Roland-Host, D., D. Behnke, S. Evans, C. H. Springer, S. Heft-Neal. Senate Bill 350 Study, Volume VIII: Economic Impact Analysis. California State Senate. July 8, 2016. Available at: http://www.caiso.com/Documents/SB350Study-Volume8EconomicImpacts.pdf

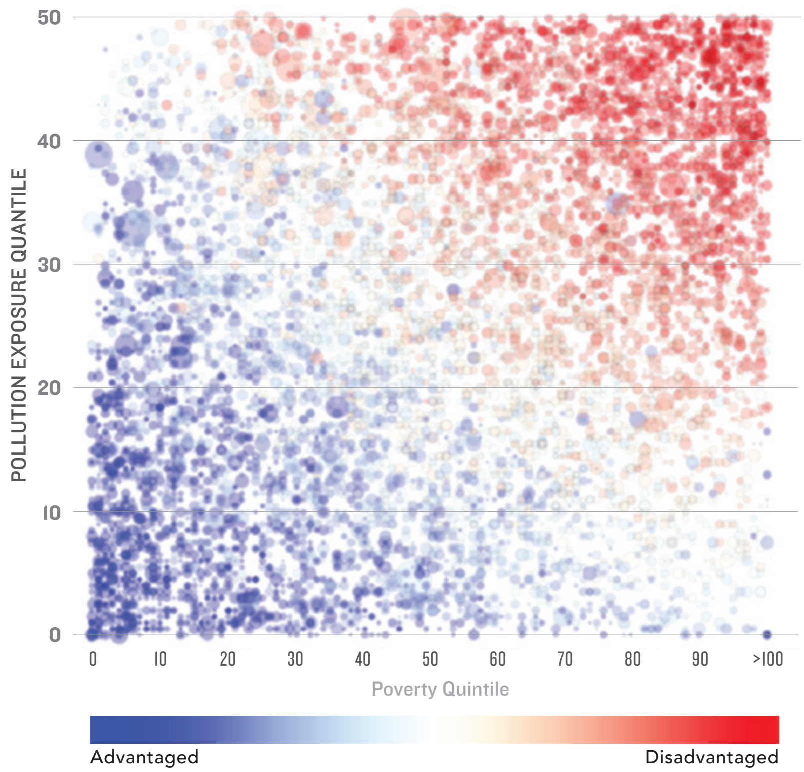
79 California Air Resources Board (CARB), 2017a. California's 2017 Climate Change Scoping Plan: The strategy for achieving California's 2030 greenhouse gas target. November 2017. Available at: https://ww3.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf

80 CalEnviroScreen 3.0. California Office of Environmental Health Hazard Assessment. Updated June 2018. Available at: https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30

census tracts in the top 25th percentile of CES scores. By this definition, there are currently 2,022 census tracts designated as DACs in California.

The communities that are designated as disadvantaged using this approach are burdened by a combination of low income, high exposure to environmental hazards, and poor health. To illustrate the importance of this combination of factors, Figure 19 highlights the relationships between pollution exposure, poverty, and CES score. Each point represents a census tract in California and the axes show poverty and pollution exposure. CES score is represented by color. DACs are concentrated in the upper right corner of the figure where both pollution exposure is high and income is low. The figure highlights the fact that most census tracts that are very poor, but exposed to low levels of pollution are not designated as disadvantaged by CalEnviroScreen 3.0. Similarly, wealthy communities exposed to high levels of pollution do not qualify as disadvantaged in this classification system. It is the combination of hazardous environmental exposure and socioeconomic status (and high health costs) that results in a community being designated as disadvantaged.

FIG 19 The Relationship Between Pollution Exposure, Poverty, and Disadvantaged Status



Source: Author analysis from Bureau of Economic Analysis and IMPLAN data[81]

Note: The x-axis shows where the census tract ranks relative to other tracts with respect to poverty, the y-axis shows the pollution exposure rank, and the color shows the CES score rank. The size of the point is proportional to the census tract population.

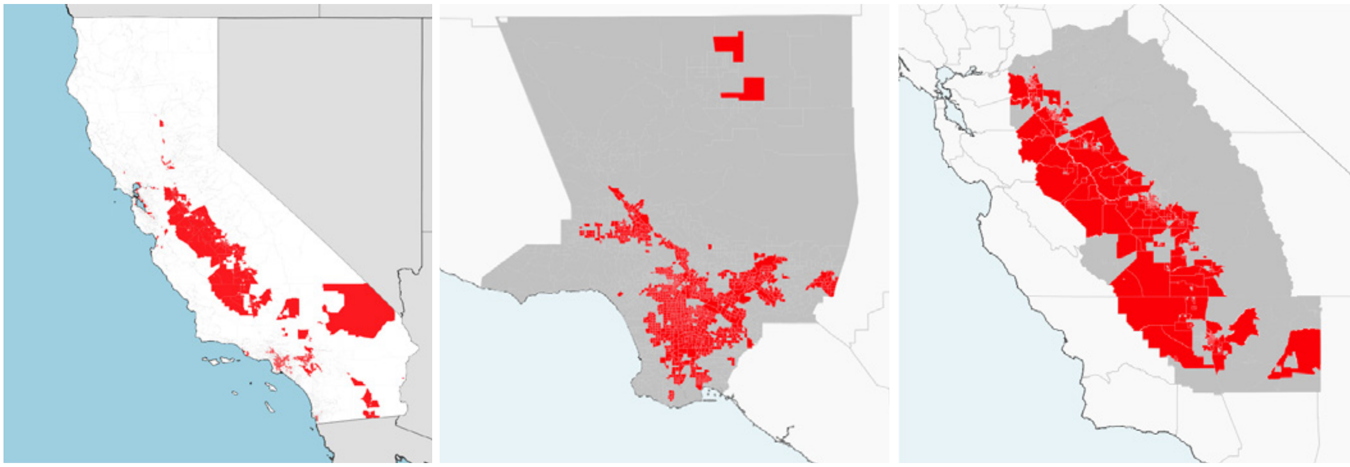
6.3 CHARACTERISTICS OF DISADVANTAGED COMMUNITIES

6.3.1 Spatial Distribution

The regional distribution of DAC communities is apparent from Figure 20. While there are disadvantaged communities throughout the state, they are highly concentrated in two regions: the Central Valley and Los Angeles. In fact, approximately half of the disadvantaged communities are in Los Angeles County alone. This includes 51 percent of disadvantaged census tracts representing 46 percent of the disadvantaged population. Another 20 percent of disadvantaged communities are located in the Central Valley (21% census tracts, 23% of disadvantaged population), so collectively these two regions contain nearly 75 percent of all disadvantaged communities. While Los Angeles County and the Central Valley are distinct in many ways, both areas include poor air quality and substantial populations of low-income residents, the qualities that designated disadvantaged status for the purpose of evaluating California environmental policy. The remaining disadvantaged communi-

81 "Exploring Economic Impacts in Long-Term California Energy Scenarios." California Energy Commission. June 2018. Available at: https://ww2.energy.ca.gov/2018publications/CEC-500-2018-013/CEC-500-2018-013.pdf

FIG 20 Location of DACs in California, and in Los Angeles County and the Central Valley



Source: Authors' Analysis

The spatial distribution of disadvantaged communities (DACs) in the state (left) Los Angeles County (middle) and the Central Valley (right). 75 percent of DACs in the state are in these two regions.

ties are mostly spread across the state, however, none of the regions besides Los Angeles and the Central Valley contain more than 10 percent of the disadvantaged communities or population.

6.3.2 Socioeconomic Status

Naturally, disadvantaged communities are less well-off than non-disadvantaged communities and these differences show up across the spectrum including lower income, education, and asset ownership. Across the state, households in DAC communities have 53 percent lower per capita income on average than their non-disadvantaged counterparts, and are 93 percent more likely to live below the poverty line.[82]

Overall DAC households are substantially more likely to be employed in the agricultural sector (4.3% vs 1.8%), however, this discrepancy is particularly stark in the Central Valley, where more than 15 percent of DAC households are in the agricultural sector compared to less than seven percent of non-DAC households. DACs also skew more heavily towards unskilled labor such as manufacturing (11.4% vs 9.3%), retail (12% vs 10.8%) and transportation (6.3% vs 4.2%).

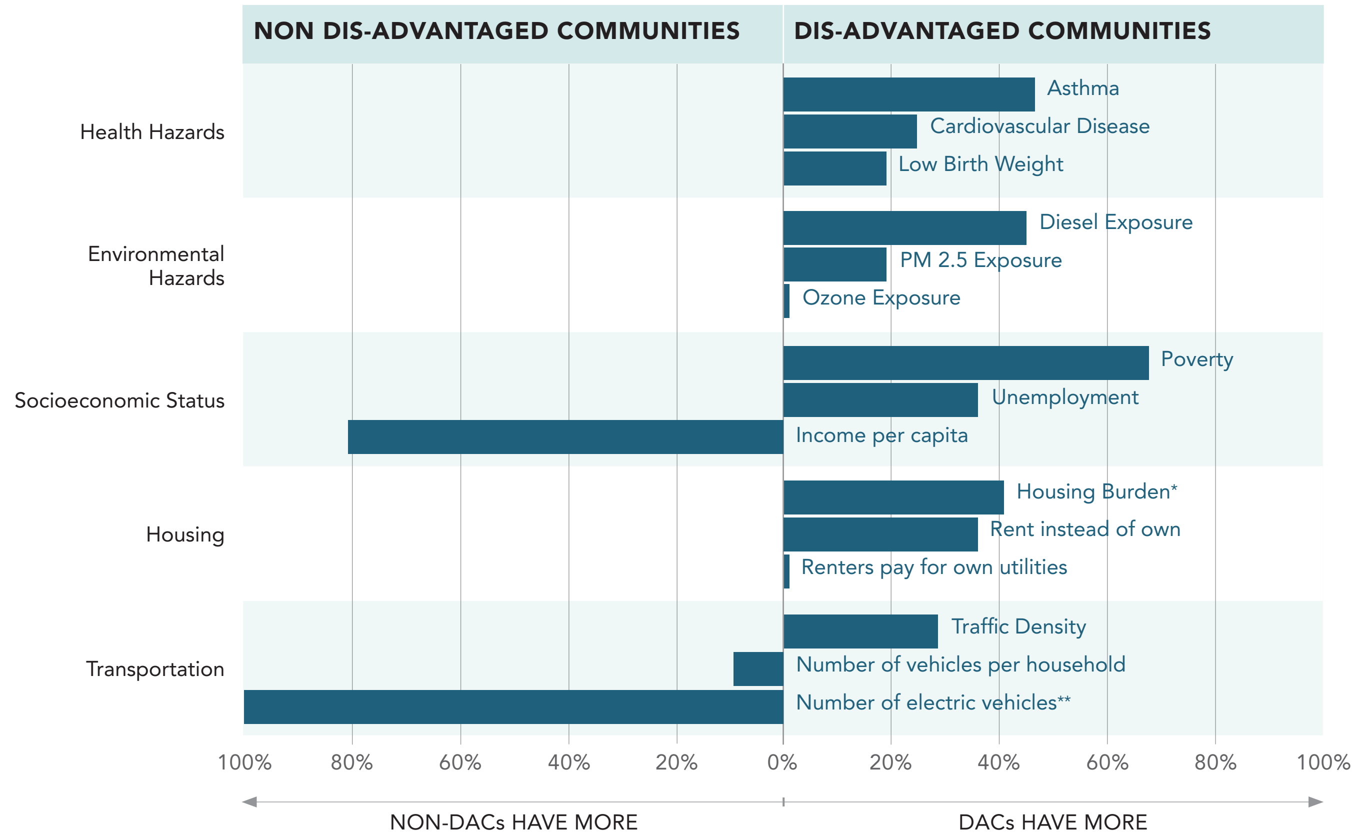
While energy usage for every census tract is not observed, the types of energy systems used for heating and cooling are observed in the ACS data. Findings indicate that non-DACs are twice as likely to use solar energy for their heating and cooling needs while DACs are three times as likely not to have any heating or cooling systems in their homes.

6.3.3 Environmental Exposure

In addition to being less well off financially, by the CES definition disadvantaged communities are also exposed to higher levels of many hazardous environmental exposures. For example, statewide emissions from diesel sources are 62 percent higher in DACs (27 compared to 17 kg of emissions day) and PM2.5 exposure from all sources is 26 percent higher (12.3 compared to 9.7 ug\m^3). Pesticide use is 11 percent higher in disadvantaged communities (340 compared to 305 lbs. per square mile). In contrast, for some pollutants that are more homogenous over space, like ozone, there is no measurable difference in exposure between disadvantaged and non-disadvantaged communities.

82 Source is author's calculations combining ACS 5-year average income estimates with CES 3.0 DAC designations.

FIG 21 Comparison Between Disadvantaged and Nondisadvantaged Communities



Source: Author estimates from Cal Enviroscreen 3.0 and the United States Census data[86]

* A household has a "Housing Burden" if they pay more than 50% of their income for housing

** Non-DACs own more than 1,100% as many electric vehicles as DAC households

There is considerable spatial variation in hazardous environmental exposure across the state. In Los Angeles County, for example, emissions from diesel sources are higher than average for all communities. Nonetheless disadvantaged communities live in locations within the county with 50 percent more diesel emissions than their non-disadvantaged counterparts (30 compared to 20 kg/day). Similarly, pesticide application is higher for both groups in the Central Valley, however, disadvantaged communities live in areas with 70 percent higher rates of pesticide application (845 compared to 498 lbs. per square mile).

6.3.4 Health Burden

The high health and overall economic costs of exposure to these hazards is well established.[83, 84, 85] Benefits from reducing harmful exposures therefore stand to be significant particularly for communities exposed to dangerously high levels. Moreover, since DACs are disproportionately likely to be exposed to high amounts of these hazards, uniform reductions across the state stand to be particularly beneficial to these communities.

83 Gibson T., E.G. Hertwich, A. Arvesen, B. Singh, and F. Verones, 2017: Health benefits, ecological threats of low-carbon electricity. Environmental Research Letters, 12, 034023. http://dx.doi.org/10.1088/1748-9326/aa6047

84 Saari, R.K., N.E. Selin, S. Rausch, T.M. Thompson, 2015: A self-consistent method to assess air quality co-benefits from U.S. climate policies. Journal of the Air & Waste Management Association, 65, 74-89. http://dx.doi.org/10.1080/10962247.2014.959139

85 Thompson, T.M., S. Rausch, R.K. Saari, and N.E. Selin, 2014: A system approach to evaluating the air quality co-benefits of US carbon policies. Nature Climate Change, 4, 917-923. http://dx.doi.org/10.1038/nclimate2342

86 "Exploring Economic Impacts in Long-Term California Energy Scenarios." California Energy Commission. June 2018. Available at: https://ww2.energy.ca.gov/2018publications/CEC-500-2018-013/CEC-500-2018-013.pdf

The combination of fewer resources to facilitate adaptation and higher exposure rates help contribute to a situation where disadvantaged households bear many of the overall health costs from poor environmental quality. For example, households in DAC communities are 64 percent more likely to have visited an emergency room for asthma-related problems (74 compared to 45 visits per 10,000 people) and 34 percent more likely to have visited for a heart attack (10 compared to 7 visits per 10,000 people). Children born in disadvantaged households are also 26 percent more likely to have low birth weights. None of these differences can be directly attributed to higher exposure to hazardous environmental conditions since, by the nature of being disadvantaged, these communities are likely to be in poorer health overall. Nonetheless, the higher rates of disease incidence, and particularly asthma, indicate that improvements in air quality are likely to be particularly beneficial to disadvantaged communities.

It should also be noted that the source of pollution exposure in DACs varies geographically. In places like the Central Valley, heavy-duty vehicles (HDV) are a main source, whereas in Los Angeles, light-duty vehicles (LDV) are a primary contributor. DACs in different regions are therefore likely to benefit more from different policies.

6.4 METHODS

Directly modeling the economic impact of statewide policies at the disadvantaged community-level using the BEAR model would require complete data on economic activities for every census tract in California. Since these data do not exist, statewide impacts disaggregated to the census tract-level were utilized instead and then impacts in those census tracts designated as disadvantaged were highlighted. The process of disaggregating statewide results to the census tract-level is different for each outcome and these processes are described in detail below.

6.4.1 Downscaling BEAR Model Employment results

The BEAR model produces job impact estimates measured as total jobs by sector and by occupation. Jobs impacts are downscaled from the state to the census tract using occupational and sector employment information in the American Communities Survey (ACS). ACS 5-year estimates (2011-2015) of the share of number of households with residents employed in each sector and each occupation were utilized. This study relies on the assumption that changes in jobs are uniformly spatially-distributed across the state within sector and occupations so total job changes at the state-level are allocated evenly across the state to households within that sector and within that occupation.

Direct employment is distinguished from indirect and induced employment using employment intensities for the sectors directly impacted by the PATHWAYS decarbonization scenarios. These direct effects are then netted out to determine the indirect and induced employment impacts of the decarbonization scenario.

6.4.2 Caveats

Lacking enough information to predict the location of new jobs, it is instead assumed that future jobs are created in the locations where current jobs exist. Therefore, the authors assume that future jobs, within a given sector and occupation, are uniformly spatially distributed across the locations of current workers. Relying on this assumption allows the model to allocate total job changes at the state level evenly to households within that sector and occupation. For example, this analysis assumes that construction jobs in 2030 are in the same locations that they are now, so all new 2030 construction jobs are assigned to each census tract proportionally to the number of current construction workers. If new construction jobs are generated in places that do not currently have construction jobs, those jobs would be captured in our macro estimates but would not be assigned to the correct census tracts.

6.4.3 Low-Emission Vehicle Analysis

In order to downscale the impacts of clean vehicle use to the census tract level, the authors rely on vehicle registration data provided by the DMV as well as the Center for Sustainable Energy's Clean Vehicle Rebate Project data set. The Clean Vehicle Rebate Project (CVRP) is a publicly available database maintained by the Center for Sustainable Energy (CSE) for the California Air Resources Board.[87] It includes data on all PEV rebate claims in California at the census track level. While not all PEVs are captured in the database (as not every eligible vehicle owner applies to the CVRP), over the first five years of the program approximately 75 percent of eligible PEV purchases received CVRP rebates. Using this information on the location of clean vehicles in conjunction with DMV vehicle registration data allows us to model EV adoption and to downscale E3's statewide electric vehicle projections in order to examine the impacts on DACs.

In earlier rounds of CVRP, more than 90 percent of incentivized clean vehicles in California were purchased by households in non-disadvantaged communities. This has given rise to concerns about the risk of "free riding" on the vehicle subsidy program by households who would otherwise have bought eligible vehicles in any case. While this raises important equity considerations, a more definite policy concern is lack of "additionality." To the extent that incentives go to buyers who would have acquired a PEV anyway, public funds are achieving lower overall adoption per dollar.

The data noted above is then used together with income data and detailed demographic information to model PEV purchases. Next, the BEAR model estimates of income are used to predict purchasing patterns under different scenarios (holding demographic characteristics fixed). The BEAR model produces statewide estimates for changes in income by tax bracket. Beginning with the ACS data set, the distributional impact of these changes on disadvantaged communities is examined by constructing a sample of household shares from each tax bracket in every California census tract, using the 5-year averages from annual data over the period 2011-2015. The census tract level shares of households in each tax bracket are then disaggregated throughout the state in proportion to the number of households in each tax bracket. This approach assumes that, for each tax bracket, income effects are distributed evenly around the state for households within the tax bracket. Local factors are of course important determinants of how policies impact a particular community. Therefore, for any given census tract this approach is unlikely to accurately predict income change from the simulated policy. That being said, on average the statewide impacts within a tax bracket will impact the populations within that bracket so the statewide DAC vs non-DAC comparison are a reasonable second-best estimate.

The income estimates from this model represents total income and the authors therefore present the study's census tract level results as community income per household in 2030 and 2050. In order to estimate community income per household *the number of households* in each census tract in 2030 and 2050 must first be estimated. To do so, DOF estimates of population growth by county are used. Population growth within counties is assumed to be uniform across census tracts and it is further assumed that household size remains constant so population growth is equivalent to growth in households. With these data and assumptions, household growth rates for each census tract can be calculated and applied to the current number of households in order to forecast the number of households in each census tract in 2030. These estimates of number of households are then used as the denominator in the income per household measure. Predicted income changes for each scenario are then used to model PEV purchasing patterns, which are in turn used to downscale the state-level electric vehicle projections for each scenario.

87 California Clean Vehicle Rebate Project can be found at: https://cleanvehiclerebate.org/eng

6.4.4 Caveats

This approach allows purchasing patterns to vary by income, but it does assume that household demographics are constant between now and the modeled years. While demographics do play an important role in predicting PEV purchasing patterns (and they are controlled for in the model to try and isolate the role of income), recent research has found that income is by far the most important predictor of PEV purchases.[88] This study finds that, at lower level incomes, additional income has an insignificant effect on the number of PEVs purchased. However, at relatively high levels of income, additional income does increase the number of PEVs purchased.

6.5 EXAMINING HEALTH BENEFITS FROM REDUCTION IN GHG EMISSIONS

Poor air quality imposes substantial and unequal public health costs across the state. Conversely, averting such costs is an important co-benefit of reductions in GHG emissions and commensurate improvements in air quality. As part of this study's medium and longer-term economic assessment of the state's future energy system, an exploratory analysis to quantify the value health benefits (i.e., avoided health costs) associated with a reduction in criteria pollutant emissions (NOX, SOX and PM2.5) from LTES policies is presented. This is done in four sequential steps.

Step 1: Estimating how reductions in GHG emissions reduce concentrations of criteria pollutants

Air quality is negatively correlated with GHG emissions, and criteria pollutants (e.g. PM2.5 and Ozone) have been linked to harmful effects on human health. However, the relationship between reduced GHG and criteria emissions is not 1:1 (i.e., a 5% reduction in GHG emissions does not necessarily translate to a 5% reduction in PM2.5) and this relationship varies over time and space. Modeling the relationship between GHG emissions and criteria pollutants is therefore the important first step to estimating health benefits. Until recently this relationship has not been well understood, but new research has shed important light on these linkages.

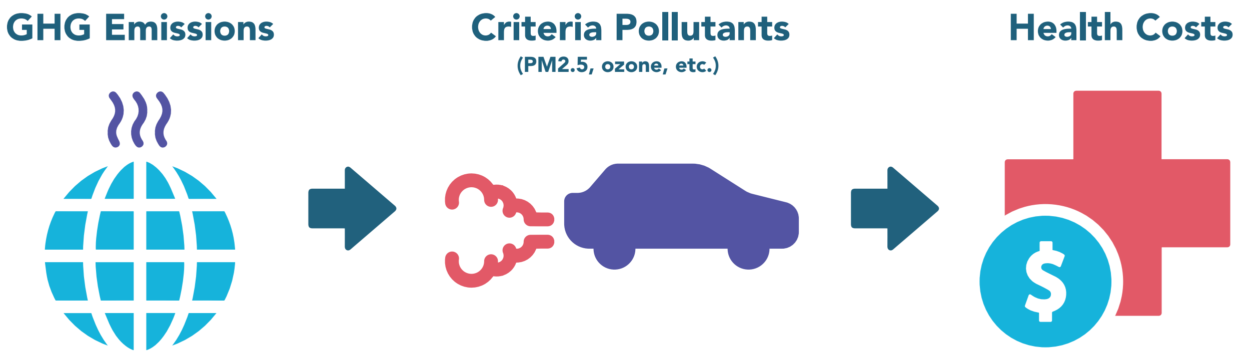
The authors of this study are not able to directly model how reductions in GHG emissions from LTES policies will specifically translate into lower criteria pollutant concentrations, however. Doing so would require an intensive modeling effort by physicists and environmental scientists and is far beyond the scope of the current project. Fortunately, this study was able to leverage recent research by Zhang et. al. on the link between GHG emissions in the energy sector and mortality risk in the United States.[89] The model evaluates the RCP 4.5 ENERGY scenario, a generic suite of cost minimizing policies that reduce GHG emissions in the national energy sector by a given amount.[90] These emissions reductions come from changes in electric power generation and energy extraction and transformation and are modeled to the year 2050. These estimates were then adjusted to more closely reflect potential emissions reductions from policies and to estimate benefits in 2030. According to E3 scenario numbers, by 2030 about half of 2050 GHG emission reductions will have taken place. The authors of the Zhang et. al. study were kind enough to share their data with this study's authors, which include ~50km x 50km gridded estimates of reductions in PM2.5 and Ozone, so these values were scaled to be half of their 2050 reductions.

88 California Air Resources Board (CARB), 2017b. "Factors Affecting Plug-In Electric Vehicle Sales in California", May 2017. Prepared by UCLA.

89 Zhang, Yuqiang et al, 2017. "Co-Benefits of global, domestic, and sectoral greenhouse gas mitigation for US air quality and human health in 2050". *Environmental Research Letters.* 12. 114033. Available at: https://iopscience.iop.org/article/10.1088/1748-9326/aa8f76

90 Thomson, A., Calvin, K., Smith, S., Kyle, G.P., Volke, A., Patel, P., Delgado-Arias, S., Bond-Lamberty, B., Wise, M., Clarke, L. and J. Edmonds, 2011. "RCP4.5: A Pathway for Stabilization of Radiative Forcing by 2100". *Climatic Change,* November 2011, 109: 77.

FIG 22 Broad Overview of Health Benefits Analysis



Sources: Model of meteorology and air quality, Yuquiang Zhang et al 2017 Environ. Res. Lett. "Co-benefits of global, domestic, and sectoral greenhouse gas mitigation for US air quality and human health in 2050;"

EPA's BenMAP model for mapping exposure to health benefits, http://www.epa.gov/benmap

Step 2: Estimating the effects of lower criteria pollutant concentrations on avoided pre-mature deaths

The Zhang et. al. data also includes 50x50km gridded estimates for the number of avoided pre-mature deaths due to avoided PM2.5 exposure and the number of avoided pre-mature deaths due to avoided Ozone exposure. The avoided pre-mature deaths estimates were derived from the EPA's BenMAP model. This model takes as inputs criteria pollution concentrations and outputs mortality risk estimates so it can be used to input the predicted reductions in PM2.5 and Ozone concentrations and output estimates for reductions in pre-mature deaths.[91]

Step 3: Valuing mortality and morbidity

The standard approach for valuing the cost of an avoided pre-mature death is to use a concept known as the Value of a Statistical Life (VSL). Report authors utilize the EPA's $7.5 million for the VSL, which also represents a de facto consensus from legal actuaries in California. This value does not mean that the EPA places a dollar value on individual lives. It represents a survey-based estimate of how much people are willing to pay for small reductions in their risk of dying from adverse health conditions that may be caused by environmental hazards and scale these estimates to represent a death.[92]

Multiplying the number of avoided pre-mature deaths by the EPA's VSL provides an estimate of the value of avoided pre-mature deaths, however, it ignores the costs associated with morbidity from air pollution. These comprise all averted medical costs due to lower incidence of respiratory and other air pollution related illness (e.g. asthma) which—for OECD populations—is normally estimated to be larger than mortality costs. Note, however, that this estimate is still conservative because it does not value non-medical costs like absenteeism, reduced effort, productivity, etc.

Directly estimating morbidity costs would require extensive information health costs incurred by cause, again outside this study and in many cases unavailable. The authors therefore rely on the EPA's regulatory assessment for the Review of the Particulate Matter National Ambient Air Quality Standards (NAAQS) to get an idea of the ratio of total health costs (mortality + morbidity) to mortality costs alone. In this regulatory assessment, the EPA estimated morbidity benefits to

91 Environmental Protection Agency, 2018. BenMAP model documentation: https://www.epa.gov/benmap

92 Environmental Protection Agency. Mortality Risk Valuation. Available at: https://www.epa.gov/environmental-economics/mortality-risk-valuation

be 2.5 times larger than mortality benefits. Scaling this study's benefits estimates by a factor of 2.5, the value of total health benefits in California associated with the volume of reductions in GHG emissions forecast from policies in 2030 is estimated.

Step 4: Spatially Disaggregated (DAC-level) Estimation

Because the data provided by Zhang et. al. are on a ~50x50km grid, the avoided pre-mature deaths can be matched to individual communities and US census tracts (the geographic basis for DAC definition). This is done by taking the total avoided deaths in a grid cell and downscaling them across census tracts, weighting by population. For example, if five census tracts are contained within one grid cell and that grid cell predicts 10 avoided pre-mature deaths, then each of the five census tracts will be assigned a fraction of the 10 deaths proportional to the population in that census tract. The census tracts designated as DACs by CalEnviroScreen 3.0 are identified and DAC and regional totals for the health benefits are then estimated.

Caveats

This study utilizes nationally-modeled 50x50km-gridded health benefits estimates from GHG emissions reductions in the energy sector and is intended to be illustrative of the potential magnitude of health benefits. However, studies devoted specifically to analyzing California policies at the local level are needed (and several are currently underway) in order to illuminate highly localized effects.

Another main caveat is that detailed GHG reductions from LTES policies are not modeled. Benefits are modeled from GHG reductions due to transformations in the energy sector including changes in electric power generation (e.g. California's Renewable Portfolio Standard) and energy extraction and transformation. These emissions are then scaled proportionately to expected emissions reductions from LTES policies.[93] The spatial patterns of criteria pollutant reduction from changes in power generation and extraction are therefore assumed to be the same as the spatial patterns of criteria pollutant reductions from LTES policies. This results in underestimating benefits in places where LTES policies will reduce criteria pollutants in ways other than through electricity generation. For example, this analysis does not consider the location of GHG emissions from the transportation sector, however, the total GHG emissions reductions in our health benefit estimates do reflect emissions reductions from transportation since the Zhang et al estimates are scaled to the level of total expected reductions in GHG emission from LTES policies.

The other main assumption is that total health benefits and avoided pre-mature deaths conform to a 2.5 multiple relationship observed at the national level. This assumption is based on previous work by the EPA and takes averages from estimates in the EPA regulatory assessment for the National Ambient Air Quality Standards. It should be noted, however, that EPA estimates of morbidity costs in this study range widely and while the average is taken, other estimates within the confidence interval would result in some variation of total avoided health cost estimates.

Additional assumptions include the following:

- value of a statistical life is $7.5 million,
- BenMAP, a national assessment tool, appropriately estimates the number of avoided deaths from reductions in criteria pollutants,[94]
- the total number of avoided deaths in a 50x50km area will be realized proportionately to population within that area

Lastly, this analysis assumes that, because most PEV policies affect dispersed pollutants, mitigation is achieved uniformly across the state. Criteria pollutants can be

93 All these changes are documented in CEC's report on the LTES, with supporting analysis by E3 (2016) and other energy sector researchers.

94 Environmental Protection Agency. How BenMAP-CE Estimates the Health and Economic Effects of Air Pollution. Available at: https://www.epa.gov/benmap/how-benmap-ce-estimates-health-and-economic-effects-air-pollution

more localized, but there is currently a lack of complete data on how PEV adoption will affect these patterns. In reality, urban census tracts will probably see greater mitigation from higher initial concentrations, while rural census tracts will begin with better air quality and see smaller improvements. As such, this analysis could be overestimating benefits in some areas where higher concentrations persist, but of course it also means that more targeted policies could achieve even larger benefits.

In addition to the caveats above, it should also be noted that this study does not cover all potential co-benefits from GHG emissions reductions. Benefits not covered here include:

- Local environmental, health, and safety benefits from electrification of the vehicle fleet
- Productivity benefits from lower criteria pollutant concentrations (e.g. work and school attendance, performance, etc.)
- Local environmental and health benefits from rooftop solar[95]
- Benefits from avoided local temperature increases due to lower GHG emissions.[96] Higher temperatures have been found to impact many outcomes including, but not limited to, agriculture, income, education, and crime.[97]

These (and other) benefits would be additional to those estimated in this study.[98]

6.6 AGGREGATE DAC RESULTS

From the perspective of lower-income communities, the most important finding of this assessment is that large-scale California vehicle electrification benefits them regardless of which patterns of adoption were analyzed. As long as the state accelerates PEV deployment, the savings from this will expand service-intensive household demand, creating jobs across the economy that are more likely to benefit lower wage, less skilled workers. It should also be emphasized that these multiplier benefits may not be directly observable as links to higher-income groups adopting efficient vehicles, yet the indirect expenditure linkages are inexorable. Of course, it would also be desirable for lower-income communities to enjoy the direct efficiency and local pollution benefits of PEVs, but these impacts are secondary to the overall job intensive stimulus resulting from expansion of a more fuel-efficient light vehicle fleet. These indirect employment gains are also far greater than direct income and job creation from the PEV sector itself.

These comparisons are summarized in Tables 13 and 14 for 2030. The level changes in Table 13 are encouraging since both categories of community benefit in every EV adoption scenario. At least as important for policy, however, are the relative impacts, which can be seen in Table 14. Noting first that DACs comprise 25 percent of California's population, the table illustrates that this group's job growth significantly exceeds this share (36%) in all scenarios. When statewide vehicle cost savings are lower (LTES), so are absolute and individual percentage income and job gains, but the composition of diverted expenditure and thus new job creation remain the same. Results for PEVs are dictated by vehicle adoption trends in LTES and Innova-

95 Some of the benefits from rooftop solar are implicitly included in our health benefits estimates insofar as rooftop solar helps reduce demand for other dirtier forms of electricity generation and therefor contributes to lower GHG emissions in the energy sector statewide. However, this process is not explicitly modeled and we cannot directly account for the location of potential solar expansion.

96 Our health benefits estimates are derived from modeled GHG reductions in the energy sector that translate to lower criteria pollutant concentrations. We do not quantify any of the many benefits that would come from avoiding higher temperatures through reduced GHG emissions.

97 Carleton, T. and S. Hsiang 2016. "Social and Economic Impacts of Climate". Science (2016) doi:10.1126.

98 For more information on non-health co-benefits from reductions in GHG emissions, including examples of studies estimating damages to each of the mentioned outcomes (and more), see Carleton and Hsiang "Social and economic impacts of climate," Science 2016.

tion scenarios. LTES reflects the highest PEV purchase price disadvantage, so highly unequal adoption that is familiar in today's market can be seen. With more optimistic (Innovation) technological progress, accelerated low income adoption can be seen as PEVs cross the cost parity threshold earlier. For the Equity scenario, it is assumed that PEV adoption rates in DACs converge to those of Non-DACs by 2030, requiring even faster acceleration of demand in DACs. In terms of averted health costs from reduced vehicular criteria pollution, DACs again enjoy relatively greater benefits that Non-DAC communities, regardless which of the three PEV adoption patterns prevails.

To summarize, for all scenarios evaluated, compared to the rest of the state's population, Disadvantaged Communities (DACs) will experience higher job growth and larger per capita economic benefits from reduced mortality and morbidity than in the Baseline case. Next, this study will take a more detailed look at the spatial characteristics of these impacts.

TABLE 13 Aggregate Economic Impacts on Households by Community Type

	SCENARIO	DAC	NONDAC	TOTAL
Jobs (,000s)	LTES	140	254	394
	Innovation	193	339	532
	Equity	192	337	530
Household Income (2016 billions)	LTES	49	262	311
	Innovation	55	296	351
	Equity	57	300	357

Source: Authors' analysis

TABLE 14 Macroeconomic Impacts of PEV Deployment in 2030

IMPACT	SCENARIO	DAC_ SHARE	NONDAC_ SHARE
Jobs	LTES	36%	64%
	Innovation	36%	64%
	Equity	36%	64%
PEVs	LTES	11%	89%
	Innovation	40%	60%
	Equity	45%	55%
Avoided Health Costs	LTES	33%	67%
	Innovation	34%	66%
	Equity	34%	66%

Source: Authors' analysis

6.7 JOB CREATION

Modeling results from this study suggest that – without exception – policies beyond the Baseline reference scenario stimulate the overall California economy, with DACs experiencing relatively greater job creation than the statewide average. More specifically, the most growth-oriented Innovation Scenario delivers the following job creation patterns:

- By 2030
  - » 192,000 more jobs would be created in DACs
  - » 337,000 more jobs would be created in non-DACs
  - » DACs (25% of state population) take 36 percent of new jobs
- By 2050
  - » 652,000 more jobs created in DACs, still 36 percent of new jobs
  - » 1.160 million more jobs created in non-DACs

The largest job creation potential is demonstrated in the Innovation Scenario, which is the focus of the remaining job creation discussion below.

6.7.1 2030 Job Creation

Job growth statewide is driven by new jobs in service industries and these sectors happen to be sectors that disproportionately employ DAC workers. However, the benefits for this job creation will be experienced unevenly across the state and regions with employees in the noted sectors will benefit most. In Los Angeles, for example, 45 percent of the population lives in DAC communities and DAC workers are 55 percent more likely to be employed in service industries, so more than half of the 161,000 forecast jobs in Los Angeles County in the Innovation Scenario are forecast to be created in DACs. Similarly, DAC workers in the Central Valley are more likely than non-DAC workers in that region to be employed in transportation and construction sectors. However, DAC and non-DAC workers are about equally as likely to be employed in Service Sectors in this region. Consequently, more than 32,000 of the 59,000 jobs created in the Central Valley in the Innovation Scenario by 2030 are forecast to be created in DACs.

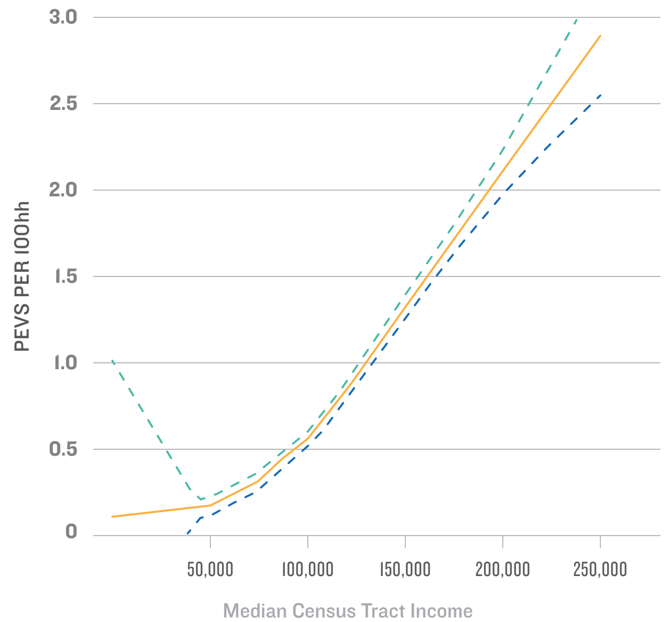
6.7.2 2050 Job Creation

Like in 2030, the Innovation Scenario has the highest job growth. Compared to Baseline growth, the Innovation Scenario gives rise to 1.812 million additional jobs across the state, with more than 36 percent generated for DAC households, due in large part to expansion of service sector demand. Both Los Angeles County (192 jobs created per DAC) and the Central Valley (216 jobs created per DAC) enjoy substantial incremental employment benefits.

6.8 ELECTRIC VEHICLE ADOPTION

Relying on data from the DMV, electric vehicle rebate programs, and official sources on household income and demographic, the study authors estimated patterns of EV adoption. The approach is consistent with recent research in that it found the most important predictor of EV adoption is income.[99] In order to model future adoption, stable demographics are assumed and predicted changes in income from the BEAR model are used. This

FIG 23 Modeling the Relationship between Census Tract Income and the Number of EVs Purchased



Source: Authors' analysis from Cal Enviroscreen 3.0 and the United States Census data[101]

approach found that for low-income households, in the absence of targeted programs,[100] additional income generated by energy policies has a negligible impact on EV adoption. For relatively wealthy households, a small but positive increase in adoption was observed in the Innovation and Equity scenarios.

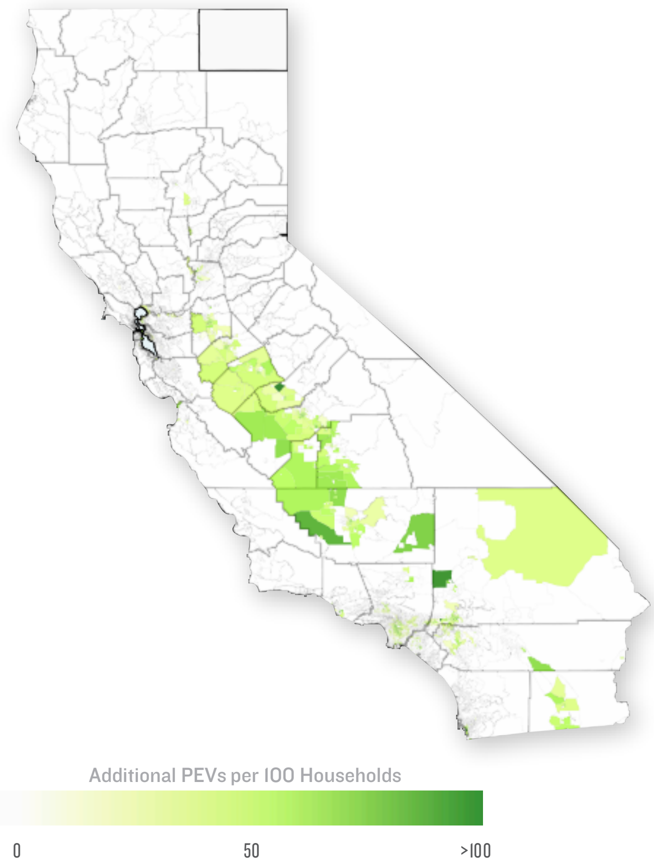
Additional income at lower levels (<~$75,000) results in little additional EV purchasing while additional income at higher median levels has a positive impact on purchasing patterns. Dotted lines in Figure 23 represent 95 percent confidence intervals.

99 California Air Resources Board (CARB), 2017b. "Factors Affecting Plug-In Electric Vehicle Sales in California", May 2017. Prepared by UCLA.

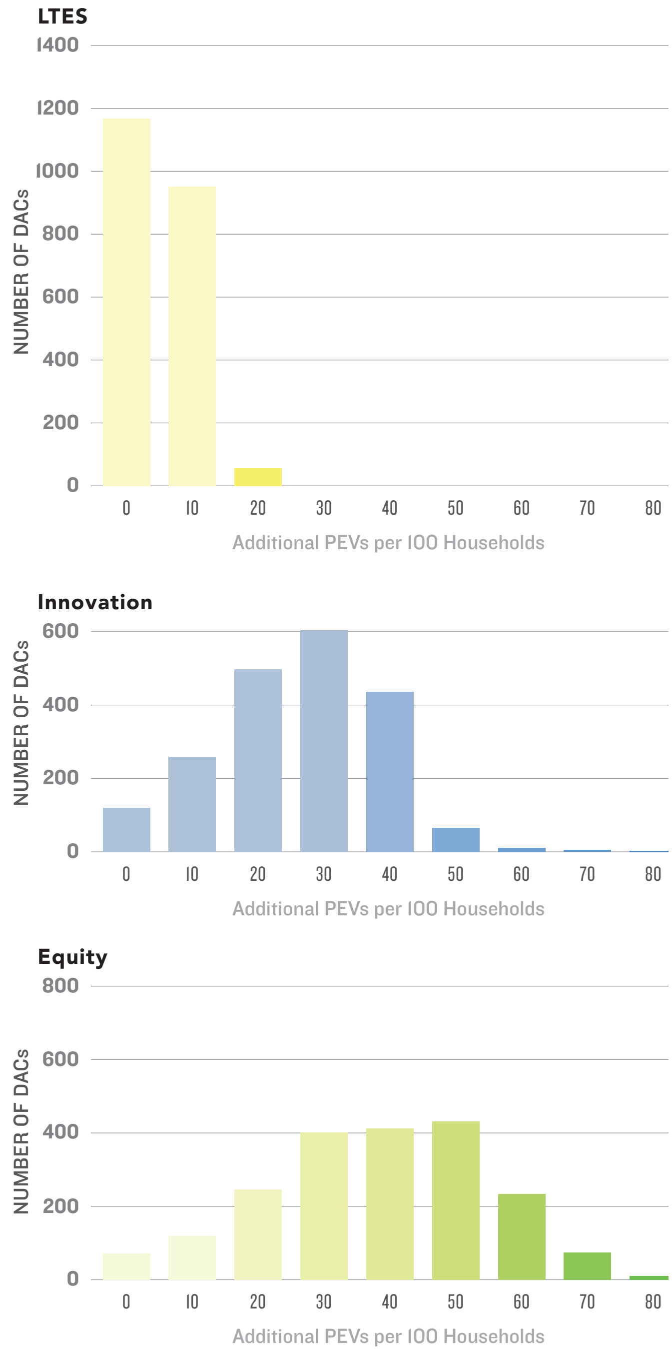
100 Governor Brown's recent mandate has called for implementation of incentives to increase the penetration of EVs in DAC areas. Because the Executive Order lacked details required to model these policies however if they are implemented then our estimates could be significantly underestimating DAC EV adoption.

101 "Exploring Economic Impacts in Long-Term California Energy Scenarios." California Energy Commission. June 2018. Available at: https://ww2.energy.ca.gov/2018publications/CEC-500-2018-013/CEC-500-2018-013.pdf

FIG 24 Modeling the Relationship between Census Tract Income and the Number of EVs Purchased



Source: Authors' Analysis

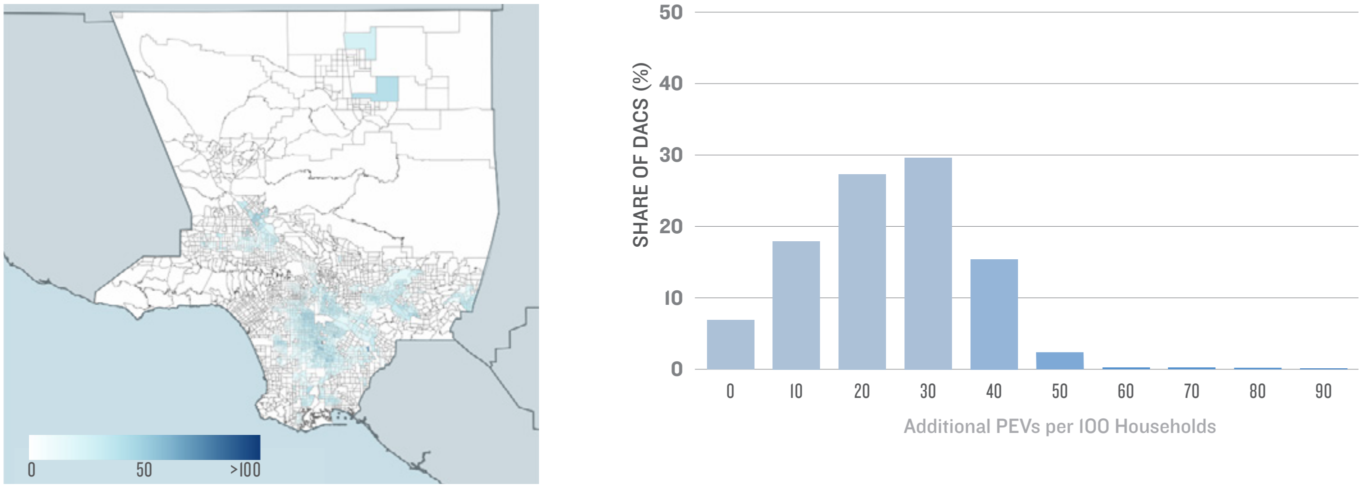


Specifically, comparing the Equity and Baseline scenarios, the authors estimate that:

- By 2030, there will be:
- 180,000 new DAC EVs (6 additional EVs per 100 DAC households)
- 1.5 million new non-DAC EVs (14 additional EVs per 100 non-DAC households)
- By 2050, there will be:
- 810,000 new EVs in DACs
- 11 million new EVs in non-DACs

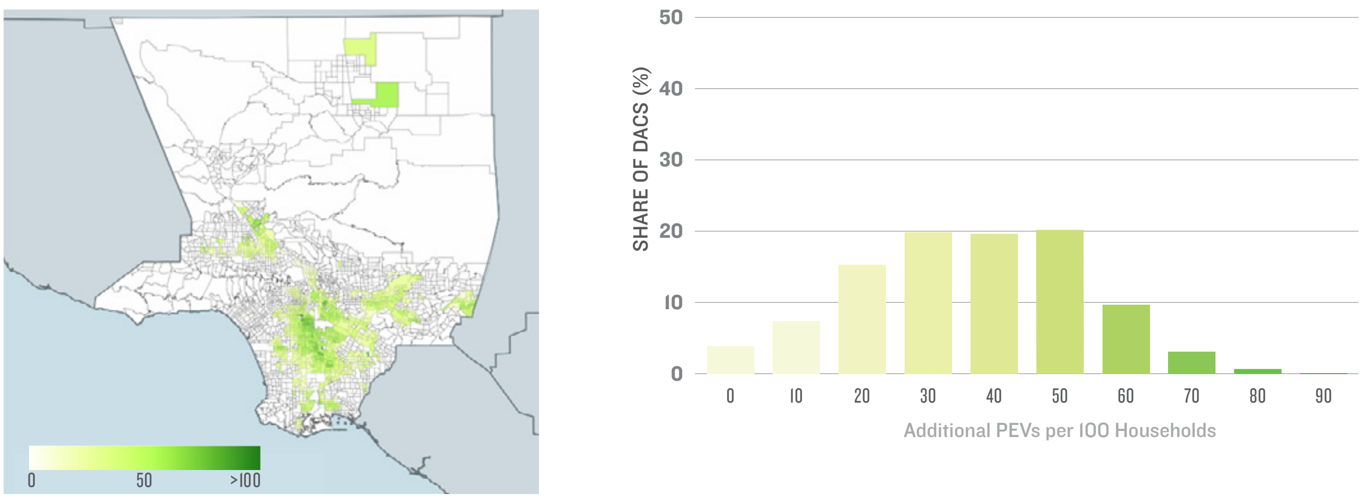
Estimates for DAC adoption patterns in 2030 are illustrated in Figure 24 for the entire state. Adoption is greatest in the Equity scenario, but this is by policy assumption. However, more optimistic vehicle technical progress (Innovation) still yields substantial incremental adoption in lower-income communities. This means incentive costs will be lower for agencies trying to promote greater PEV use.

FIG 25 PEV Adoption in Los Angeles Country DACs, Innovation Scenario, 2030, Change from Baseline Scenario



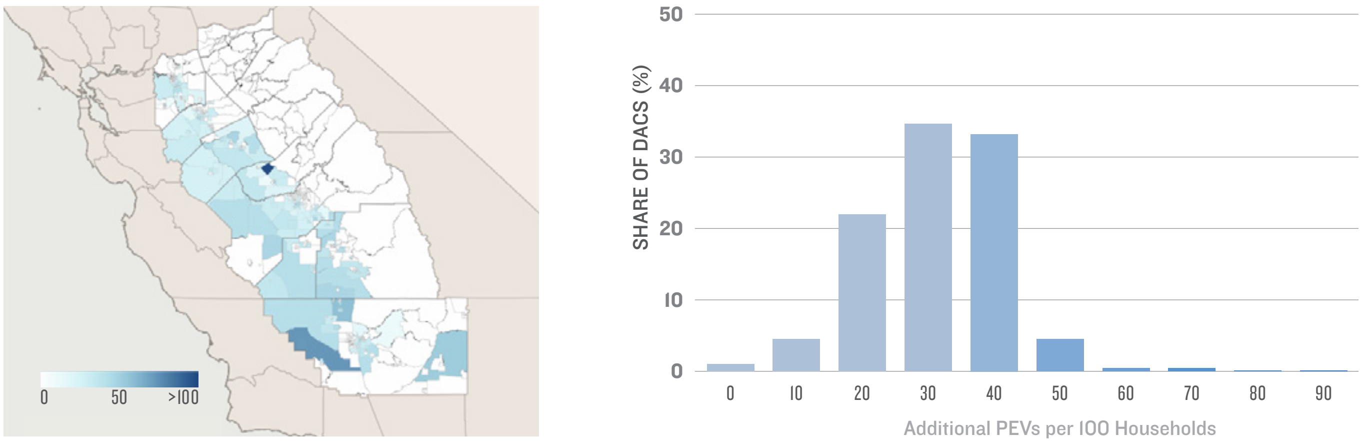
Source: Authors' analysis

FIG 26 PEV Adoption in Los Angeles Country DACs, Equity Scenario, 2030, Change in Baseline Scenario



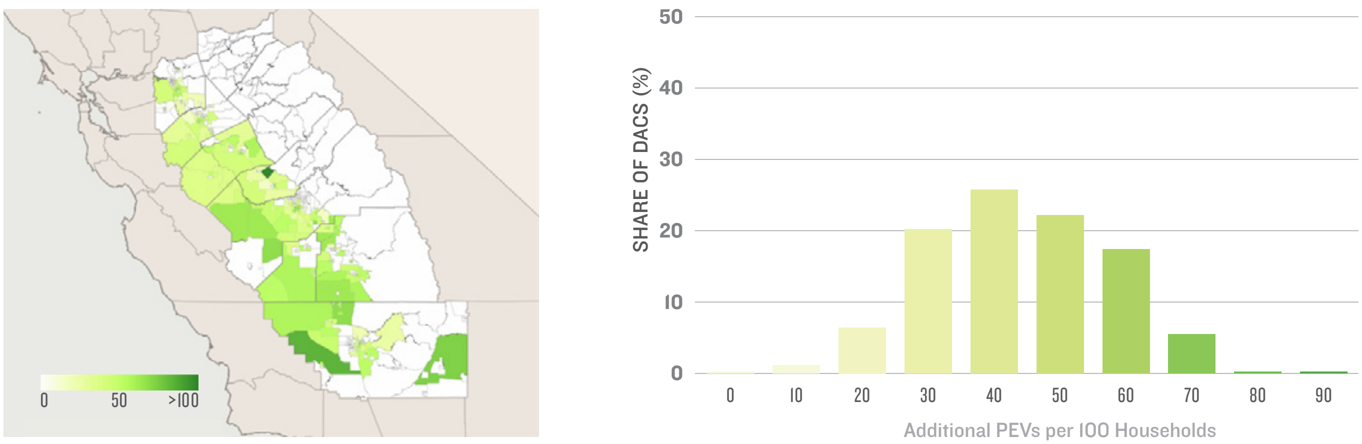
Source: Authors' analysis

FIG 27 PEV Adoption in the Central Valley DACs, Innovation, 2030, Change from Baseline Scenario



Source: Authors' analysis

FIG 28 PEV Adoption in the Central Valley DACs, Equity, 2030, Change from Baseline Scenario



Source: Authors' analysis

More detailed results (Figure 25) show that Los Angeles County achieves widespread voluntary adoption by 2030, yet this remains below the Equity objective (Figure 26).

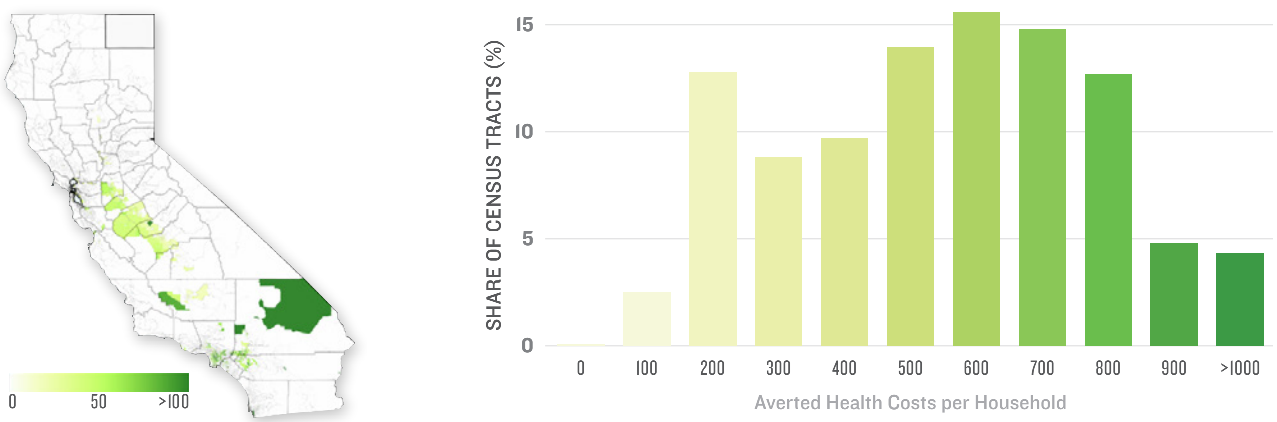
Likewise, in the Central Valley, which together with Los Angeles comprises 75 percent of DAC communities, autonomous adoption with optimistic technology Innovation yields substantial growth of PEV use, but incentives will probably still be needed to achieve the Equity Scenario.

6.9 HEALTH BENEFITS

While this analysis is exploratory in nature, these estimates are intended to provide insight on the potential order of magnitude of health benefits and it is quite clear that emissions mitigation policy will make highly valuable contributions to public health across California. Specifically, this analysis estimates for the Equity scenario that:

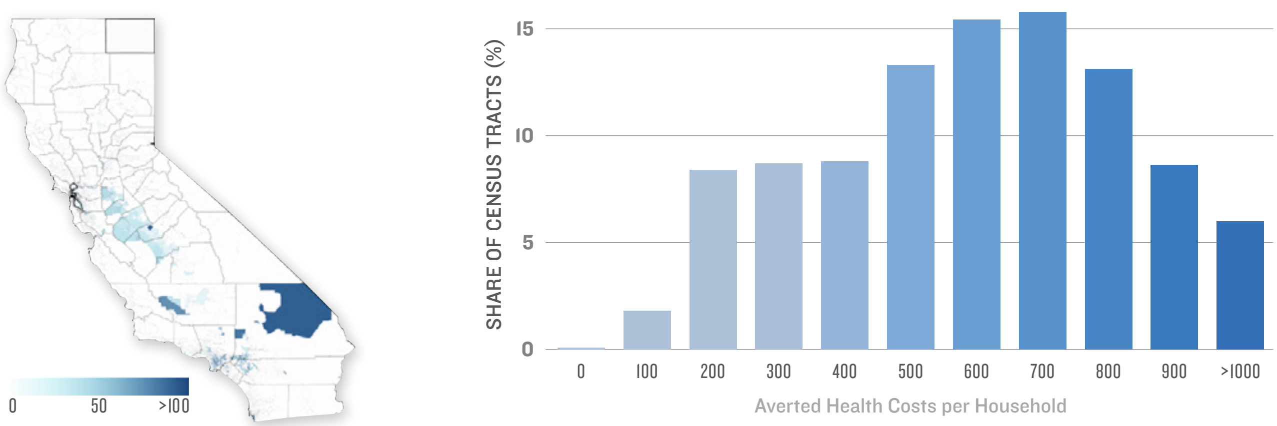
- In 2030 alone, the economic value health benefits from criteria pollution reductions in the energy and fuel sector will be $2.0 billion, of which:

FIG 29 Estimated DAC Health Cost Savings, Equity Scenario, 2030, Change from Baseline Scenario



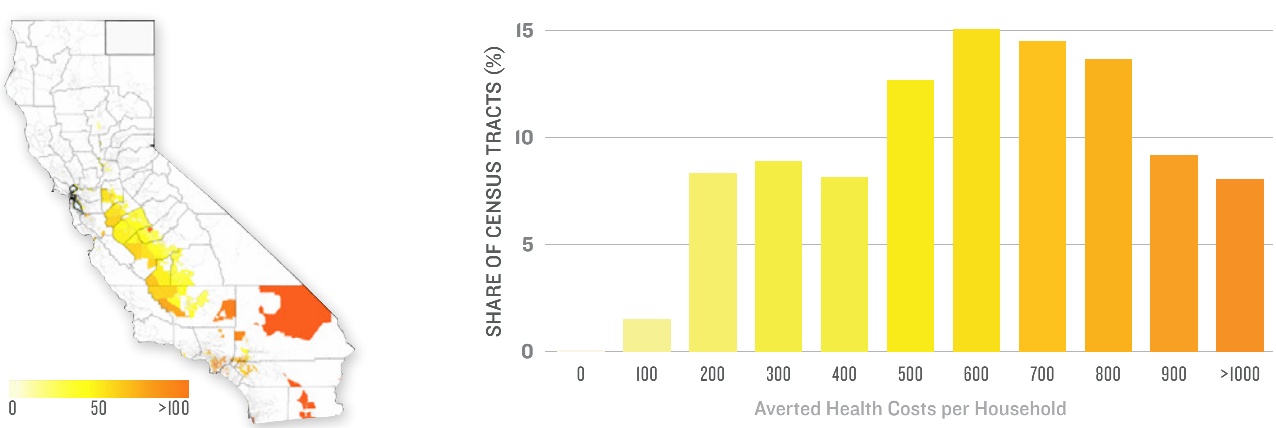
Source: Authors' analysis

FIG 30 Estimated DAC Health Cost Savings, Innovation Scenario, 2030, Change from Baseline Scenario



Source: Authors' analysis

FIG 31 Estimated DAC Health Cost Savings, LTES Scenario, 2030, Change from Baseline Scenario



Source: Authors' analysis

- » $800 million is due to averted mortality
- » $1.2 billion is due to averted medical (morbidity) costs

This study's estimates represent health benefits associated with reductions in GHG emissions in the vehicle sector alone, but do not quantify many of the other expected benefits that are known to be substantial. However, assuming uniform statewide emission reductions, these absolute benefits are higher for households in disadvantaged communities. Moreover, this analysis likely underestimates the total benefits to DACs of these policies because the potential electrification of the transportation sector cannot be fully account for, which is likely to benefit DACs because of their proximity to transportation networks.[102]

Estimates of health benefits are based on morbidity and mortality costs averted and include:

- » $581 averted per DAC household
- » $494 averted per non-DAC household

Because DAC households have lower incomes, these gains are even more dramatic in relative terms. However, more targeted policies could produce even greater gains.

By 2030, authors of this study's forecasts indicate that health benefits across DACs in California could be substantial, even in more technology-pessimistic LTES scenario (Figure 31), but they would be even greater with higher rates of PEV innovation (Figure 30) and low-income household vehicle adoption (Figure 29).

While this study examines the health benefits associated with reducing GHG emissions in California's energy sector, other potential co-benefits not estimated here include:

- » Productivity benefits from lower criteria pollutant concentrations (e.g. work and school attendance, performance, etc.)
- » Local environmental, health, and safety benefits from electrification of the vehicle fleet
- » Local environmental and health benefits from rooftop solar
- » Benefits from avoided local temperature increases due to lower GHG emissions. Higher temperatures have been found to impact many outcomes including, but not limited to, agriculture, income, education, and crime[103]

These (and other) benefits would be additional to those estimated in this study.

It should also be noted that estimates of public health benefits included in this study are not directly linked to our EV analysis, but are instead inferred from following California's aggregate trajectory for GHG reductions. In other words, the economics of PEV deployment are modeled, but do not explicitly capture spatial detail on vehicle emission reductions. Places like Los Angeles, where a significant portion of emissions come from LDVs, are more likely to benefit from new EV purchases than places like the Central Valley where HDVs are a larger contributor to emissions. For more information on transportation networks and DAC exposure to pollution see CEC's 2017 IEPR.[104]

While most of the avoided deaths are a result of reductions in PM2.5, the avoided deaths in San Bernardino DACs will also result from lower Ozone exposures. The census tracts in the dark green (15-20 lives saved per 100,000 households) are in the 93rd percentile of Ozone exposure statewide and the meteorological model from Zhang et al predicts a substantial reduction in Ozone exposure around San Bernardino.

102 Chapter 10: Climate Adaptation and Resiliency, Section 6: "Increasing Climate Resilience in Disadvantaged Communities" includes a detailed description of how DAC exposure to poor air quality correlates with proximity to transportation networks. Available at: http://www.energy.ca.gov/2017_energypolicy/

103 Carleton, T. and S. Hsiang 2016. "Social and Economic Impacts of Climate". Science (2016) doi:10.1126.

104 Chapter 10: Climate Adaptation and Resiliency, Section 6: "Increasing Climate Resilience in Disadvantaged Communities" includes a detailed description of how DAC exposure to poor air quality correlates with proximity to transportation networks. Available at: http://www.energy.ca.gov/2017_energypolicy/

6.10 CONCLUSIONS

Our DAC analysis used a combination of downscaled results from the BEAR macroeconomic model of the California economy and downscaled state-of-the-art health benefits estimates for reductions in criteria pollutants results from GHG emissions reductions. To summarize, the study found the following:

6.10.1 Job Creation

New job creation is largely in sectors and occupations that disproportionately employ people from DAC households, including construction, transportation and services. This group (25% of state population) captures 36 percent of annual new jobs by 2030 and the same share by 2050.

Construction and transportation jobs are related to direct job growth (i.e., jobs generated through new investments) while service jobs are more related to indirect job growth (coming through savings-induced spending).

6.10.2 Pollution and Health in DACS:

DAC households are currently burdened by high levels of criteria pollutant exposure (25% higher PM2.5 levels on average) and suffer from higher-than-average rates of associated diseases (55% higher asthma rates).

DACs therefore benefit disproportionately from improvements in air quality that can reduce the mortality and morbidity costs they bear (30% of avoided deaths and costs in DACs, 25% of state population).

However, these benefits among DACs are unevenly distributed across the state with DACs in Los Angeles benefitting more than DACs in the Central Valley, for example, because the sources of pollution in the Central Valley are less likely to be impacted by the policies considered here.

Transitions to a cleaner energy sector and vehicle fleet are more likely to improve air quality (and thus benefit DACs) in areas like Los Angeles than in areas in the Central Valley. This is because much of the hazardous exposure that DAC households in the Central Valley face arises from diesel emissions from farm equipment, agrochemical exposure, and other hazards that are less directly related to energy policies or vehicle emissions. That being said, reducing GHG and allied emissions in other parts of the state is still likely to contribute to better air quality in the Central Valley.

Section Seven

Conclusion

Conclusion

This study examines the economic impacts of large-scale electrification of the California light-vehicle sector, including long-term projections that would contribute to reductions of global warming pollution by 40 percent and 80 percent below 1990 levels, in 2030 and 2050, respectively. Scenarios incorporate the most up-to-date technical information on emerging vehicle technologies, as well as a variety of pathways for adoption among economically disadvantaged groups.

The results indicate that, while consistent with long-term climate goals, policies that encourage large-scale PEV deployment can also be a potent catalyst for medium and long-term economic growth, benefitting millions of Californians over the next decade and beyond. In all of the scenarios evaluated, large-scale carbon fuel savings translate into billions of dollars of new in-state consumption, income, and tax revenue, creating thousands of new jobs across the state economy. Because growth is concentrated in service sectors, lower-income workers see relatively greater opportunity for employment and livelihood improvement. The study also includes an assessment of the economic impacts of another important co-benefit—better public health via air quality improvements—and finds these benefits operate in exactly the same direction. Up to one-third of the total economic gains from decarbonizing the transportation sector and electric power supply come from increased public health benefits.

For example, electrification that reduces light-duty vehicle emissions by 40 percent below 1990 levels would increase GSP in 2030 by $82 to $142 billion, real income by $311 to $357 billion, and California state revenue by $4 to $7 billion, depending on scenario. Perhaps the most arresting feature of these numbers is how they dwarf the amounts accruing to California's cap-and-trade program, as well as the budgets thus far committed to clean vehicle incentive programs. If more vehicle electrification can deliver even a fraction of the estimated revenue for any of the alternative scenarios considered, it could be very lucrative for the state.

These economic stimulus effects point to another important policy issue for California—reliance on incentives over standards. Currently, there are persistent uncertainties regarding the state's authority to regulate vehicles and other energy use technologies. Fiscal authority is much more secure, and results suggest California could pursue economic incentives much more aggressively, reaping GHG emissions reductions and the above co-benefits on its own terms. The scope for incentive design and targeting can also be significantly expanded, including purchaser prices, financing, vehicle sharing, dealer and manufacturer incentives, charging infrastructure and component technology subsidies.

With regard to jobs, the study estimates an increase of at least 394,000 new jobs in 2030 with higher cost PEVs, and over half a million new jobs with the more recent, lower vehicle purchase and operating cost projections. Incorporating more recent vehicle cost data from ICCT's sources significantly improves the aggregate economic stimulus, and more inclusive vehicle adoption yields essentially the same overall benefit. Once again, it should be emphasized that the threefold stimulus from accelerated PEV deployment creates growth and jobs broadly across the economy, with many Californians benefitting whether they by a PEV or not.

Extending the analysis to 2050 (and an 80% emissions reduction) significantly amplifies the growth dividends associated with more energy-efficient mobility. Like interest, energy and other use savings from more efficient technologies compound over time, where the multiplier in this case is coming from expenditure diverted from (largely imported) energy fuels to in-state goods and (predominately) services. The result is that extending the scenario horizon threefold (from 10 to 30 years in the future) increases economic benefits (real GSP) by a multiple of seven to eight. Even in the relatively conservative LTES scenario, vehicle electrification increases California GSP about 5 percent by 2050, assuming the state meets its adoption goals under a relatively high-cost scenario. Incorporating the more recent vehicle cost estimates, the gains are almost twice as large.

Less obvious is the finding that accelerating PEV adoption by low-income groups has positive spillover effects for higher-income groups. Most arresting is the Equity scenario, which allocates a fixed number of vehicles preferentially to lower-income groups, delivering substantial economic benefits to them without significant offsetting declines among higher-income groups. This results from two drivers—differences in income sources and shared technology benefits. Firstly, lower-income households are more dependent on net earned income and spend a higher share of their income on essentials like energy and mobility services. Higher-income groups have more diverse income sources, including non-labor asset income (property and securities) and entitlements (dividends and pension income), and potential energy savings are a smaller share of this income. In the Equity scenario, lower-income groups benefit substantially from direct employment and greater fuel savings, while higher-income groups continue to benefit from aggregate economic growth. Also, multiplier effects are larger from low-income stimulus because these groups have lower saving rates.

Secondly, this evidence helps to dispel the notion that technology access is a zero-sum game. Even if the supply of fuel-efficient vehicles were limited, allocating some preferentially to lower-income groups can benefit the economy more than allocating them all to higher-income groups. This is because, on average, these groups are currently driving less fuel-efficient vehicles, and they are experiencing higher levels of (absolute and relative) health costs from local criteria pollution. Savings in both these categories would be greater for them, conferring greater multiplier benefits on the overall economy.

Third, and extending the previous reasoning, the entire state benefits from an expanding technology sector. Every time California establishes standards or incentives for adoption of new technology, it creates an incubator the size of the world's fifth-largest economy. Firms know that establishing marketable innovations here can prepare them for global export competitiveness. This is a central tenet of California's knowledge-intensive growth model—induced growth from technology innovation benefits the overall economy, rewarding even those people who neither develop nor adopt the new technology. For more widely-known new mobility solutions (such as autonomous navigation), California has already captured leadership. If PEV numbers continue to increase faster in this state than elsewhere, it can become a magnet for the next generation of vehicle R&D.