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Exploring Economic Impacts in Long-Term California Energy Scenarios

California Energy Commission

Edmund G. Brown Jr., Governor

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ABSTRACT

California Senate Bill 350 and Executive Order B-30-15 require the California Energy Commission to consider impacts to disadvantaged and vulnerable communities in its climate-related planning and funding. The Energy Commission is sponsoring a set of coordinated studies (EPC 14-072, EPC 14-074, and EPC 14-069, the "Long-Term Energy Scenario Project") to assess the impacts and implications of California's long term climate goals to the state's 1) energy system, including the building and transportation sectors; 2) infrastructure; and 3) economy. For analyses of impacts to disadvantaged communities, however, the models must be able to estimate impacts at very fine geographical resolution, such as the census level.

The presented computer-aided analysis conducted by Berkeley Economic Advising and Research models implications to disadvantaged communities from multiple potential energy scenarios from the present to 2050 at the required fine scale of geographic resolution. Implications include, but are not exclusive to, potential disproportional economic impacts, improved job opportunities, and probable increases in electricity rates.

Results from this research demonstrate that the benefits of lasting, committed public and private investments in a new generation of energy production and use technologies can significantly outweigh the costs. Moreover, the findings show that average economic benefits are relatively greater in disadvantaged communities than in nondisadvantaged communities from the primary job stimulus in the construction and services sectors. More dramatically, average public health benefits are greater in absolute (dollar) terms for disadvantaged communities than for nondisadvantaged communities. Overall, the results suggest that climate policy benefits are not only inclusive, but can contribute to reducing inequality.

Keywords: California economy, disadvantaged communities, energy scenarios, job growth, public health

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EXECUTIVE SUMMARY

Introduction

As part of the state's groundbreaking commitments to a lower-carbon future, the California Energy Commission sponsored a suite of coordinated studies to assess the effects of long-term climate goals on the state's energy system, including the building and transportation sectors, infrastructure, and the overall economy. This report summarizes the results of an economic assessment of California's long-term energy scenarios developed by these studies. This integrated policy framework is designed to accelerate greenhouse gas emission reductions with a combination of more renewable electric power, electrification of transportation and heating, and a wide array of technology-driven energy efficiency improvements.

Berkeley Economic Advising and Research used a dynamic forecasting model of the California economy to conduct a detailed assessment of how these low-carbon energy policies would affect incomes and employment across the state, with more focused attention to disadvantaged communities that are located in the areas throughout California suffering most from a combination of economic, health, and environmental burdens. This research yielded four general insights:

- Energy system investments are a potent catalyst for income and job growth.
- Technology adoption benefits can far exceed the associated direct costs.
- Energy savings from implementing the policies are substantial and induce broad-based job creation.
- Statewide savings from averted death and disease are comparable to the direct costs of the energy system buildout.

Project Purpose

California is reaffirming its climate commitments as more aggressive medium-term greenhouse gas reduction; now is an opportune time to evaluate the basis of evidence supporting these policies in the public interest. This research will assess long-term net benefits of California's low-carbon energy strategy and make the findings known to public and private stakeholders.

Until recently, the primary justifications for California "going it alone" on climate policy were more general, such as "it's the right thing to do" and it provides strong growth leverage to the state's dynamic technology sector. These arguments, while plausible, have been challenged by some who feel that environmental and energy policy should be identified with more local public interests. To that end, this research identifies community-level economic impacts across the state.

Project Process

On an intensive production schedule spanning only three months, the Berkeley Economic Advising and Research team updated its economic forecasting model that simulates demand, supply, and resource allocation in California and produces estimates of economic outcomes annually. Some of the options considered in this model include influences of changing regulation, capital markets, and other trading partners, while simulating price-directed interactions between firms and households in commodity and factor markets.

The team also incorporated into the model the new information from leading energy experts, including detailed and state-of-the-art energy system and economic data from the larger Electric Program Investment Charge project portfolio. This information will set a foundation for 2030 and 2050 projected outcomes for the California economy.

Project Results

Conservative estimates, based on detailed investment and technology cost analysis provided by the energy consultant, E3, indicate California's proposed energy buildout and technology adoption programs will be potent catalysts for income and job growth across the state.

In particular, lasting commitments to a new generation of lower-carbon energy infrastructure and use technology have the potential to:

- Increase California real gross state product 2 percent by 2030 and 9 percent by 2050.
- Create more than 500,000 additional full-time-equivalent jobs by 2030 and 3.3 million by 2050.

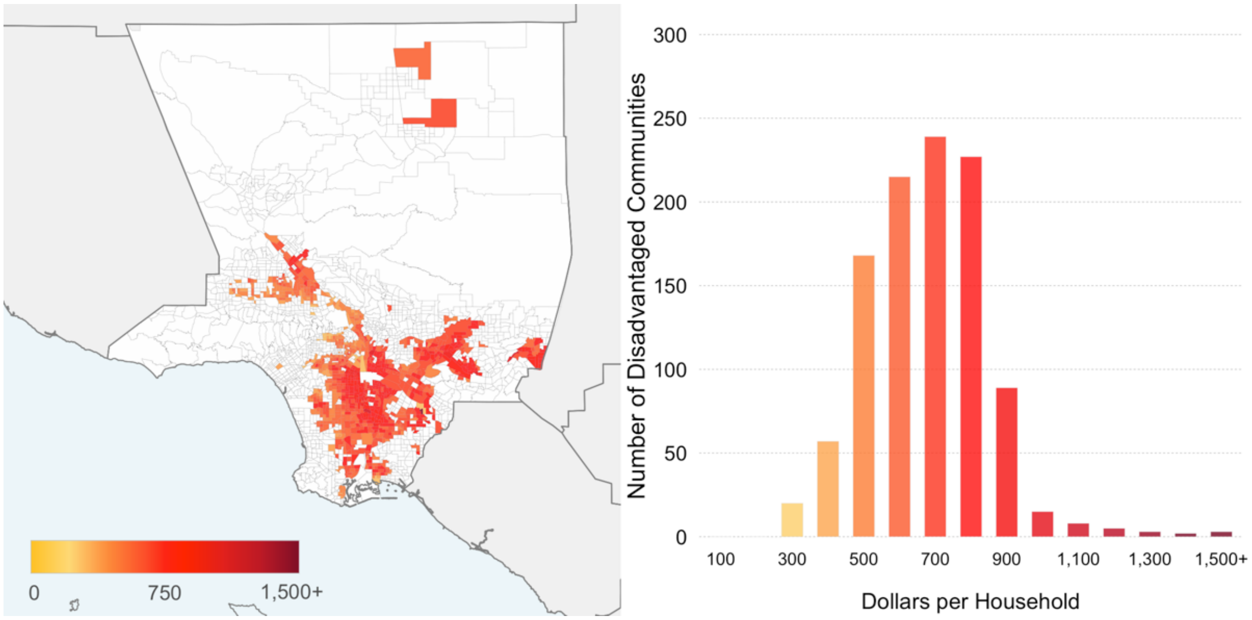
Expected additional gains from higher productivity and induced innovation will amplify these net benefits.

The team also examined two additional economic aspects of the new energy policies. Using recent evidence on links between pollution mitigation and public health, the model was able to estimate long-term economic benefits from averted deaths and medical care attributable to California climate policy. The team estimated the economic value of these health benefits is comparable to the direct costs of the entire energy system buildout. Thus, the state's climate initiative, still controversial for some, could be justified solely on public health grounds.

This research also explains economic and health impacts spatially across the state, with particular attention to disadvantaged community populations. The results forecast employment impacts across each of the state's 8,000 census tracts and 2,000 disadvantaged communities.

Disadvantaged households are disproportionately burdened by high levels of criteria pollutant (carbon monoxide, nitrogen dioxide, sulfur dioxide, ground-level ozone, particulate matter, and lead) exposure (e.g. 25 percent higher particulate matter [PM] 2.5 levels on average) and suffer from higher than average rates of associated diseases (55 percent higher asthma rates for example). The team estimated that disadvantaged communities would benefit from improvements in air quality that can reduce the costs of deaths and disease (30 percent of avoided deaths and related costs in disadvantaged communities, 25 percent of state population). For example, this analysis projects health benefits for many disadvantaged communities in Los Angeles County for 2030 would be $500 or more per household (Figure 1).

Figure 1: Medium Cost Scenario Health Benefits in 2030 for Los Angeles ($ per Household)



Source: Berkeley Economic Advising and Research

Other potential benefits to disadvantaged communities include:

- Productivity benefits from lower criteria pollutant concentrations (for example, work and school attendance, performance, and so forth).
- Local environmental, health, and safety benefits from electrification of vehicles.
- 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.

Benefits to California

This research demonstrates that the benefits of public and private investments in a new generation of energy production and use technologies can far outweigh the associated costs, such as investments in research and development. Moreover, direct and indirect net benefits are distributed extensively across the state economy and its diverse population. These results show net job creation and income growth, as well as valuable public health benefits, at all income levels and in all counties. For example, model projections predict 170,000 more jobs created in disadvantaged communities and 406,000 more jobs in nondisadvantaged communities by 2030. These numbers imply that 30 percent of new jobs will be added in disadvantaged communities, which have only 25 percent of state population. The average economic benefits are relatively greater in disadvantaged communities, because the primary job stimulus is in the construction and services sectors. In addition, average public health benefits are greater in absolute (dollar) terms for disadvantaged communities than for non-disadvantaged communities. For example, the costs of averted morbidity and mortality are projected to be $581 per disadvantaged community household, and $494 per nondisadvantaged community household. Because disadvantaged community households have lower incomes, these gains are even more dramatic in relative terms. Both results suggest that climate policy benefits are not only inclusive, but can contribute to reducing inequality.

However, these benefits among disadvantaged communities are unevenly distributed across the state, with disadvantaged communities in Los Angeles benefitting more than disadvantaged communities in the Central Valley, for example, because the sources of pollution in the Central Valley are less likely to be affected by the policies considered in this study. More targeted policies could achieve different outcomes in total benefits and associated statewide distribution. Indeed, the very heterogeneity observed in initial conditions and the long-term estimates suggest there are many opportunities for larger and more inclusive benefits. The present work is best seen as indicative. More effective policies should be supported by more intensive and extensive policy research.

CHAPTER 1: Macroeconomic Analysis

As part of its established commitments to a lower-carbon future, California is committed to an ambitious long-term program for emissions reductions. One of its most important initiatives is the Long-Term Energy Strategy (LTES) – a strategy that envisions accelerating greenhouse gas (GHG) emission reductions with a combination of expanded renewable electric power, electrification of transportation and heating, and a wide array of technology-driven energy efficiency improvements.

Berkeley Economic Advising and Research (BEAR) used a dynamic forecasting model of the California economy to assess the implications of LTES for incomes and employment across the state, with detailed attention to disadvantaged communities. Conservative estimates, based on investment and detailed technology cost analysis, indicate that California's proposed energy buildout and technology adoption programs will be potent catalysts for income and job growth across the state.

For the economy as a whole, determined commitments to a new generation of lower-carbon energy infrastructure and use technology have the potential to:

- Increase California real gross state product (GSP) 2% by 2030 and 9% by 2050.
- Create more than 500,000 additional full-time equivalent (FTE) jobs by 2030 and 3.3 million jobs by 2050.[1]

Expected additional gains from higher productivity and induced innovation will amplify these net benefits. This assessment also takes a novel approach to estimating the economic benefits these policies would have from improved public health, and these benefits alone are comparable to the direct costs of the base cost mitigation policy scenario. In other words, California's commitment to climate leadership can be justified solely by averted health and mortality costs.

The findings for disadvantaged communities are even more positive. LTES-induced job creation occurs in sectors and occupations that disproportionately employ people from disadvantaged households; these sectors include construction, transportation, and services. This group (25% of state population) captures 30% of annual new jobs by 2030 and 29% by 2050.

Disadvantaged households are burdened by high levels of criteria pollutant exposure (25% higher particulate matter [PM] 2.5 levels on average) and suffer from higher-than-average rates of associated diseases (for example, 55% higher asthma rates). Disadvantaged communities benefit more in absolute terms than others, meaning their benefits are greater in relative terms (30% of avoided deaths and costs in disadvantaged communities, 25% of state population). Disadvantaged community benefits are unevenly distributed across the state. For example, disadvantaged communities in Los Angeles benefit

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[1] FTE is equivalent to one employee working full-time in the year considered (e.g. 2030 and 2050). These FTE estimates are additional in the sense that total state employment is higher by the estimated number of (FTE) workers.

more than disadvantaged communities in the Central Valley, because the sources of pollution in the Central Valley are less likely to be affected by the policies considered in this report.

1.1 BEAR Model Description

The BEAR model is a dynamic economic forecasting model for evaluating long-term growth prospects for California (Roland-Holst, 2015). The model is an advanced policy simulation tool for demand, supply, and resource allocation across the California economy, estimating economic outcomes annually from 2015–2030. This type 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 businesses and households in commodity and factor markets. The roles of government, capital markets, and other trading partners are also included, with varying degrees of detail, to close the model and account for economywide resource allocation, production, and income determination.

BEAR is calibrated to a 2015 dataset of the California economy and includes highly disaggregated, or broken down, representations of business, household, employment, government, and trade behavior (Table 1). The 2015–2030 baseline of the model is calibrated to the California Department of Finance economic and demographic projections. That baseline is then recalibrated to incorporate the new data whenever new projections are released.

Table 1: BEAR Model 2015 - Current Structure

1.	195 production activities
2.	195 commodities (includes trade and transport margins)
3.	15 factors of production
4.	22 labor categories
5.	Capital
6.	Land
7.	Natural capital
8.	10 household types, defined by income decile
9.	Enterprises
10.	Federal government (7 fiscal accounts)
11.	State government (27 fiscal accounts)
12.	Local government (11 fiscal accounts)
13.	Consolidated capital account
14.	External trade account

Source: Berkeley Economic Advising and Research

For the LTES assessment, the BEAR model aggregated data from 60 economic sectors (Table 2). The electric power sector was disaggregated by eight generation types to be consistent with the detailed energy framework put forward by E3.

Table 2: 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	A43AirTrns	Air transportation
A14EleOth	Electric power generation- All other	A44GndTrns	Rail and pipeline transportation
A15DistElec	Electric power transmission and distribution	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
A23TxtApri	Textile and apparel manufacturing	A53BusServ	Business services
A24WoodPlp	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: Berkeley Economic Advising and Research

1.2 Scenarios

To account for uncertainty in future technology costs, E3 worked with three generic GHG mitigation scenarios, assuming conservative, high, and intermediate costs for acquisition and adoption of new energy technology. All scenarios are assumed to meet California's GHG mitigation targets of 40% reductions below 1990 levels by 2030 and 80% reductions by 2050. Proposed LTES mitigation strategies are an enhancement of preexisting state commitments to renewables, so each reference case reflects different cost assumptions. The resulting scenarios are:

- Median mitigation scenario with medium base costs (E3), Mit_Med.
- Scenario with lower assumed fossil fuel prices and higher capital financing rates, resulting in a higher cost alternative, Mit_High.

- Scenario with higher assumed fossil fuel prices and lower capital financing rates resulting in a lower cost alternative, Mit_Low.

The Reference Cases reflect pre-Senate Bill 350 (De León. Chapter 547. Statutes of 2015) policies (such as 33% RPS, historical energy efficiency goals) continued with each of the three alternative cost assumptions. The high-/low-cost scenarios reflect E3 assumptions about future fuel prices and access to capital financing.

Basic technical inputs on the energy system come from E3's PATHWAYS model. The model generates fuel and stock spending estimates for the following categories:

- Commercial Building Durable Goods
- Residential Durable Goods
- Industrial Sectors
- Transportation
- Electric Power Sector Investment is not included in E3 results but implicit in the assumption of new electric power capacity development.

Spending for commercial buildings durable goods and residential durable goods includes changes in fuel spending as fuel consumption shifts from the current electric power mix to a decarbonized electric power mix. Stock spending includes estimated net spending to replace the existing durable goods stock with more energy-efficient goods.[2] Spending types in industrial sectors include both changes in fuel and stock spending. Changes in fuel occur as different industries consume more energy from renewable sources. Changes in stock spending occur as industries switch to more energy-efficient capital goods. Transportation spending, which accounts for the largest component of the direct spending, reflects fuel spending changes as vehicles consume more electricity and less petroleum, and stock changes as the fleet turns over from internal combustion engine (ICE) vehicles to plug-in hybrid electric vehicles (PHEV) and battery-electric vehicles (BEV).

Summaries of the fuel and stock expenditures from the E3 PATHWAYS model[3] are shown in Table 3 (for 2030) and Table 4 (for 2050). Total net spending is approximately $7.9 billion in 2030 and $25.2 billion in 2050.

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[2] Residential net spending is negative because of cost improvements with respect to baseline technologies.

[3] The E3 PATHWAYS model for deep decarbonization scenarios is a tool for GHG mitigation planning that evaluates long-term GHG abatement scenarios and performs cost analysis. https://www.ethree.com/tools/pathways-model/.

Table 3: Summary of PATHWAYS Model Fuel and Stock Expenditures in 2030 ($ Billion)

	Reference			2030 Mitigation Scenario (Mit_Med)			Difference		
	Stock Costs	Fuel Costs	Total Costs	Stock Costs	Fuel Costs	Total Costs	Stock Costs	Fuel Costs	**Total Costs**
Residential Building	16.9	25.1	42	16.3	25.8	42.1	-0.6	0.7	**0.1**
Commercial Building	18.7	24.9	43.6	19.8	25.8	45.6	1.1	0.9	**2**
Transportation	95.1	47.5	142.6	100.2	40.2	140.4	5.1	-7.3	**-2.2**
Industrial	0.9	19.1	20	8.7	19.3	28	7.8	0.2	**8**
Total	**131.6**	**116.6**	**248.2**	**145**	**111.1**	**256.1**	**13.4**	**-5.5**	**7.9**

Source: Berkeley Economic Advising and Research

In addition to the direct spending on stock and fuels, the team modeled investments in new electric power generation in the state. The team used the annual incremental change in electric power generation by source generated by PATHWAYS and multiplied by the levelized capital costs for each technology. These investments require $7.1 billion and $10.3 billion in new electric power capacity investment in 2030 and 2050, respectively (Table 5). The bulk of this investment is in solar, energy storage, and wind technologies.

Table 4: Summary of PATHWAYS Model Fuel and Stock Expenditures in 2050 ($ Billion)

	Reference			2050 Mitigation Scenario (Mit_Med)			Difference		
	Stock Costs	Fuel Costs	Total Costs	Stock Costs	Fuel Costs	Total Costs	Stock Costs	Fuel Costs	**Total Costs**
Residential Building	23.5	28.0	51.5	23.3	24.8	48.1	-0.2	-3.2	**-3.4**
Commercial Building	23.9	32.7	56.5	26.7	35.1	61.8	2.8	2.4	**5.2**
Transportation	121.3	56.4	177.6	141.9	42.8	184.7	20.7	-13.6	**7.1**
Industrial	1.2	23.0	24.2	11.5	29.1	40.6	10.3	6.1	**16.4**
Total	**169.9**	**140.0**	**309.9**	**203.4**	**131.8**	**335.2**	**33.5**	**-8.3**	**25.2**

Source: Berkeley Economic Advising and Research

Table 5: Investments in Electric Power Capacity for 2030 and 2050 ($ Billion)

	2030			2050		
Generation Type	**Mit_Med**	**Reference**	**Difference**	**Mit_Med**	**Reference**	**Difference**
Geothermal	1.1	0.0	1.1	0.0	0.0	0.0
Natural Gas	0.0	0.7	-0.7	0.0	1.2	-1.2
Solar	4.9	0.0	4.9	5.0	0.5	4.5
Storage	1.4	0.0	1.4	2.3	0.0	2.3
Wind	0.3	0.0	0.3	4.7	0.0	4.7
Total Investment	**7.8**	**0.7**	**7.1**	**12.0**	**1.7**	**10.3**

Source: Berkeley Economic Advising and Research

1.3 Results

The LTES macroeconomic assessment results are presented for 2030 and 2050 as either a percentage or level difference from the baseline scenario. The baseline scenario reflects pre-SB350 policies, such as the 33% RPS and historical energy efficiency goals.

There are three fundamental drivers of the macro results: growth-positive investment stimulus, fuel efficiency benefits, and growth-negative costs of technology adoption. The complex interplay of these drivers determines the net outcome for the economy. Because these forces are countervailing, the related aggregate effect is an empirical question. The relative importance of each depends on initial conditions, policy compliance, and economic behavior.

Overall, results show that LTES would confer significant economic benefits from investment-driven direct stimulus in low-emissions technologies and indirect household real-income benefits from energy savings. These two effects combine to outweigh technology adoption and other compliance costs associated with installing new renewable electric power capacity, electrifying the vehicle fleet, and upgrading commercial and residential building appliances.

In the medium run (2030), all macroeconomic indicators show net benefits to the California economy for the median-cost and low-cost scenarios (Table 6). For example, GSP and overall employment are projected to increase by 2.1% relative to the baseline in the median-cost scenario (Mit_Med). The other macroeconomic indicators – real business output, real income, and state revenue – follow similar patterns.

The high-cost scenario in 2030 shows negative, but negligible, effects to GSP, output, and income. For this scenario, the macroeconomic effects of the higher technology adoption costs slightly outweigh the stimulus effects of the fuel savings and investment spending.

Table 6: Macroeconomic Summary in 2030

	Mit_Med	Mit_High	Mit_Low
Gross State Product	2.11% ($117.262)	-0.06% (-$3.325)	0.62% ($34.569)
Real Output	2.12% ($175.069)	-0.06% (-$5.145)	0.63% ($51.711)
Employment (,000)	2.11% (575.743)	0.01% (2.406)	0.60% (162.767)
Real Income	1.10% ($133.122)	-0.04% (-$3.722)	0.24% ($33.661)
State Revenue	2.41% ($16.488)	0.05% (-$0.542)	0.67% ($3.640)

(% and $billion difference from baseline in 2030)

Source: Berkeley Economic Advising and Research

Table 7 shows the key macroeconomic indicators for the LTES scenarios in 2050, relative to the baseline. As shown in the previous expenditure input tables, the stock and fuel expenditures are substantially higher in the long run as deep decarbonization requires substantial stock investments in transportation, industrial efficiency, and building efficiency, and continued electric power investments in solar, wind, and energy storage technologies. The economywide stimulus effects in the long run are generally about four times as large as the 2030 macroeconomic impacts. This makes intuitive sense as both direct expenditures on low-emissions technologies are higher, and there is more time for the multiplier effects from earlier expenditures to accumulate.

Table 7: Macroeconomic Summary in 2050

	Mit_Med	Mit_High	Mit_Low
Gross State Product	8.92% ($1,109.995)	2.37% ($294.886)	3.68% ($457.451)
Real Output	8.23% ($1,531.660)	1.70% ($316.714)	3.02% ($562.394)
Employment (,000)	7.32% (3,299.247)	1.78% (801.416)	2.78% (1,252.795)
Real Income	5.61% ($1,094.382)	1.86% ($310.110)	2.47% ($446.733)
State Revenue	8.13% ($127.168)	1.72% ($42.231)	2.79% ($56.046)

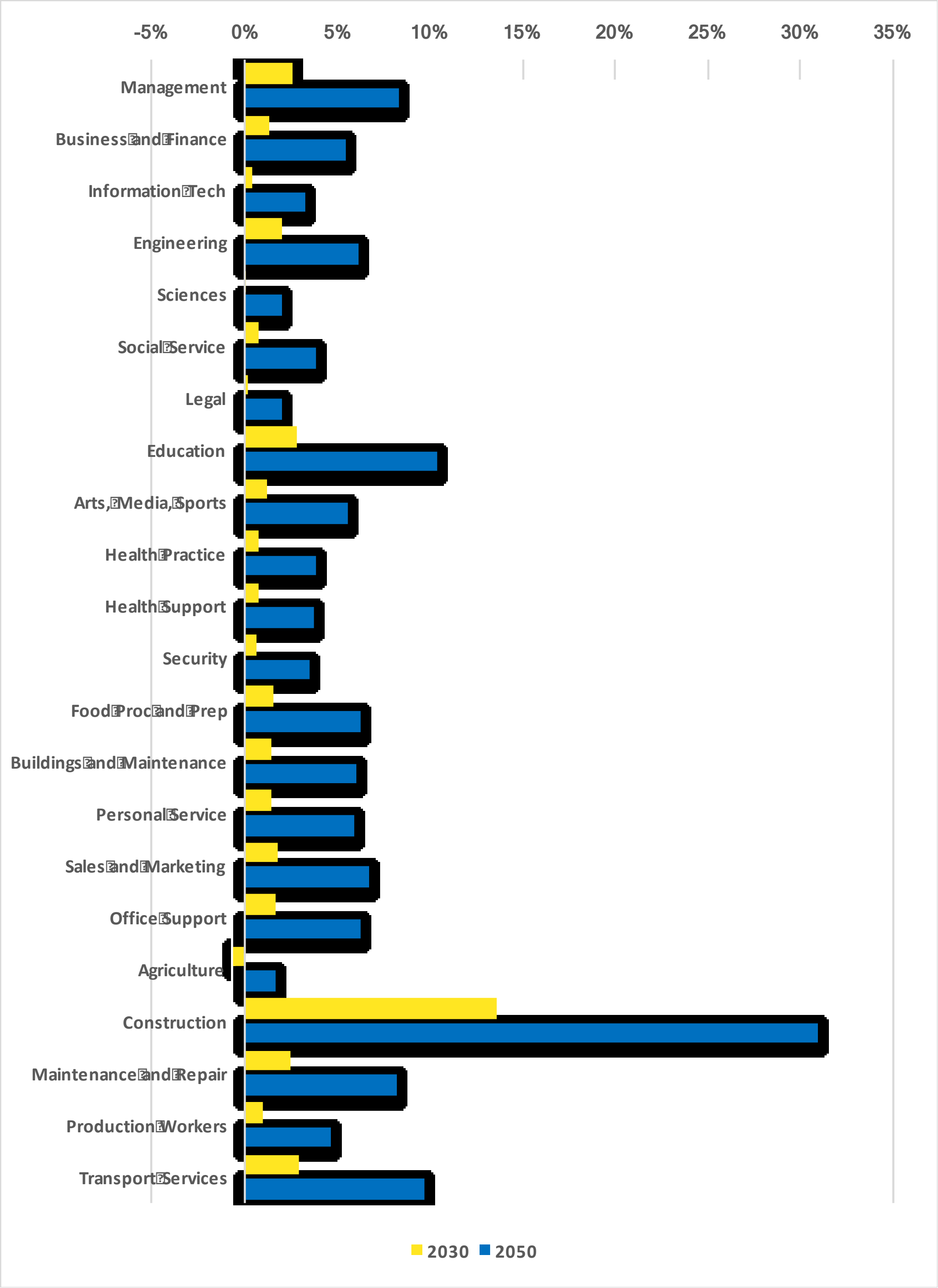
(% and $billion difference from Baseline in 2050)

Source: Berkeley Economic Advising and Research

1.3.1 Employment Impacts by Occupation

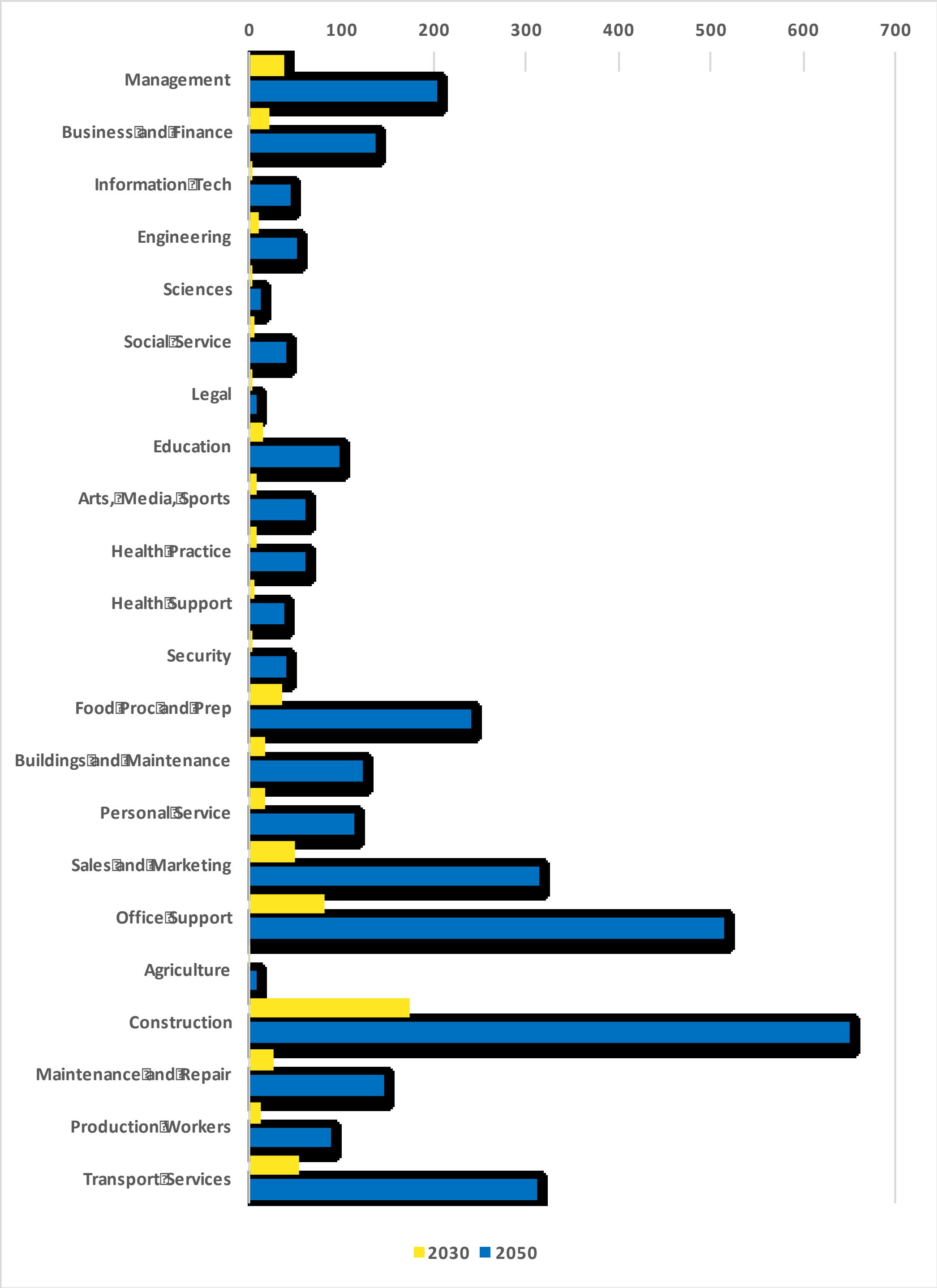
One of the salient features of the BEAR model is the ability to forecast employment effects by occupation. The employment effects (relative to the pre-SB350 baseline) are presented in Figures 2 and 3 by occupation median-cost scenario (Mit_Med). Significant gains in employment span a variety of diverse sectors, signaling the large scope of indirect and induced effects from LTES. For example, while there are large increases in employment sectors readily associated with the renewable buildout and building efficiency activities such as construction, there are also large projected increases in sectors that are less direct, such as office support, sales and marketing, and food processing and preparation.

Figure 2: Employment Impacts by Occupation
(Mit_Med Scenario, Percentage Change From Baseline)



Credit: Berkeley Economic Advising and Research

Figure 3: Employment Impacts by Occupation
(Mit_Med Scenario, 1,000 FTE Change From Baseline)

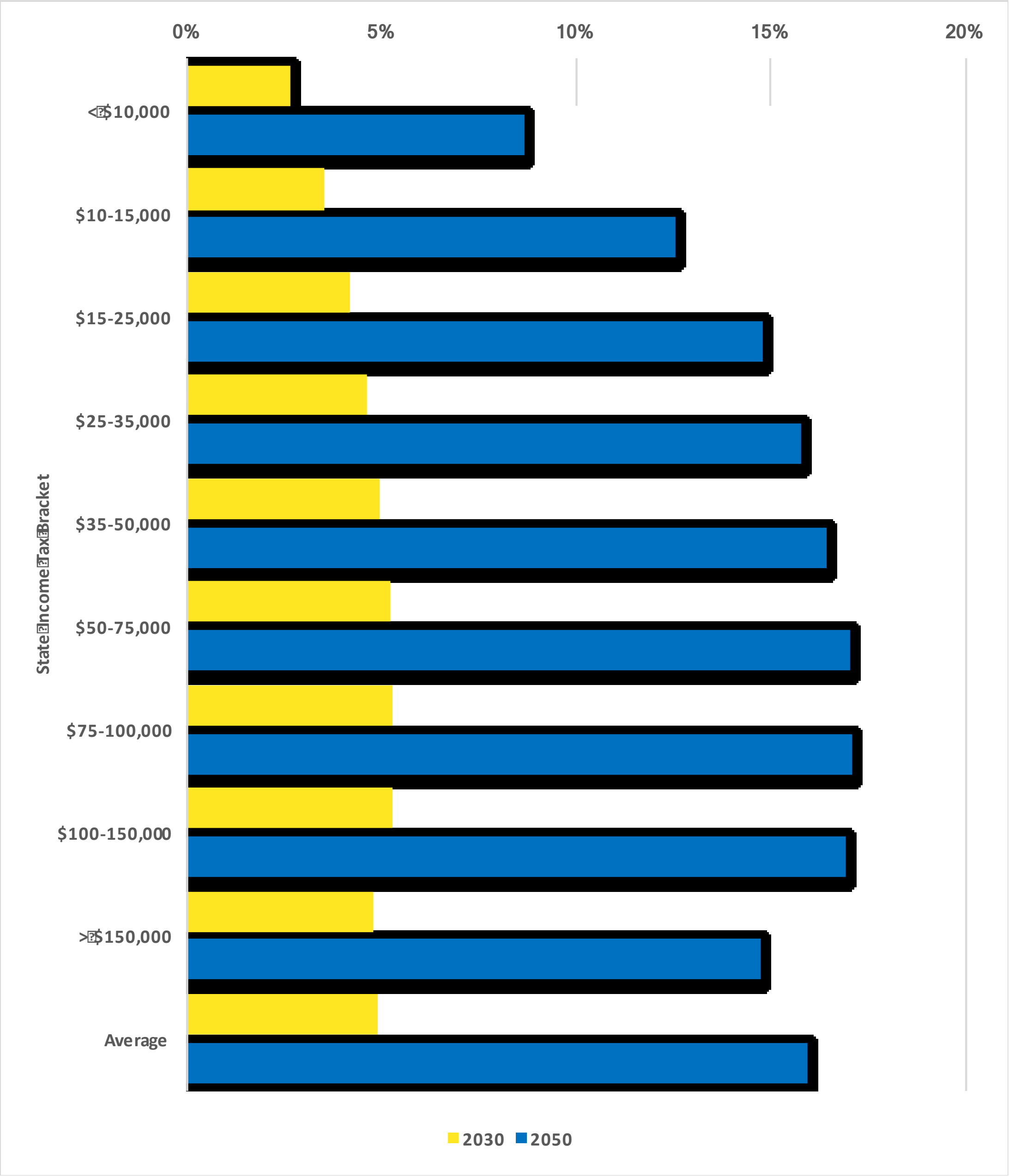


Credit: Berkeley Economic Advising and Research

1.3.2 Impacts by Income Decile

The BEAR model can forecast results across state household income tax brackets. Given that the benefits from increased expenditures on low-emissions technologies will not be uniformly distributed across the population, this feature of the model is particularly relevant. The results for income impacts by tax bracket are listed in Figure 4.

Figure 4: Household Real Income Changes by Tax Bracket (Mit_Med, Percentage Change From Baseline)



Credit: Berkeley Economic Advising and Research

The difference in statewide income across all tax brackets can be clearly seen in the changes in 2050 household real incomes that would result with full implementation of LTES with median technology cost assumptions (Mit_Med scenario). These figures, however, should not be interpreted as how much additional income each household in California will enjoy as a result of the new energy system buildout. Instead, those households that get new jobs will receive the majority of this in direct benefits, while other households will see smaller increases from indirect and induced income effects and reductions in respective energy costs.

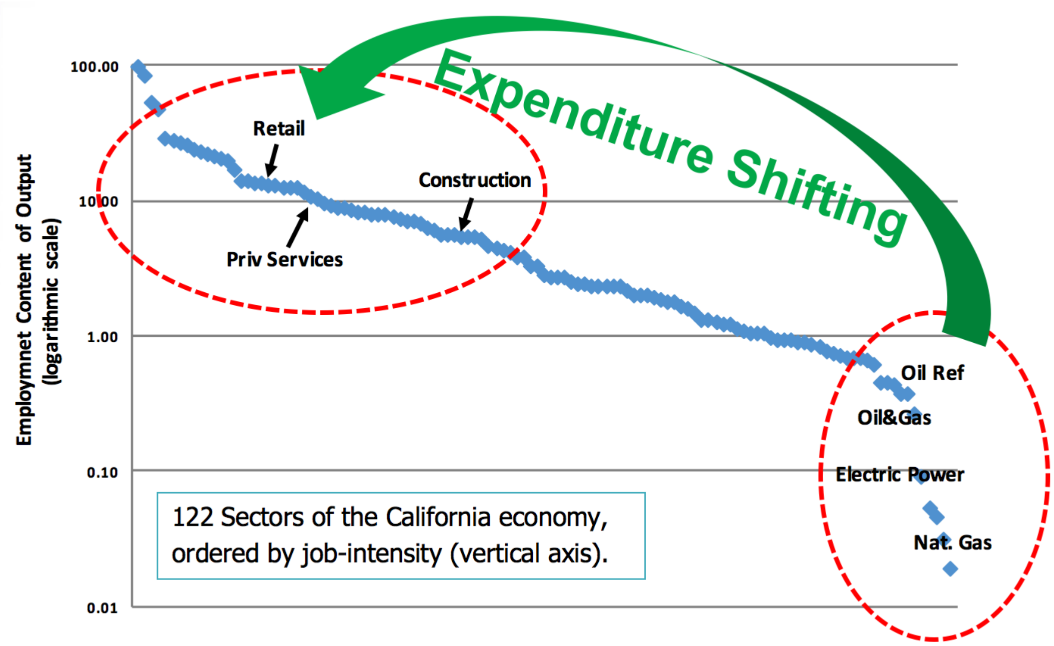
The overall income and employment benefits from properly balanced and targeted policies like Mit_Med are driven by combined investment stimulus and energy savings (growth positive) offsetting technology adoption costs (growth negative). The stimulus from investment is classical ("shovel-ready") job creation composed of direct, indirect, and induced demand for workers, resources, and capital goods. Growth stimulus from energy saving is subtler but more pervasive. Promoting energy efficiency saves money for households and enterprises. These savings will be diverted to other expenditures, most of which go to in-state services that:

- Employ workers of all skill levels and demographics.
- Are nontradable, meaning these new jobs cannot be outsourced.

To understand how potent this driver is, it helps to recall that 70% of California aggregate demand (GSP) is household consumption and 70% of that household consumption is on services. Thus, about half of incremental income or expenditure shifting from fuel savings can be expected to go to this category of employment, the most labor-intensive and skill-diverse in the economy.

As Figure 5 makes clear, the carbon fuel supply chain is among the least employment-intensive activities in the state economy, even before discounting this spending for a significant import share. Jobs per million dollars of revenue in the carbon fuel supply chain, for example, are 1% to 10% of comparable job content numbers in the service sector, differences far too large to be offset by potentially higher energy wages. 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. Moreover, most services are not tradable, so these new jobs cannot be outsourced.

Figure 5: Job Creation Through Expenditure Shifting



Credit: Berkeley Economic Advising and Research

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CHAPTER 2: Disadvantaged Community Analysis

Statewide models of the economy are useful tools for evaluating the costs and benefits of proposed policies to California. However, state-level results provide little information about how policies will affect specific communities. In particular, the distributional component of costs and benefits must be considered 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 SB 350*[4] commissioned by the California Independent System Operator (California ISO) (BEAR and Aspen 2016) and the *Economic Analysis of the 2017 Scoping Plan*[5] developed by the California Air Resources Board (CARB) (CARB 2017).

Building on previous studies listed above, this study incorporates an exploratory analysis of health benefits associated with reduced criteria pollutant concentrations, resulting from a move toward cleaner energy sources. In addition to income and employment effects, this study uses detailed vehicle registration data from the DMV with rebate data to examine adoption patterns of electric vehicles in disadvantaged and nondisadvantaged communities. Lastly, the previously used methods are updated by drawing on CalEnviroScreen 3.0 to identify disadvantaged communities (previous studies have used CalEnviroScreen 2.0, which weighted hazards differently) and by updating census tract level data from the American Community Survey (U.S. Census Bureau; ACS 2016) used to calibrate community shares. The team expects this approach will further develop the template for future analysis of environmental policy impacts on disadvantaged communities in California.[6]

2.1 Identifying Disadvantaged Communities

To identify disadvantaged communities with respect to environmental policies, the California Environmental Protection Agency (CalEPA) worked with the Office of Environmental Health Hazard Assessment (OEHHA) to develop the CalEnviroScreen (CES) tool that evaluates economic and environmental conditions of every census tract in California. The most recent version, CalEnviroScreen 3.0, was released in January 2017 and takes into account factors such as environmental conditions, health outcomes, and socioeconomic status to construct a score for each census tract. This score can then be used to identify vulnerable communities likely to be sensitive to changing policies. These disadvantaged communities are commonly defined using this tool as census tracts in the top twenty-fifth percentile of CES scores. By this definition, there are 2,022 census tracts designated as disadvantaged communities in California.

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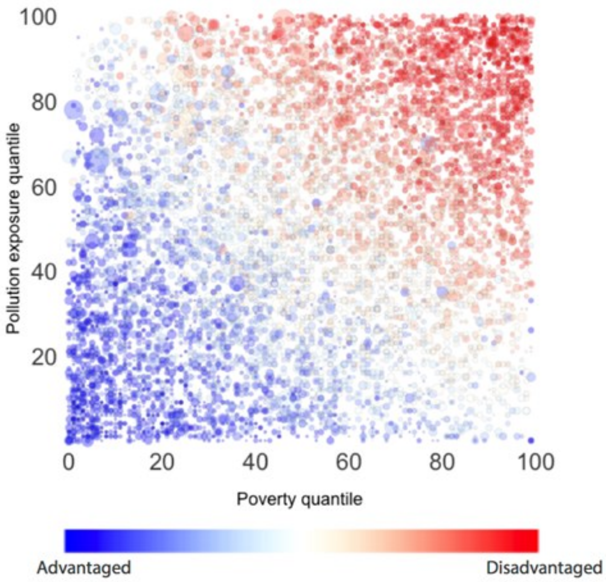
[4] http://docketpublic.energy.ca.gov/PublicDocuments/16-RGO-01/TN212468_20160726T125323_Presentation_on_SB_350_Study_72616.pdf.

[5] https://www.arb.ca.gov/cc/scopingplan/2030sp_pp_final.pdf.

[6] https://oehha.ca.gov/calenviroscreen

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 6 highlights the relationships among 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. Disadvantaged communities 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.

Figure 6: The Relationship Among Pollution Exposure, Poverty, and Disadvantaged Status



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.

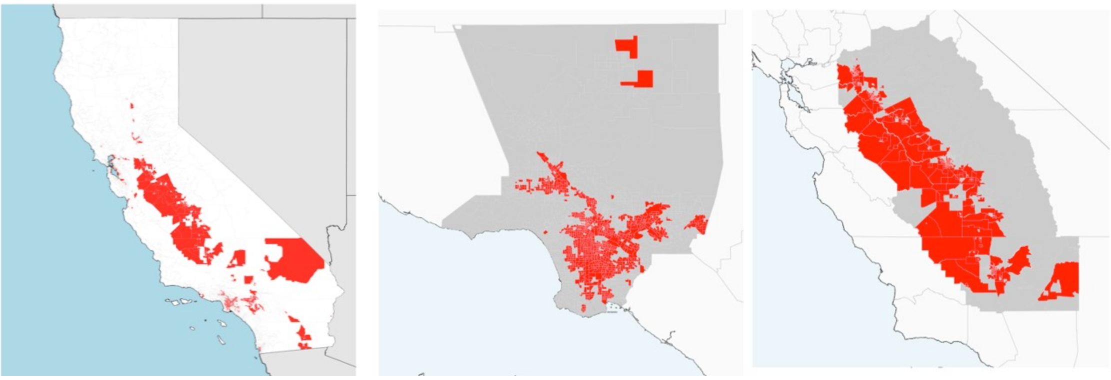
Credit: Berkeley Economic Advising and Research

2.2 Characteristics of Disadvantaged Communities

2.2.1 Spatial Distribution

The regional distribution of disadvantaged communities is apparent from Figure 7. While there are disadvantaged communities throughout the state, they are concentrated in two regions – the Central Valley and Los Angeles. In fact, nearly half of the disadvantaged communities are in Los Angeles County. These communities include 51% of disadvantaged census tracts representing 46% of the disadvantaged population. Another 20% of disadvantaged communities are in the Central Valley (21% census tracts, 23% of disadvantaged population), so collectively, these two regions contain nearly 75% 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 designate disadvantaged status for evaluating California environmental policy. The remaining disadvantaged communities are mostly spread across the state, but no regions outside Los Angeles and the Central Valley contain more than 10% of the disadvantaged communities or populations.

Figure 7: Los Angeles and the Central Valley Contain Nearly 75% of All California Disadvantaged Communities



The spatial distribution of disadvantaged communities (Disadvantaged communities) in the state (left), Los Angeles County (middle), and the Central Valley (right).

Source: Berkeley Economic Advising and Research

2.2.2 Socioeconomic Status

Naturally, disadvantaged communities are less well off than nondisadvantaged communities, and these differences show up across the spectrum, including lower earned income, lower level of education, and lower asset ownership. According to data from CalEnviroScreen 3.0 (CES), across the state, households in disadvantaged communities average 53% lower per capita income than their nondisadvantaged counterparts and are 93% more likely to live below the poverty line used for DAC classification (bottom quartile of the state income distribution).[7]

The CES data also reveal that disadvantaged community households are substantially more likely to be employed in the agricultural sector (4.3% vs 1.8%); however, this discrepancy is particularly evident in the Central Valley, where more than 15% of disadvantaged community households are in the agricultural

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[7] Source: Author's calculations combining ACS five-year average income estimates with CES 3.0 DAC designations.

sector compared to less than 7% of nondisadvantaged community households. Disadvantaged communities also have higher proportions of unskilled labor than the rest of the state, such as manufacturing (11.4% vs 9.3%), retail (12.0% vs 10.8%) and transportation (6.32% vs 4.21%).

While energy use for every census tract is not observed, the types of energy systems used for heating and cooling in the American Community Survey data (ACS; U.S. Census Bureau 2016) were observed. Nondisadvantaged communities are twice as likely to use solar energy for their heating and cooling needs, while disadvantaged communities are three times as likely not to have any heating or cooling systems in their homes.

2.2.3 Environmental Exposure

In addition to being less well off financially, by the CES definition, disadvantaged communities are also exposed to higher levels of many environmental hazards. For example, statewide emissions from diesel sources are 62% higher in disadvantaged communities (27 kilograms [kg] compared to 17 kg of emissions day) and $PM_{2.5}$ exposure from all sources is 26% higher (12.3 compared to 9.7 microgram per cubic meter ($\mu g \backslash m^3$). Pesticide use is 11% higher in disadvantaged communities (340 pounds compared to 305 pounds per square mile). In contrast, for some pollutants that are more spatially homogenous, such as ozone, there is no measurable difference in exposure between disadvantaged communities and nondisadvantaged communities.

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% more diesel emissions than their nondisadvantaged counterparts (30 compared to 20 kg/day). Similarly, pesticide application is higher for both groups in the Central Valley; however, disadvantaged populations are in areas with 70% higher rates of pesticide application (845 pounds compared to 498 pounds per square mile).

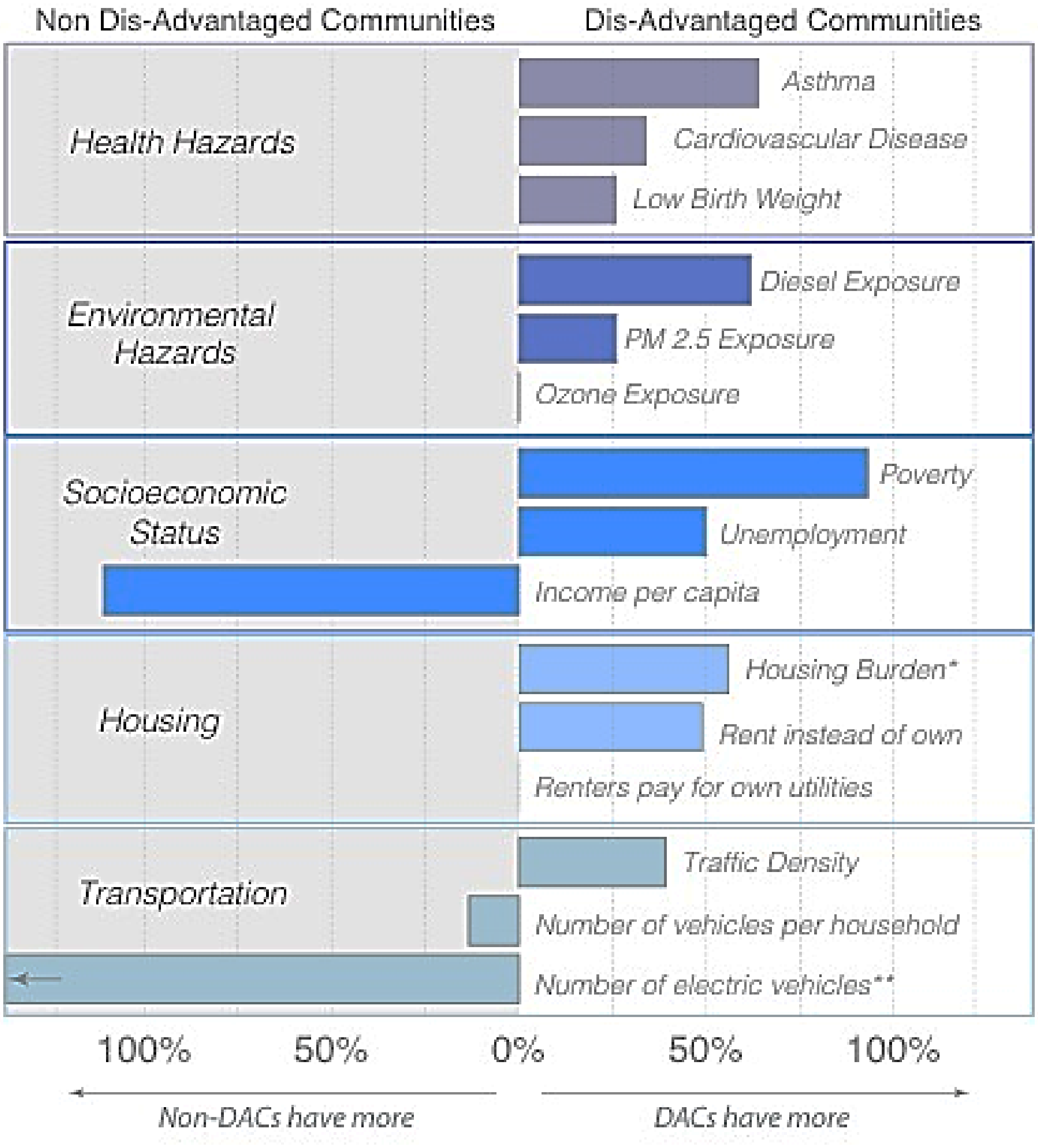
2.2.4 Health Burden

The high health and overall economic costs of exposure to these hazards is well established (Gibson et al 2017; Saari et al 2015; Thompson et al 2014). Benefits from reducing harmful exposures therefore stand to be significant, particularly for communities exposed to dangerously high levels. Moreover, since disadvantaged communities 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 (Figure 8).

The combination of fewer resources to promote 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, according to CES California households in disadvantaged communities are 64% more likely to have visited an emergency room for asthma-related problems (74 compared to 45 visits per 10,000 people) and 34% 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% more likely to have low birth weights. None of these differences can be directly attributed to higher exposure to hazardous environmental conditions. Nonetheless, the higher rates of disease, particularly asthma, indicate that improvements in air quality are likely to be particularly beneficial to disadvantaged communities.

The source of pollution exposure in disadvantaged communities vary geographically. In places like the Central Valley, much of the poor air quality is due to diesel exhaust from farm equipment and emissions from heavy-duty vehicles (HDV), whereas in Los Angeles, light-duty vehicles (LDV) are a primary contributor. Disadvantaged communities in different regions are therefore likely to benefit more from different policies.

Figure 8: Comparison Between Disadvantaged and Nondisadvantaged Communities



*** A household has a "housing burden" if its members pay more than 50% of their income for housing**

**** Nondisadvantaged communities own more than 1,100% as many electric vehicles as DAC households**

***** The source of pollution exposure and local geographic features (e.g., Central Valley is in a "closed air basin" with high pollutant residence times) in disadvantaged communities vary greatly. In places like the Central Valley, much of the poor air quality is due to diesel exhaust from farm equipment and emissions from heavy-duty vehicles (HDV), whereas in Los Angeles, light-duty vehicles (LDV) are a primary contributor. Disadvantaged communities in different regions are, therefore, likely to benefit more from different policies.**

Source: Berkeley Economic Advising and Research

CHAPTER 3: Methods

Directly modeling the economic effect of statewide policies at the disadvantaged communities level using the BEAR model would require complete data on economic activities for every census tract in California. Since these data do not exist, the team used statewide effects broken down by census tract and then highlighted those effects in the census tracts designated as disadvantaged. Disaggregating statewide results to the census tract level is different for each outcome, and these processes are detailed below.

3.1 Downscaling BEAR Model Employment Results

The BEAR model produces job impact estimates measured as total jobs by sector and by occupation. Job impacts are downscaled from the state to the census tract using occupational and sector employment information in the American Communities Survey (ACS). The model uses ACS five-year estimates (2011-2015) of the share of number of households with residents employed in each sector and each occupation. The team relied 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.

3.1.1 Caveats

There is not enough information to predict the location of new jobs, so it was assumed that future jobs are created in the locations where current jobs exist. Therefore, the team assumed future jobs, within a given sector and occupation, are spatially distributed uniformly across the locations of current workers. Relying on this assumption, total job changes at the state level can be allocated evenly to households within that sector and occupation. For example, construction jobs in 2030 are assumed 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 the macro estimates but would not be assigned to the correct census tracts.

3.2 Clean Energy Vehicle Analysis

To downscale the effects of clean-vehicle use to the census tract level, the team used vehicle registration data provided by the California Department of Motor Vehicles (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. It includes data on all PEV rebate claims in California at the census-tract 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, nearly 75% of eligible PEV purchases received CVRP rebates. Using this information on the location of clean vehicles in conjunction with DMV vehicle registration data allowed the team to model EV adoption and to downscale E3's statewide electric vehicle projections to examine the effects on disadvantaged communities. More than 93% of clean energy vehicles in California are owned by households in nondisadvantaged communities.

These data are then used with income data and detailed demographic information to model EV purchases. The BEAR model then uses estimates of income to predict purchasing patterns under different scenarios (holding demographic characteristics fixed). The BEAR model produces statewide estimates for changes in income by tax bracket. To examine the distributional effect of these changes on disadvantaged communities, the team relied on the ACS and constructed census-tract-level shares of households in each tax bracket using the five-year averages covering 2011-2015. The census-tract-level shares of households in each tax bracket were then disaggregated throughout the state proportionally to the number of households in each tax bracket. This approach assumes that, for each tax bracket, income effects are distributed evenly throughout the state across households within the tax bracket. Local factors are, of course, important determinants of how policies affect 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 affect the populations within that bracket so the statewide disadvantaged community vs. nondisadvantaged community comparisons are a reasonable best estimate.

The income estimates from the model represent total income, and the census-tract-level results are presented as community income per household in 2030. To estimate community income per household, the *number of households* must first be estimated in each census tract in 2030. To do so, the California Department of Finance estimates of population growth by county were used. It is assumed that population growth within counties is constant across census tracts and that household size remains constant, so population growth is equivalent to growth in households. Relying on these assumptions, household growth rates can be calculated for each census tract and applied to the current number of households 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.

The team used these predicted income changes to model EV purchasing patterns, then used these patterns to downscale the state-level electric vehicle forecasts generated by E3.

3.2.1 Caveats

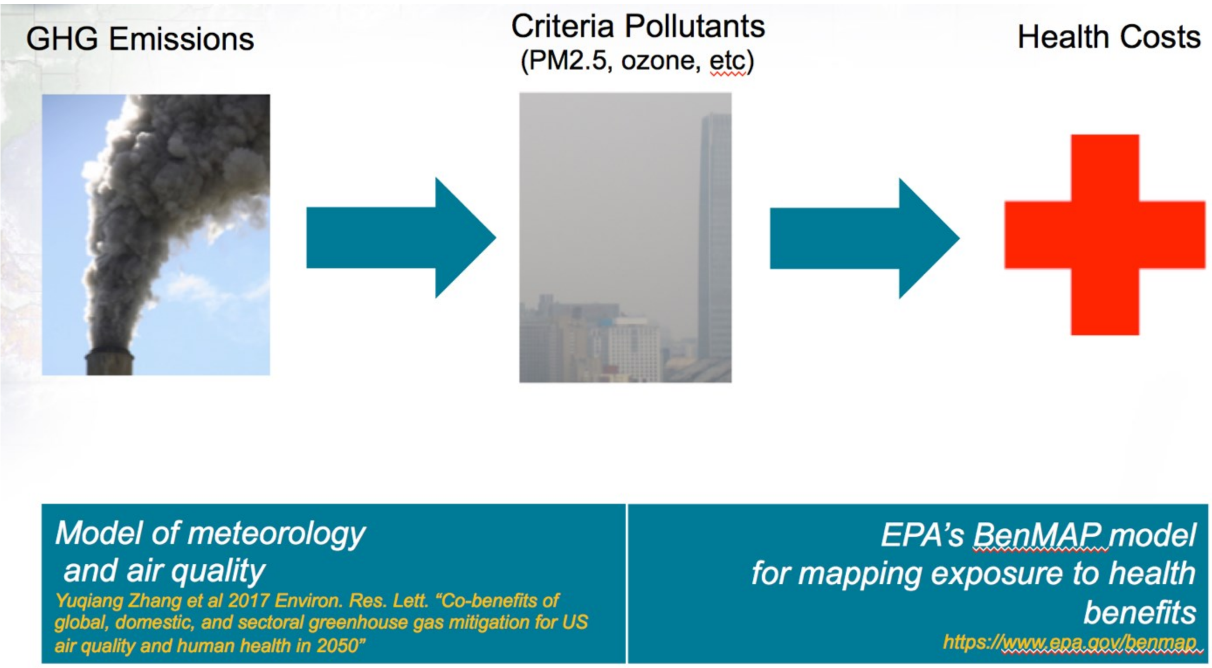
This approach allows purchasing patterns to vary by income; however, it is assumed that household demographics are constant between now and the modeled years. While demographics play an important role in predicting EV purchasing patterns and they are controlled in the model by isolating income, recent research has found that income is by far the most important predictor of EV purchases (CARB 2017b). At lower-level incomes, additional income has an insignificant effect on the number of EVs purchased; however, at relatively high levels of income, income increases do not significantly affect the number of EVs purchased significantly.

3.3 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 benefit of reductions in GHG emissions and commensurate improvements in air quality (Figure 9). Moreover, the magnitude of benefits are expected to be large and likely to be realized in the near term.[8] As part of the medium- and longer-term economic assessment of the state's future energy system, an exploratory analysis to quantify the value health benefits (such as avoided health costs) associated with a reduction in GHG emissions from LTES policies was done in four sequential steps.

Figure 9: Overview of Health Benefits Analysis



Source: Berkeley Economic Advising and Research

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[8] Recent work by Shindell et al estimates that lower emissions associated with global carbon dioxide (CO2) reductions of 180 GtC (to get to 2 degrees C warming) would lead to 153 million fewer deaths by 2100, with 40% of benefit realized by 2050.

3.3.1 Step 1: Estimating How Reductions in GHG Emissions Reduce Concentrations of Criteria Pollutants

Air quality is negatively correlated with GHG emissions, and criteria pollutants (for example. $PM_{2.5}$ and ozone) have been linked to harmful effects on human health. However, the relationship between reduced GHG and criteria emissions is not 1:1 (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 the important first step to estimating health benefits. Until recently, this relationship has not been well understood; however, new research has shed important light on these links.

The team was not able to directly model how reductions in GHG emissions from LTES policies will specifically translate into lower criteria pollutant concentrations since it requires an intensive modeling effort by physicists and environmental scientists and is beyond the scope of the current project. Fortunately, the team was able to leverage recent work by Zhang et al 2017 on the link between GHG emissions in the energy sector and mortality risk in the United States. The Zhang model evaluates the representative concentration pathways (RCP) 4.5 energy scenario[9] (see Thomson et al 2011 for details), a generic suite of cost-minimizing policies that reduce GHG emissions in the national energy sector by a given amount. These emissions reductions come from changes in electric power generation and energy extraction and transformation and are modeled to the year 2050.[10] The team then adjusted the estimates to more closely reflect potential emissions reductions from LTES 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 shared their data with the research team, including roughly 50 km x 50 km gridded estimates of reductions in $PM_{2.5}$ and ozone, so these values are scaled to be half of the associated 2050 reductions.

3.3.2 Step 2: Estimating the Effects of Lower Criteria Pollutant Concentrations on Avoided Premature Deaths

The Zhang et al data includes 50 x 50 kilometers (km) gridded estimates for the number of avoided premature deaths from avoided $PM_{2.5}$ exposure and the number of avoided premature deaths from avoided ozone exposure. The avoided premature deaths estimates were derived from the United States Environmental Protection Agency's (USEPA) BenMAP model. This publicly available model takes as inputs criteria pollution concentrations and outputs mortality risk estimates so it can be used to input the predicted reductions in $PM_{2.5}$ and ozone concentrations and output estimates for reductions in premature deaths (BenMAP 2017).

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[9] The RCP 4.5 scenario is a midrange scenario associated with about 1.4 degrees C warming by 2050. Benefits would be larger if the counterfactual scenario is more extreme. For example, a recent study (Zapata et al 2017) examining the avoided deaths associated with emission reductions relative to the more extreme RCP 8.5 scenario (~2 degrees C warming by 2050) estimated annual benefits by 2050 of $11 billion to $20 billion from mortality alone (i.e., not including benefits from avoided morbidity).

[10] The energy sector in the model used by Zhang et al includes not only electric power generation, but also energy extraction and transformation. Given that California's electric power generation is already relatively clean, some of the benefits captured will inevitably be due to emissions reductions associated with activities other than power generation. The California Energy Commission is also supporting more detailed assessments of California's energy sector that are underway.

3.3.3 Step 3: Valuing Mortality and Morbidity

The standard approach for valuing the cost of an avoided premature death is to use the Value of a Statistical Life (VSL). The team used the U.S. EPA's $7.6 million for the VSL, which also represents a de facto consensus from legal actuaries in California. This value does not mean that the U.S. EPA places a dollar value on a life. 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 the value of avoided death.[11]

Multiplying the number of avoided premature deaths by the U.S. EPA's VSL provides an estimate of the value of avoided premature 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 (such as. asthma), which for Organization for Economic Co-operation and Development populations is normally estimated to be larger than mortality costs. This estimate, however, is still conservative because it does not value nonmedical costs like absenteeism, reduced effort, productivity, and so forth.

Directly estimating morbidity costs would require extensive information on health costs incurred by cause, again outside this study and, in many cases, unavailable. The team relied on the U.S. EPA's regulatory assessment for the Review of the Particulate Matter National Ambient Air Quality Standards (NAAQS) for the ratio of total health costs (mortality + morbidity) to mortality costs alone. In this regulatory assessment, the U.S. EPA estimated morbidity benefits to be 2.7 times larger than mortality benefits. These benefits estimates were scaled by a factor of 2.7, estimating the value of total health benefits in California associated with the volume of reductions in GHG emissions forecast from LTES policies in 2030.

3.3.4 Step 4: Spatially Disaggregated (Disadvantaged Community Level) Estimate

Because the data provided by Zhang et al are on a ~50 km x 50 km grid, the avoided premature deaths could be matched to individual communities and U.S. census tracts (the geographic basis for DAC definition). This was 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 premature 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 disadvantaged communities by CalEnviroScreen 3.0 are identified, and the disadvantaged community and regional totals are estimated for the health benefits.

3.3.5 Caveats

This study uses nationally modeled 50 km x 50 km gridded health benefits estimates from GHG emissions reductions in the energy sector and is intended to illustrate the potential magnitude of health benefits.

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[11] https://www.epa.gov/environmental-economics/mortality-risk-valuation.

However, studies devoted specifically to analyzing California policies at the local level are required to illuminate highly localized effects. The California Energy Commission is supporting several ongoing studies examining precisely these issues.

Another main caveat is detailed GHG reductions from LTES policies were not modeled. Benefits are modeled from GHG reductions from transformations in the energy sector, including national changes in electric power generation and energy extraction and transformation. This means that some of the benefits will come from reductions in emissions in areas other than power generation. Moreover, national emissions reductions are modeled, so these benefits estimates incorporate emissions reductions in neighboring states.[12] These emissions are scaled proportionately to expected emissions reductions from LTES policies and assume that the spatial patterns of criteria pollutant reduction from changes in power generation and extraction are the same as the spatial patterns of criteria pollutant reductions from LTES policies. The benefits are underestimated in places where LTES policies will reduce criteria pollutants in ways other than through electricity generation. For example, this analysis does not consider GHG emissions reductions from the transportation sector, which are likely to be extremely important to health benefits in California. However, the total GHG emissions reductions in the 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 premature deaths at the state level make up 40% of the total observed benefits at the national level. This assumption is based on previous work by the U.S. EPA and takes averages from estimates in the U.S. EPA regulatory assessment for the National Ambient Air Quality Standards. However, U.S. EPA estimates of morbidity costs in this study range widely, and while this study uses the average, other estimates within the confidence interval would result in some variation of total avoided health cost estimates.

Additional assumptions include the following:

- The Value of a Statistical Life is $7.6 million.
- BenMAP, a national assessment tool, appropriately estimates the number of avoided deaths from reductions in criteria pollutants.[13]
- Total number of avoided deaths in a 50 x 50 km area will be realized proportionately to population within that area.

Lastly, the team assumed that, because most of the LTES policies affect dispersed pollutants, mitigation is achieved uniformly across the state. Criteria pollutants can be more localized, but data are lacking on how LTES will affect these patterns. This means these benefits could be overestimated in some areas where higher concentrations persist and that more targeted policies could achieve even larger benefits.

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[12] Zhang et al also estimate air quality changes associated with global emissions reductions. However, estimates of air quality changes associated with domestic emissions reductions are used only, so these estimates do not incorporate benefits from emissions reductions in Mexico or Asia, which are expected to be substantial for Californians.

[13] See https://www.epa.gov/benmap/how-benmap-ce-estimates-health-and-economic-effects-air-pollution for more details.

In addition to these caveats, this study does not cover all potential cobenefits 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 (for example, work and school attendance, performance, and so forth).
- Local environmental and health benefits from rooftop solar.[14]
- Benefits from avoided local temperature increases due to lower GHG emissions.[15] Higher temperatures have been found to impact many outcomes including, but not limited to, agriculture, income, education, and crime (Carleton and Hsiang 2016).

These (and other) benefits would be additional to those estimated in this study.[16]

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

[15] The health benefits estimates of this study are derived from modeled GHG reductions in the energy sector that translate to lower criteria pollutant concentrations. The many benefits that would come from avoiding higher temperatures through reduced GHG emissions are not quantified.

[16] For more information on nonhealth cobenefits 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.

CHAPTER 4: Results

If the recommended medium-term policies, present - 2030 are implemented, disadvantaged communities will experience:

- Higher job growth.
- Proportionately greater income growth.
- Larger per-capita benefits from reduced mortality and morbidity compared to the rest of the state's population.

Higher job growth in disadvantaged communities is largely because the sectors where disadvantaged community employees work (construction, transportation, and services) are the sectors with the most jobs generated. Proportionately greater income growth is due, in part, to disadvantaged community incomes that are lower to begin with, so even small increases in income from these policies can be significant. Disproportionate health benefits in disadvantaged communities occur because disadvantaged communities are exposed to higher pollution levels and have higher rates of health problems, so improvements in air quality have larger impacts.

The following sections describe the research results as they relate to job creation, electric vehicle adoption, and health benefits from lower criteria pollutants. Associated figures showing the described results are listed in the appendix.

4.1 Job Creation

The model results suggest that base cost policies stimulate the overall California economy, but disadvantaged communities experience relatively greater job creation (measured as total FTE annual employment in their community). More specifically, by 2030:

- 170,000 more jobs will be created in disadvantaged communities.
- 406,000 more jobs will be created in nondisadvantaged communities.
- 30% of new jobs will be in disadvantaged communities (25% of state population).

And by 2050:

- 964,000 more jobs will be created in disadvantaged communities, 29% of new jobs.
- 2.4 million more jobs will be created in nondisadvantaged communities.

4.1.1 Job Creation by 2030

Job growth statewide is driven by new jobs in construction, transportation, and service industries, and these sectors disproportionately employ workers from disadvantaged communities. The benefits for this job creation, however, will be experienced unevenly across the state, and regions with employees in the noted sectors will benefit most. In Los Angeles, for example, 45% of the population lives in a disadvantaged community, and workers from those communities are 55% more likely to be employed in service industries and 60% more likely to be employed in construction industries, making more than half of the 161,000 forecast jobs in Los Angeles County in the base cost mitigation scenario created in disadvantaged communities. Similarly, disadvantaged workers in the Central Valley are more likely than nondisadvantaged workers in that region to be employed in transportation and construction sectors. However, disadvantaged and nondisadvantaged workers are about equally as likely to be employed in service sectors in this region. Consequently, more than 32,000 of the 59,000 Central Valley jobs created in the 2030 Base Cost Mitigation Scenario are forecast to be in disadvantaged communities.

Low-cost mitigation means negative net cost, but it also reduces the demand stimulus effect. Overall, there is positive but limited job creation by 2030 in the low-cost mitigation scenario (Mit-Low). In disadvantaged communities specifically, there is small positive job creation. This includes Los Angeles, where 60% of disadvantaged communities experience at least 20 new jobs, and the Central Valley, where 47 % of disadvantaged communities gain at least 20 new jobs.

Unlike the Low- and Base-Cost Mitigation Scenarios, job growth is not forecast to be all positive in the 2030 High-Cost Mitigation Scenario. The high-cost scenario includes less savings and profits to spur job creation, so there is limited job creation and even some job losses by 2030. Statewide, nearly a third of disadvantaged communities lose jobs in this scenario, although the magnitude of job losses is relatively small (0-20 jobs lost). In Los Angeles, nearly 40% of disadvantaged communities lose jobs by 2030, but in the Central Valley, the share of disadvantaged communities with job losses is limited to 25%.

4.1.2 Job Creation by 2050

As in 2030, the Medium- (Base) Cost Scenario has the highest job growth; however, by 2050, investment stimulus is sufficient to generate positive job growth across the state in all scenarios. The Low-Cost Mitigation Scenario includes 883,000 jobs generated in California, and more than 40% of these jobs are generated in disadvantaged communities due, in large part, to growth in the construction industry and service sectors. Los Angeles (192 jobs created per disadvantaged community) and the Central Valley (216 jobs created per disadvantaged community) experience substantial benefits. However, these benefits are significantly smaller than jobs generated in the Medium- (Base) Cost Scenario, in which more than 3.3 million new jobs are forecast to be generated statewide, including 475,000 jobs in Los Angeles disadvantaged communities and 344,000 jobs in Central Valley disadvantaged communities. In the High-Cost Scenario, these numbers are reduced to 247,000 disadvantaged community jobs statewide and 120,000 and 49,000 jobs in Los Angeles and Central Valley disadvantaged communities, respectively.

4.2 Electrical Vehicle Adoption

The research team estimated patterns of electric vehicle (EV) adoption by relying on data from the DMV, electric vehicle rebate programs, and official sources of household income and demographic data. This approach is consistent with recent research (ARB 2017b) indicating the most important predictor of EV adoption is income. To model future adoption, stable demographics and use predicted changes in income from the BEAR model are assumed with these results (Figure 10). For low-income households, in the absence of targeted programs,[17] additional income generated by energy policies has a negligible effect on

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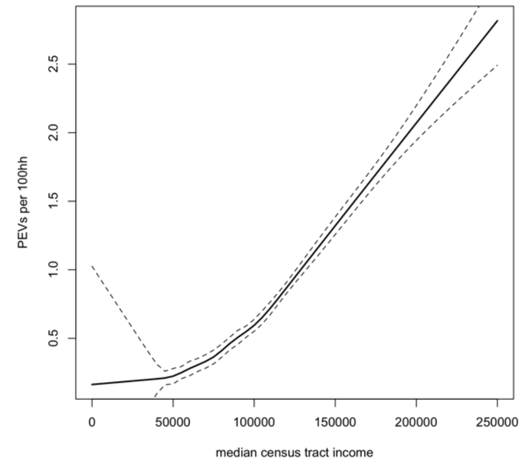
[17] Governor Edmund G. Brown Jr.'s recent mandate calls for implementing incentives to increase the number of EVs in disadvantaged areas. Because the executive order lacked details required to model these policies, however, if they are implemented, then these estimates could significantly underestimate EV adoption in disadvantaged communities.

EV adoption. For relatively wealthy households, there is a small but positive increase in EV adoption in the Base-Cost scenarios.

Figure 10: Relationship Between Census Tract Income and EVs Purchased



Additional income at lower levels (less than $75,000) results in little additional EV purchasing, while additional income at higher median levels has a positive effect on purchasing patterns. Dotted lines represent 95% confidence intervals.

Source: Berkeley Economic Advising and Research

Specifically, it is estimated that:

By 2030, there will be:

- 180,000 new disadvantaged community EVs (six additional EVs per 100 disadvantaged community households).
- 1.5 million new nondisadvantaged community EVs (14 additional EVs per 100 nondisadvantaged community households).

By 2050, there will be:

- 810,000 new EVs in disadvantaged communities.
- 11 million new EVs in nondisadvantaged communities.

Electric vehicle adoption is likely to accelerate in the coming decades. Absent specific policies targeting disadvantaged community adoption, most new vehicles are likely to be purchased by nondisadvantaged households. However, there is significant uncertainty around EV adoption in disadvantaged communities because of the unknown nature and effectiveness of potential incentive policies and future costs.

4.3 Health Benefits

While this analysis is exploratory, the estimates are intended to provide insight on the potential order of magnitude of health benefits. It is clear that an emissions mitigation policy will make highly valuable contributions to public health in California. Specifically, it is estimated that in 2030, the economic value health benefits from GHG reductions in the energy sector will be $6 billion, of which $2.4 billion is from averted mortality and $3.6 billion is from averted medical (morbidity) costs.

These benefits compare to about $8 billion in average annual direct costs of mitigation policy.[18] These estimates represent health benefits associated with reductions in GHG emissions in only the energy sector, yet do not quantify many of the other expected benefits that are known to be substantial. Assuming, however, uniform statewide emission reductions, these **benefits are higher for households in disadvantaged communities**. Moreover, it is likely the total benefits to disadvantaged communities of these policies are underestimated because the potential electrification of the transportation sector cannot be fully accounted. Transportation electrification is likely to benefit disadvantaged communities because of their proximity to transportation networks.[19]

These estimates of health benefits are based on morbidity and mortality costs averted and include $581 averted per disadvantaged household and $494 averted per nondisadvantaged household.

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

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

- Productivity benefits from lower criteria pollutant concentrations (for example, work and school attendance, performance, and so forth).
- 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 (Carleton and Hsiang 2016).

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

These estimates of public health benefits are *not* directly linked to the EV analysis. In other words, this analysis does not explicitly capture electrification of the vehicle fleet in the public health impact estimates and, therefore, cannot draw any conclusions about the distributional effects of health benefits from vehicle fleet electrification. Places like Los Angeles, where a significant portion of emissions come from light-duty vehicles, are more likely to benefit from new EV purchases than places like the Central Valley, where heavy-duty vehicles are a larger contributor to emissions. Benefits from reductions in vehicle emissions would be *in addition to* the benefits estimated here. For more information on transportation

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[18] These estimates are larger than the $1 billion to $2 billion estimated by CARB and cited in the 2030 Scoping Plan but congruent with several recent publications estimating substantially larger benefits (for example, Shindell et al 2018, Zapata et al 2017, Saari et al 2015).

[19] http://www.energy.ca.gov/2017_energypolicy/ CHAPTER 10: Climate Adaptation and Resiliency Section 6: "Increasing Climate Resilience in Disadvantaged Communities" includes a detailed description of how disadvantaged communities' exposure to poor air quality correlates with proximity to transportation networks.

networks and disadvantaged communities' exposure to pollution, see the California Energy Commission *2017 Integrated Energy Policy Report*.[20]

While most of the avoided deaths are a result of reductions in $PM_{2.5}$, the primary source of this public health benefit in San Bernardino disadvantaged communities is lower ozone exposure. The census tracts in dark green show 15-20 lives saved per 100,000 households are in the ninety-third percentile of ozone exposure statewide, and the meteorological model from Zhang et al predicts a substantial reduction in ozone exposure around San Bernardino (Figure 11).

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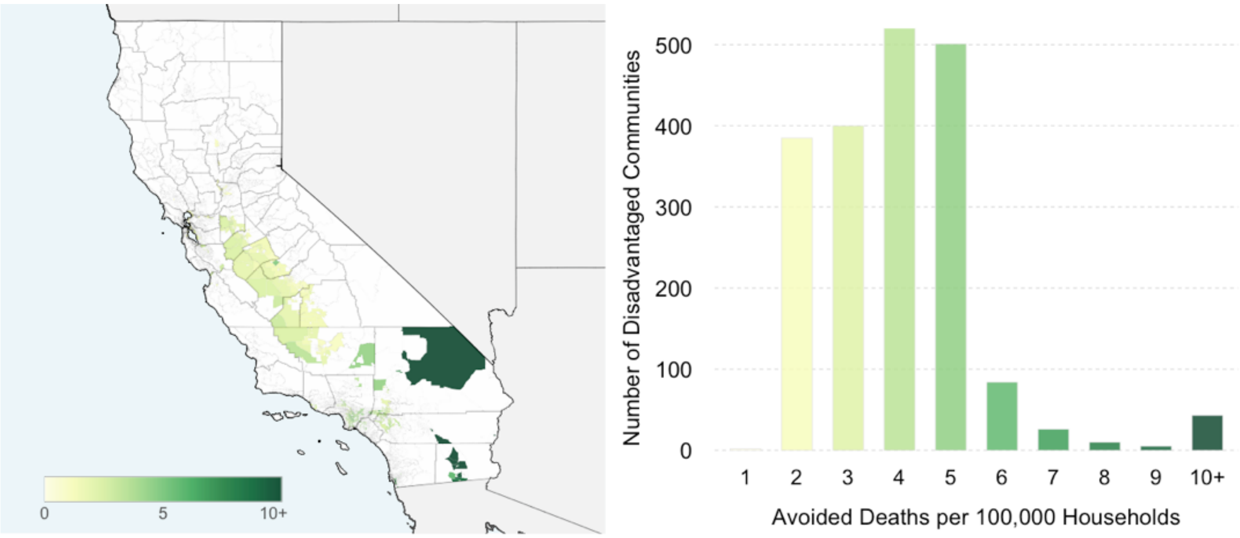
[20] http://www.energy.ca.gov/2017_energypolicy/ CHAPTER 10: Climate Adaptation and Resiliency section 6: "Increasing Climate Resilience in Disadvantaged Communities" includes a detailed description of how DAC exposure to poor air quality correlates with proximity to transportation networks.
http://docketpublic.energy.ca.gov/PublicDocuments/17-IEPR-01/TN223205_20180416T161056_Final_2017_Integrated_Energy_Policy_Report.pdf.

Figure 11: Medium-Cost Scenario Avoided Premature Deaths



Avoided deaths per 100,000 households.

See Appendix Section 5.3 for additional maps: Medium-Cost Scenario Health Benefits ($/hh); Medium-Cost Scenario Health Benefits (Los Angeles, $/household); Medium-Cost Scenario Health Benefits (Central Valley, $/household); Medium-Cost Scenario Avoided Premature Deaths (avoided deaths per 100,000 households); Medium-Cost Scenario Avoided Premature Deaths (Los Angeles) (avoided deaths per 100,000 households); Medium-Cost Scenario Avoided Premature Deaths (Central Valley) (avoided deaths per 100,000 households).

Source: Berkeley Economic Advising and Research

CHAPTER 5: Conclusion

This analysis of disadvantaged communities used downscaled results from the BEAR macroeconomic model of the California economy. This analysis also used downscaled state-of-the-art health benefits estimates for reductions in criteria pollutants from GHG emissions reductions. To summarize, the analysis finds the following.

5.1 Job Creation

New job creation is largely in sectors and occupations that disproportionately employ people from disadvantaged households, including construction, transportation, and services. This group (25% of state population) captures 30% of annual new jobs by 2030 and 29% by 2050.

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

5.2 Electric Vehicles

Electric vehicle adoption remains concentrated among wealthy households, and while the EV fleet is expected to grow substantially, in the absence of targeted policies, most new purchases are likely be by nondisadvantaged households (~90% in 2030).

Even as electric vehicle costs come down and even if subsidies for purchasing EVs were increased, absent policies targeting DAC households directly, electric vehicle adoption is likely to remain highly concentrated among wealthier households.

5.3 Pollution and Health in Disadvantaged Communities

Disadvantaged households are burdened by higher levels of criteria pollutant exposure (25% higher $PM_{2.5}$ levels on average) and suffer from higher than average rates of associated diseases (55% higher asthma rates).

Disadvantaged communities 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 disadvantaged communities, 25% of state population).

However, these benefits among disadvantaged communities are unevenly distributed across the state. For example, disadvantaged communities in areas like Los Angeles will benefit more than disadvantaged communities in the Central Valley because much of the hazardous exposure that disadvantaged households in the Central Valley experience is from diesel emissions from farm equipment, pesticide exposure, and other hazards that are less directly related to energy policies or vehicle emissions. That being said, because of the regional component of GHG emissions, reducing emissions in other parts of the state is still likely to improve air quality in the Central Valley, just not by as much as it would in places like Los Angeles, where most of the emissions are generated by sources covered by these policies.

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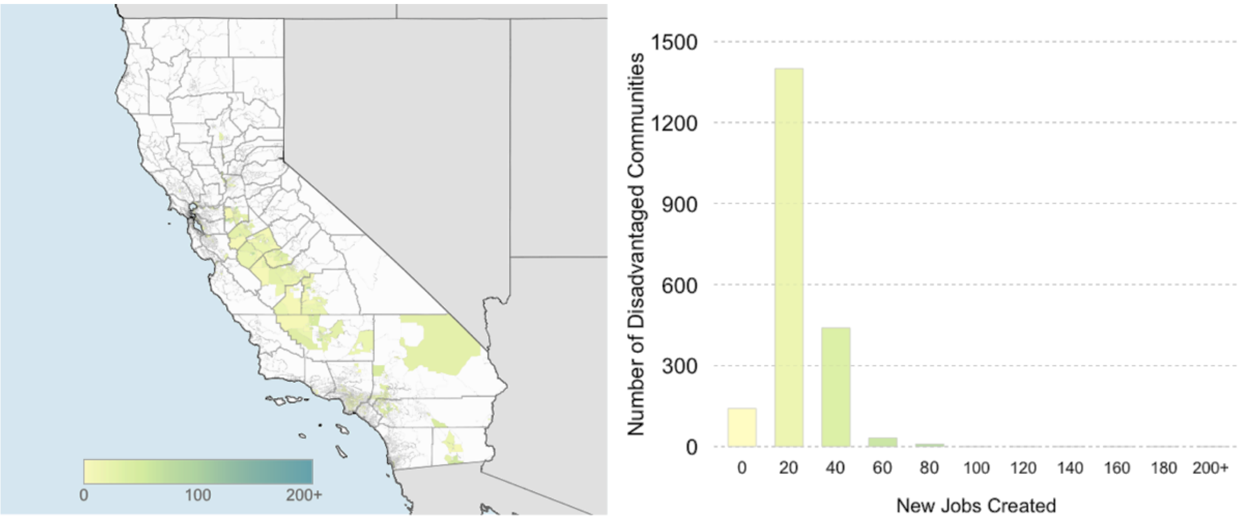
LIST OF ACRONYMS

Term	Definition
ACS	American Community Survey
BEAR	Berkeley Economic Advising and Research
CalEPA	California Environmental Protection Agency

CARB	California Air Resources Board
CEC	California Energy Commission
CES	CalEnviroScreen
CGE	Computable general equilibrium
CI	Carbon intensity
CSE	Center for Sustainable Energy
CVRP	Clean Vehicle Rebate Project
EV	Electric vehicle
FTE	Full-time equivalent
GHG	Greenhouse gases
GSP	Gross State Product
HDV	Heavy-duty vehicles
LDV	Light-duty vehicles
LTES	Long-term energy strategy
NAAQS	National Ambient Air Quality Standards
OECD	Organization for Economic Co-operation and Development
OEHHA	Office of Environmental Health Hazard Assessment
PEV	Plug-in electric vehicle
PM	Particulate matter
RPS	Renewables Portfolio Standard
VSL	Value of Statistical Life
ZEV	Zero-emission vehicle

APPENDIX A: Benefits

Figure A-1: Job Creation - 2030 Low-Cost Mitigation



Source: Berkeley Economic Advising and Research

Figure A-2: Job Creation - 2030 Medium-Cost Mitigation

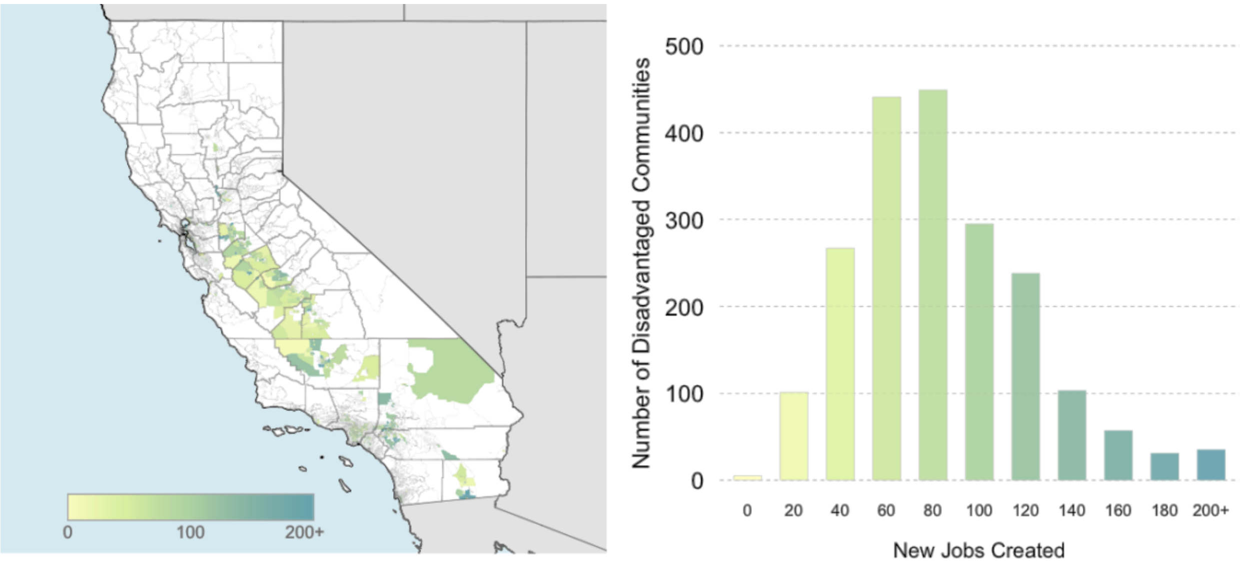


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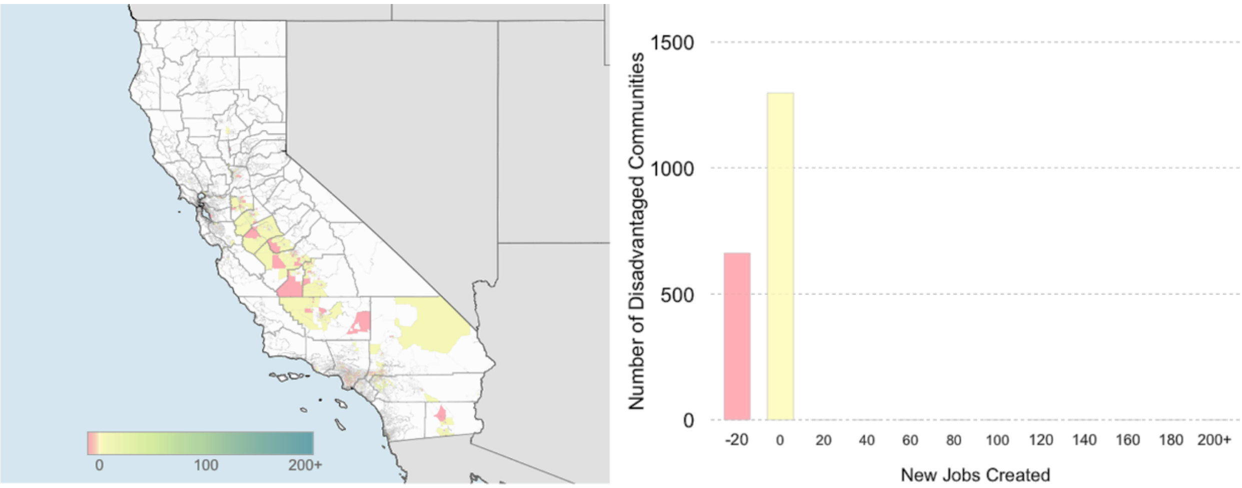
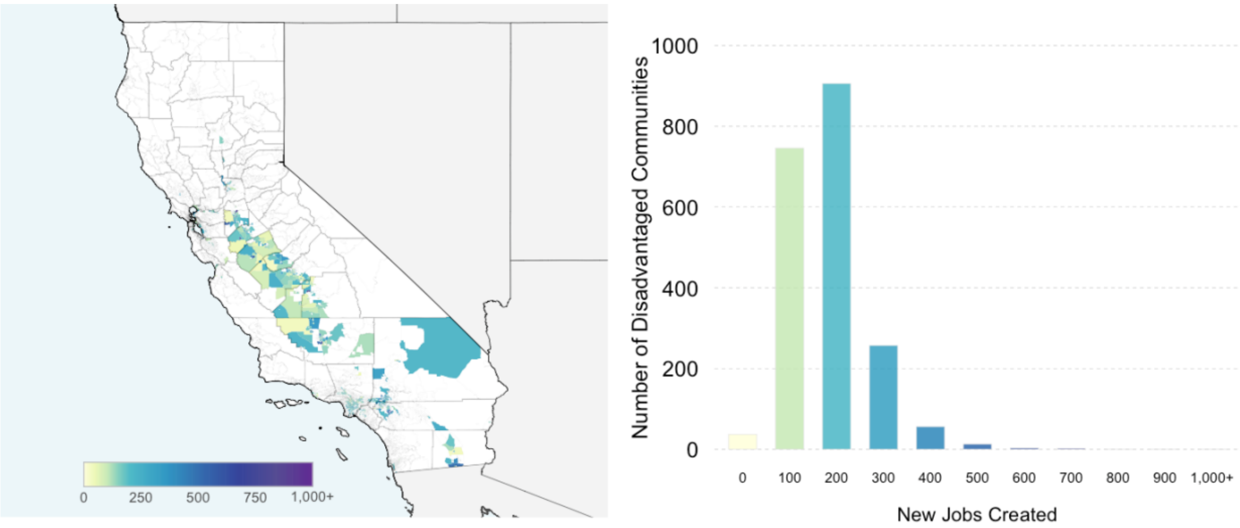
Figure A-3: Job Creation - 2030 High-Cost Mitigation



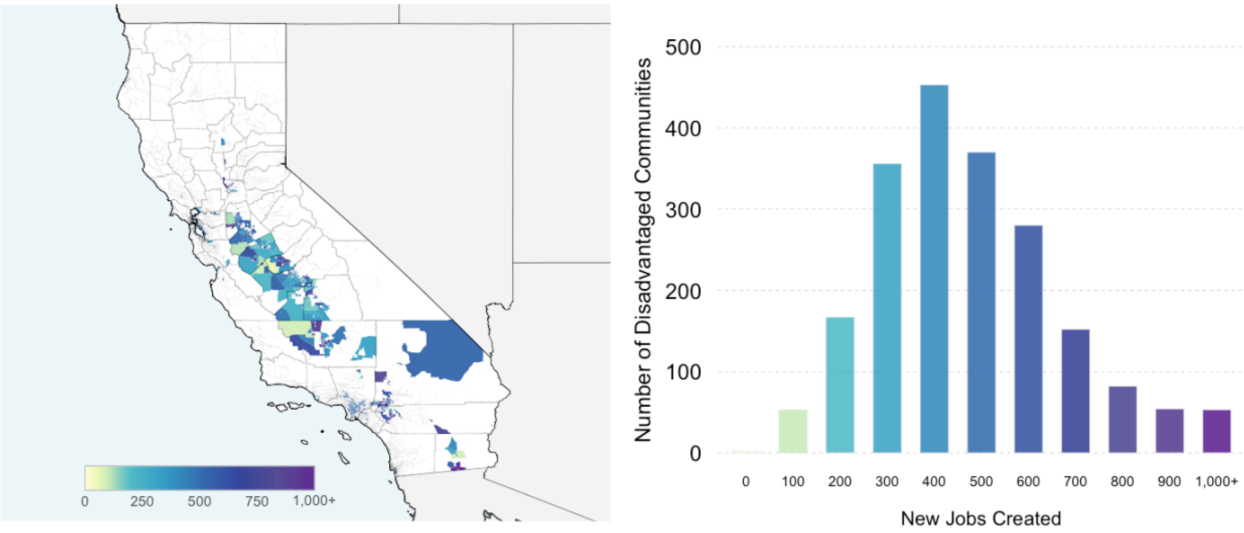
Source: Berkeley Economic Advising and Research

Figure A-4: Job Creation - 2050 Low-Cost Mitigation



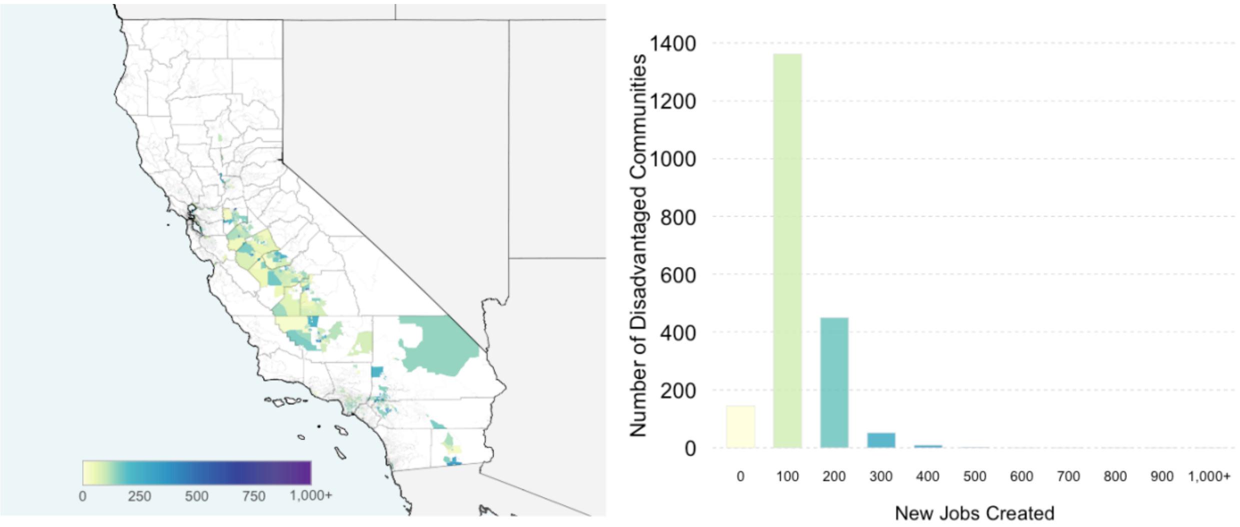
Source: Berkeley Economic Advising and Research

Figure A-5: Job Creation - 2050 Medium-Cost Mitigation



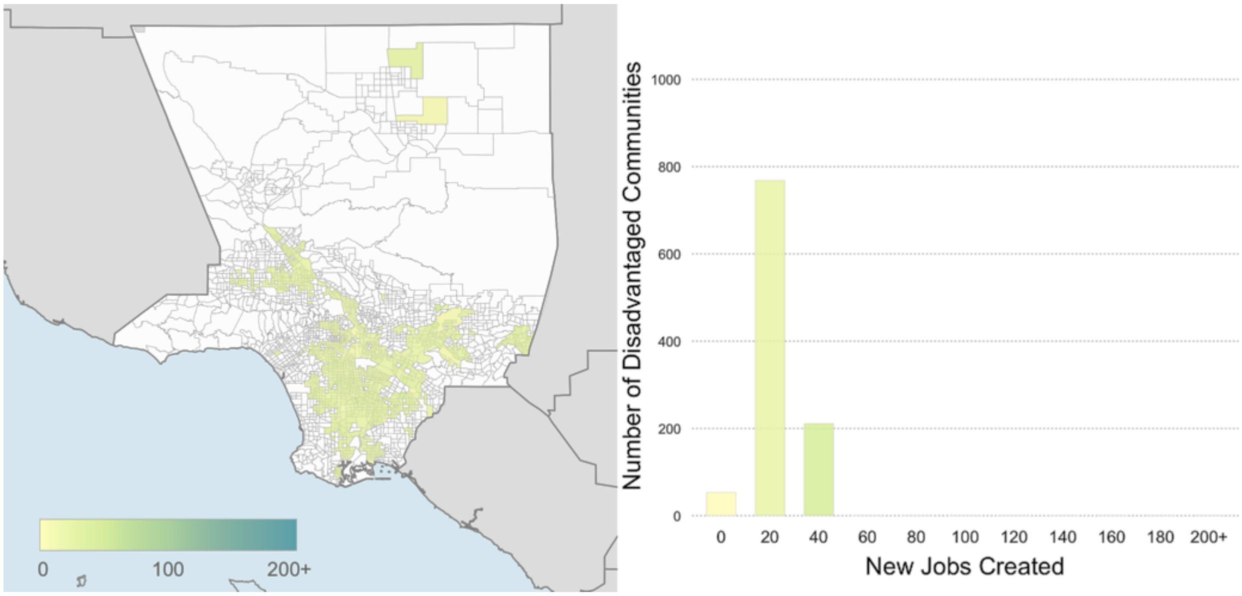
Source: Berkeley Economic Advising and Research

Figure A-6: Job Creation - 2050 High-Cost Mitigation



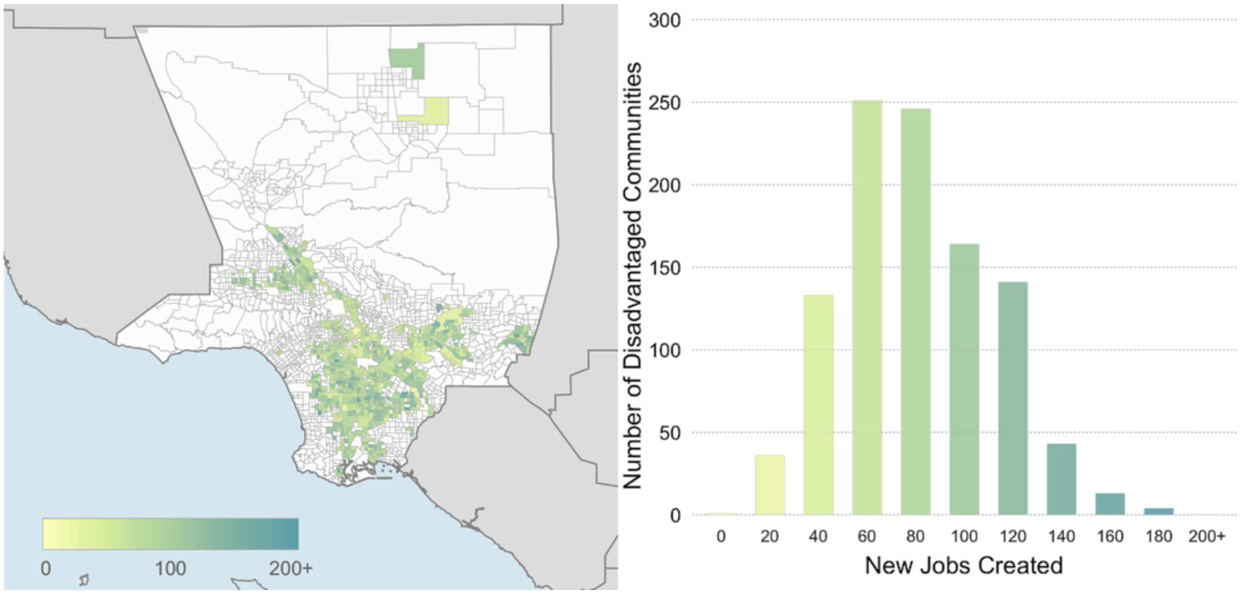
Source: Berkeley Economic Advising and Research

Figure A-7: Job Creation - 2030 Low-Cost Mitigation (Los Angeles)



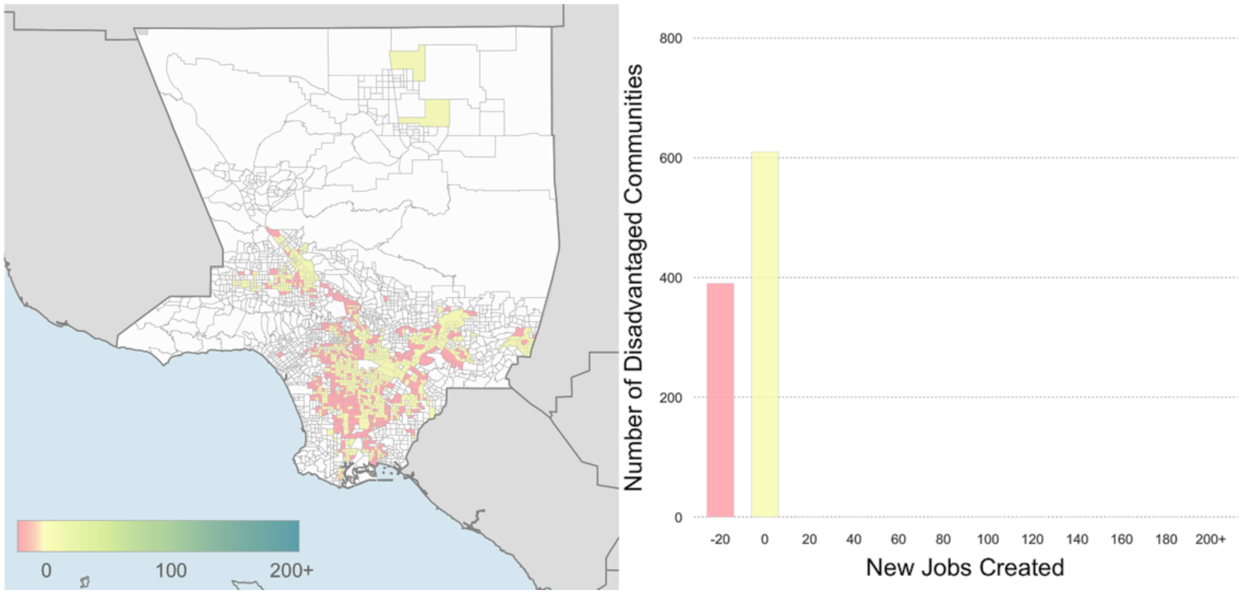
Source: Berkeley Economic Advising and Research

Figure A-8: Job Creation - 2030 Medium-Cost Mitigation (Los Angeles)



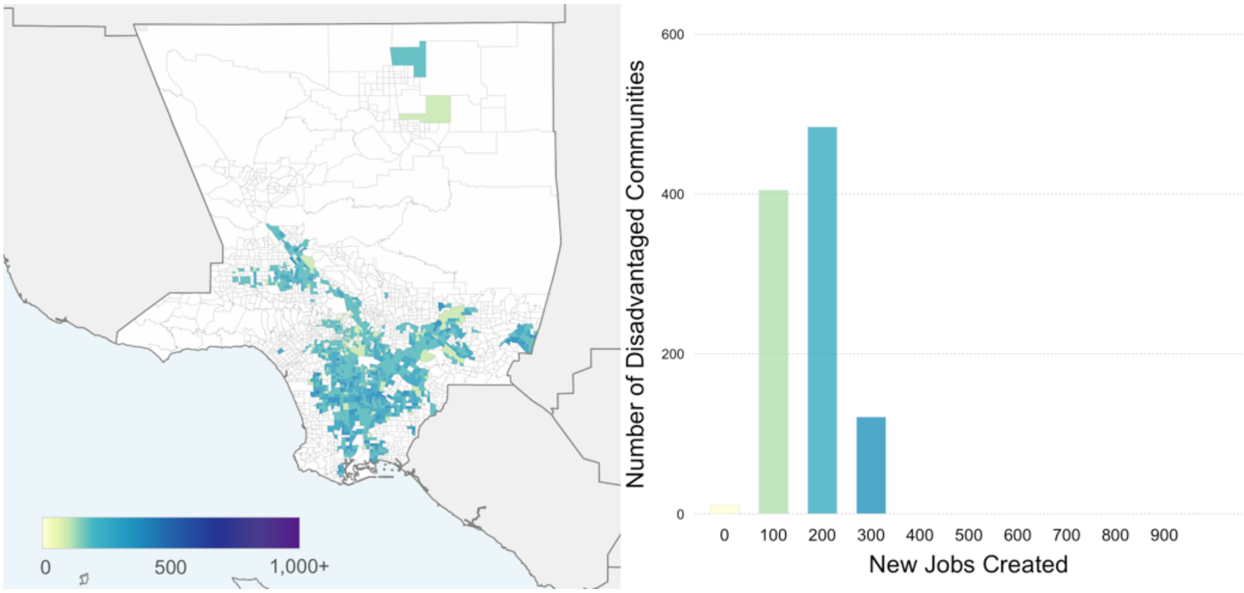
Source: Berkeley Economic Advising and Research

Figure A-9: Job Creation - 2030 High-Cost Mitigation (Los Angeles)



Source: Berkeley Economic Advising and Research

Figure A-10: Job Creation - 2050 Low-Cost Mitigation (Los Angeles)



Source: Berkeley Economic Advising and Research

Figure A-11: Job Creation - 2050 Medium-Cost Mitigation (Los Angeles)

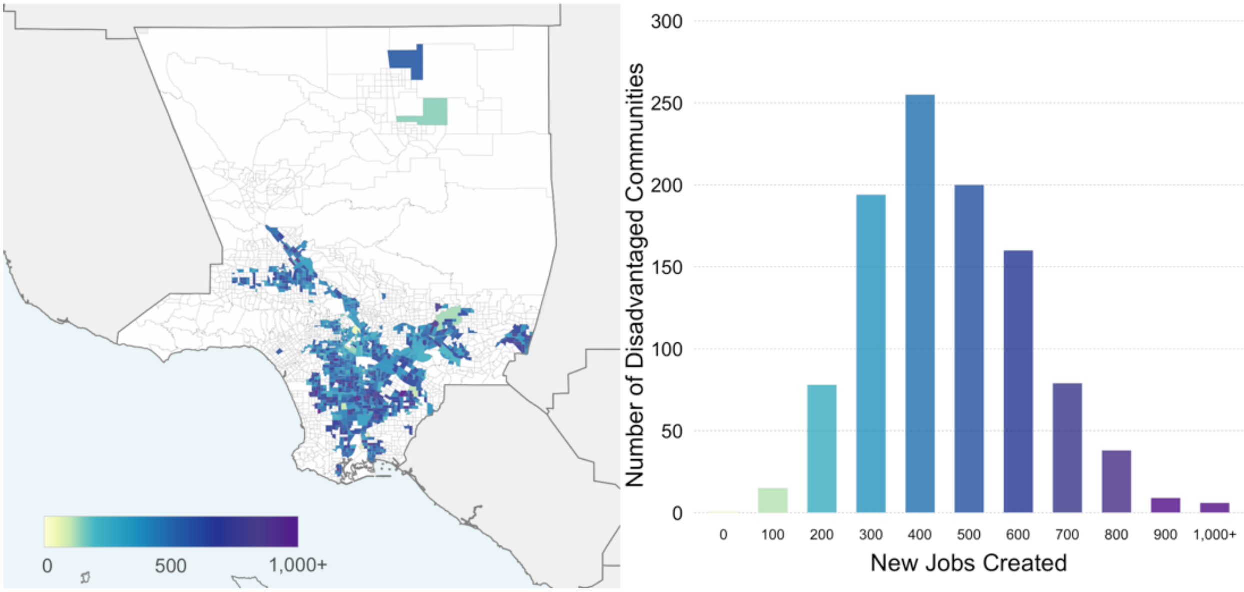


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Figure A-12: Job Creation - 2050 High-Cost Mitigation (Los Angeles)

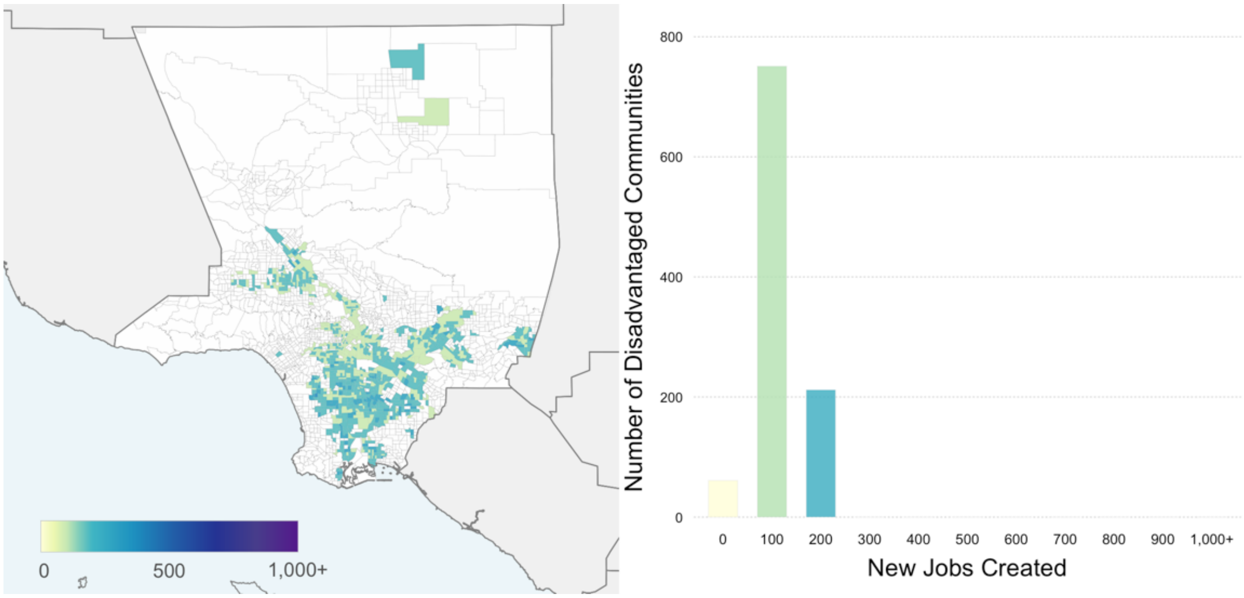

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Figure A-13: Job Creation - 2030 Low-Cost Mitigation (Central Valley)

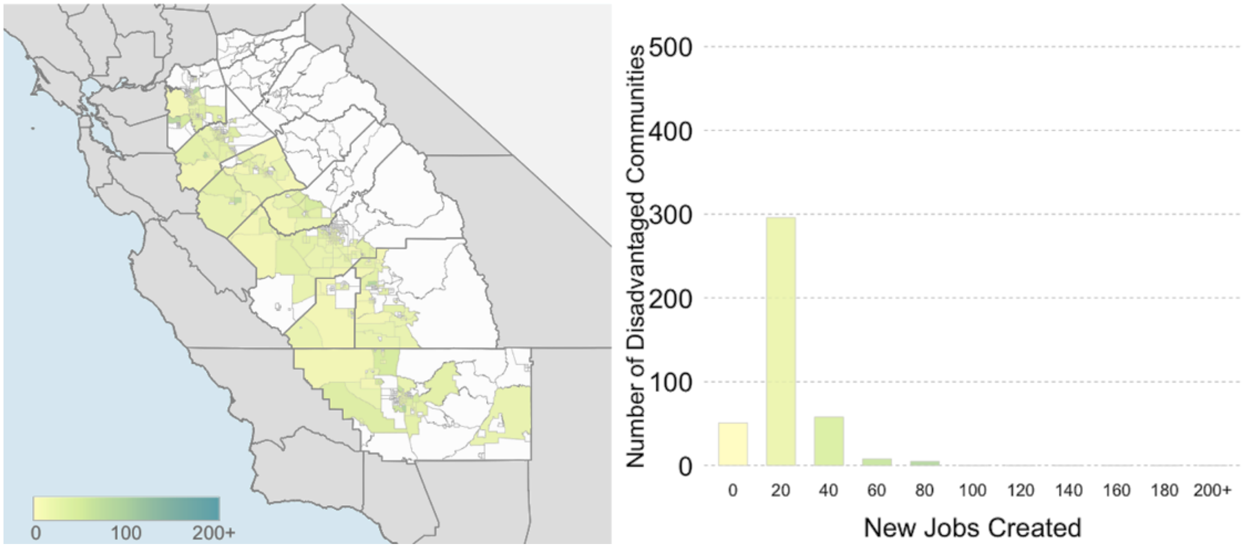

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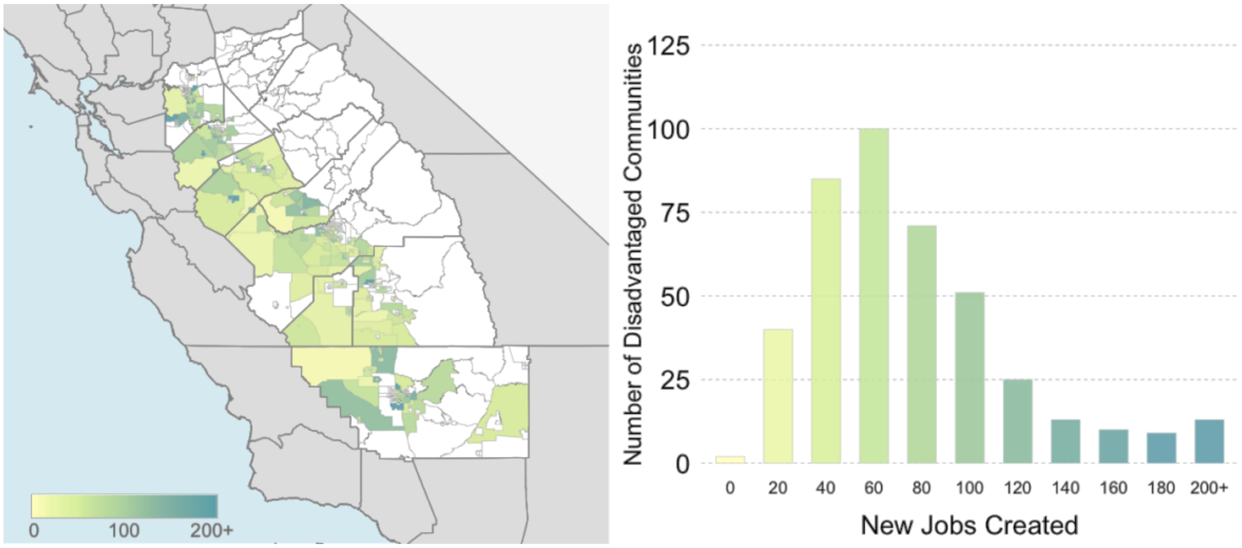
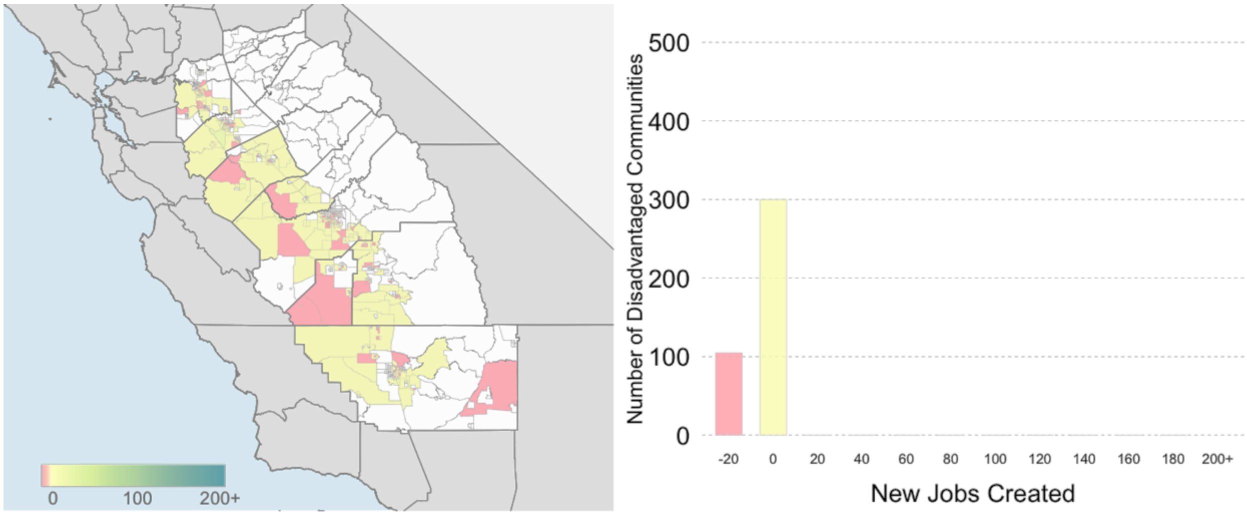
Figure A-14: Job Creation - 2030 Medium-Cost Mitigation (Central Valley)



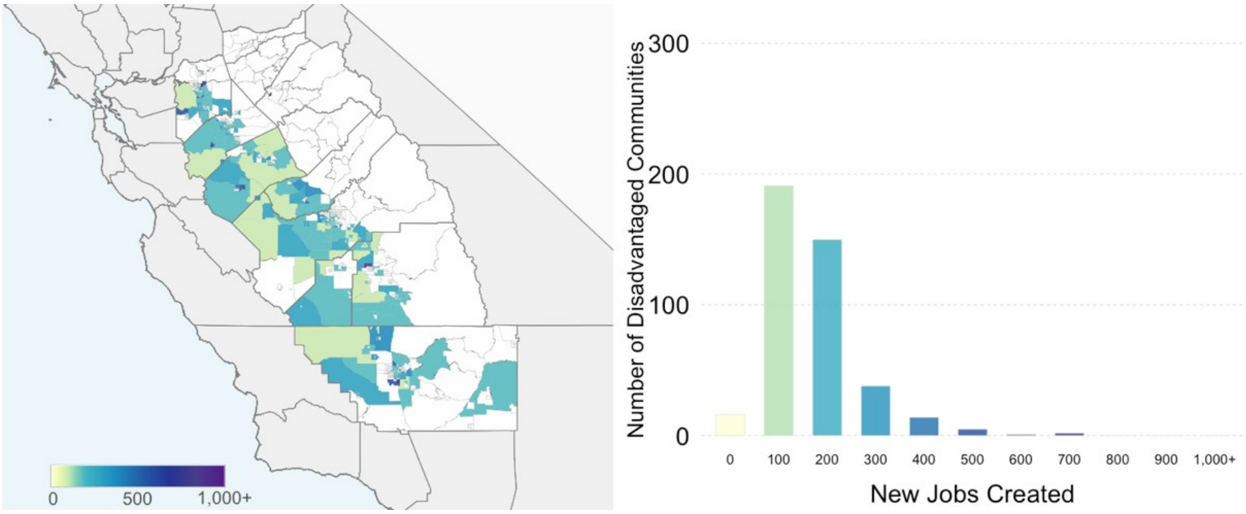
Source: Berkeley Economic Advising and Research

Figure A-15: Job Creation - 2030 High-Cost Mitigation (Central Valley)



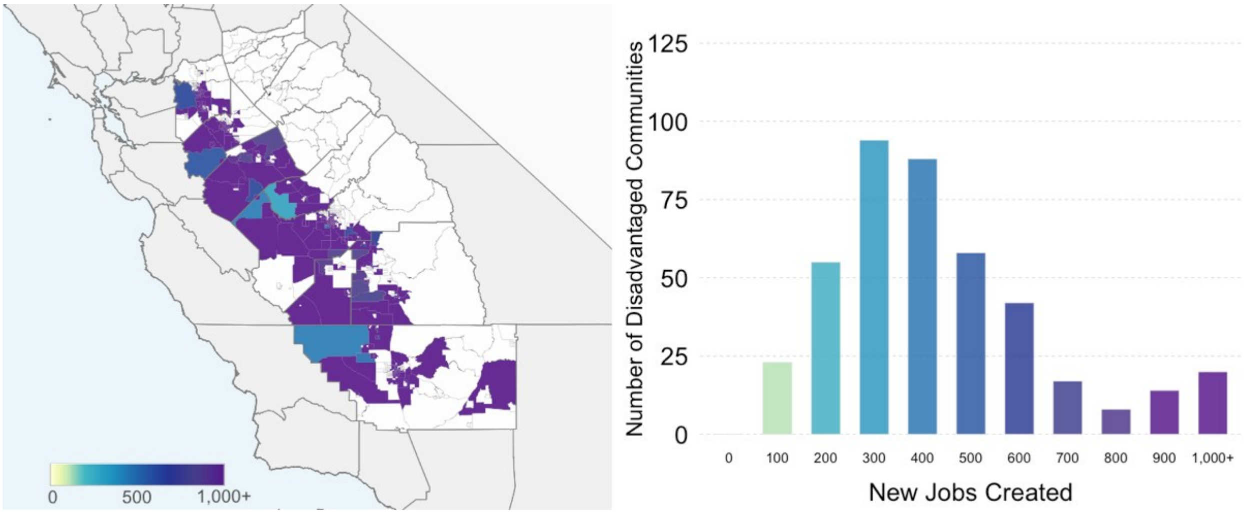
Source: Berkeley Economic Advising and Research

Figure A-16: Job Creation - 2050 Low-Cost Mitigation (Central Valley)



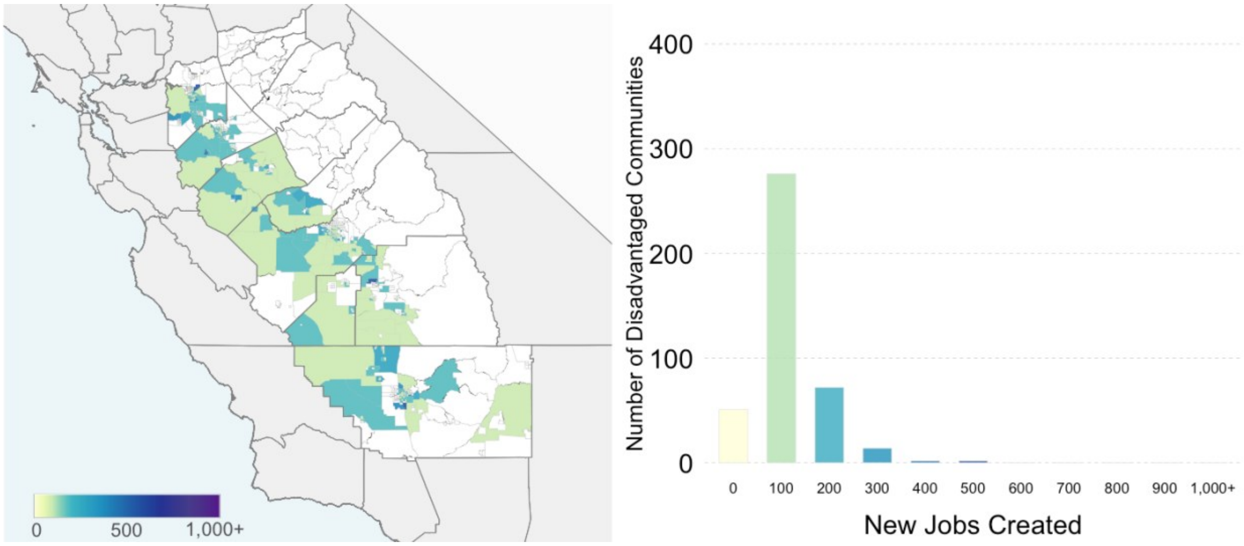
Source: Berkeley Economic Advising and Research

Figure A-17: Job Creation - 2050 Medium-Cost Mitigation (Central Valley)



Source: Berkeley Economic Advising and Research

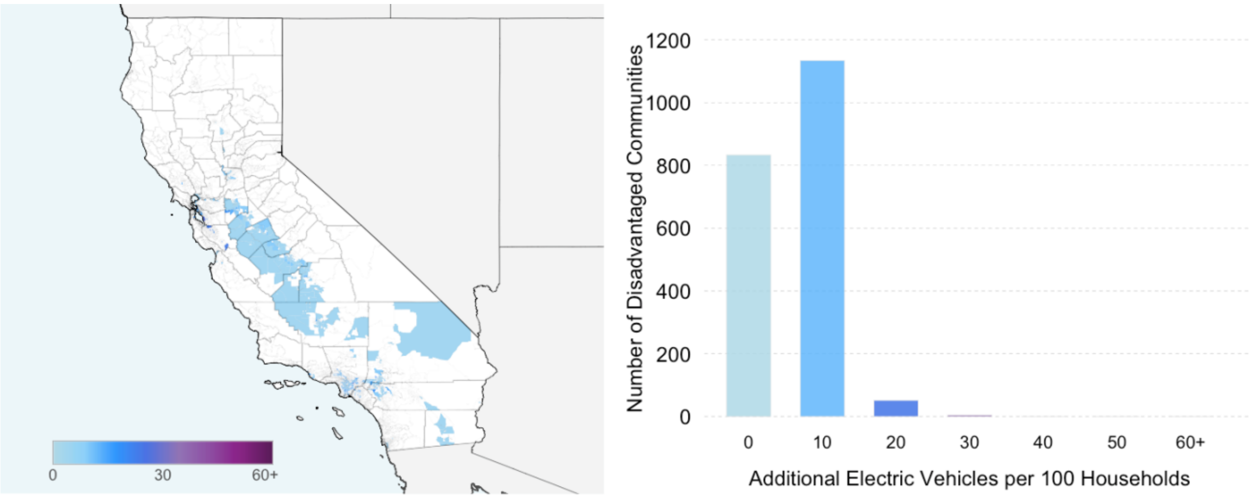
Figure A-18: Job Creation - 2050 High-Cost Mitigation (Central Valley)



Source: Berkeley Economic Advising and Research

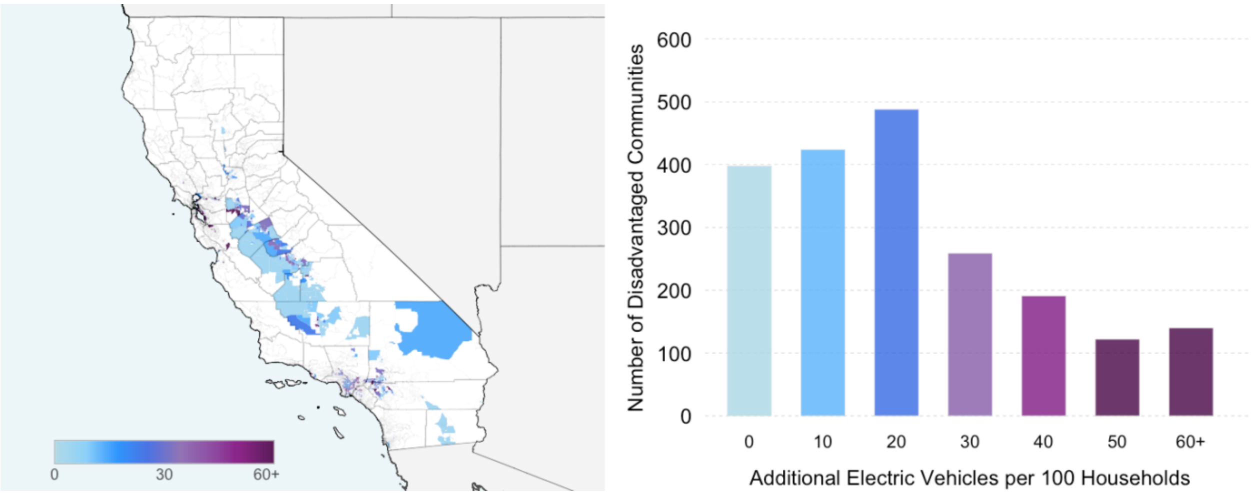
Electric Vehicle Adoption

Figure A-19: Additional Electric Vehicles - 2030



Source: Berkeley Economic Advising and Research

Figure A-20: Additional Electric Vehicles - 2050



Source: Berkeley Economic Advising and Research

Figure A-21: Additional Electric Vehicles – 2030 (Los Angeles)

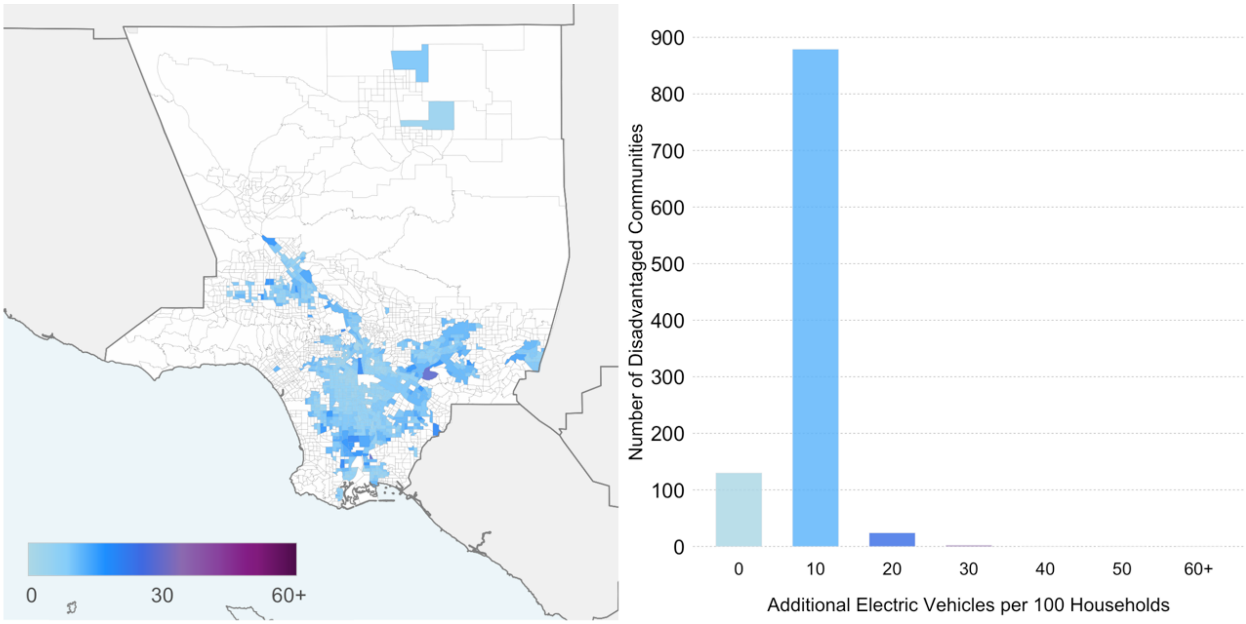


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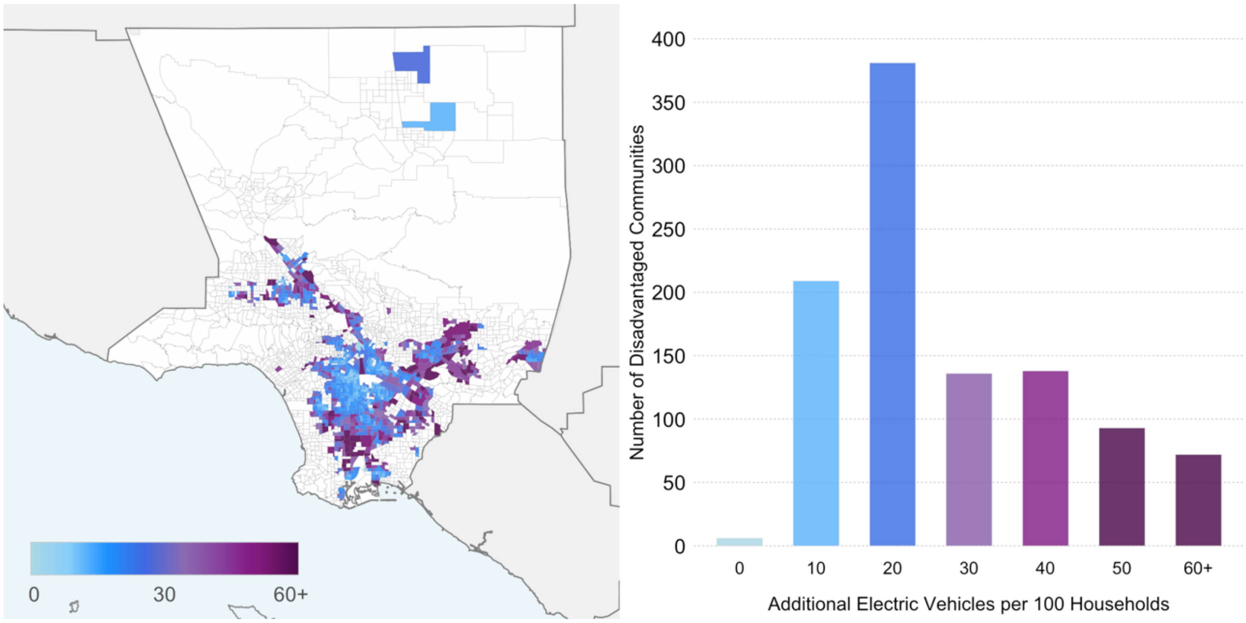
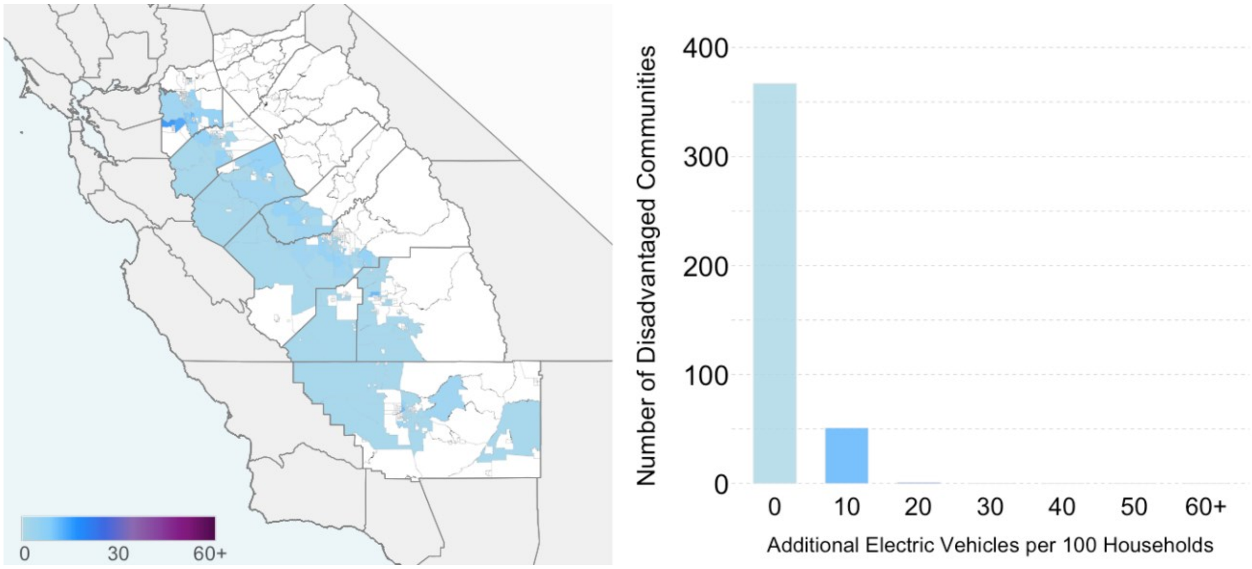
Figure A-22: Additional Electric Vehicles – 2050 (Los Angeles)



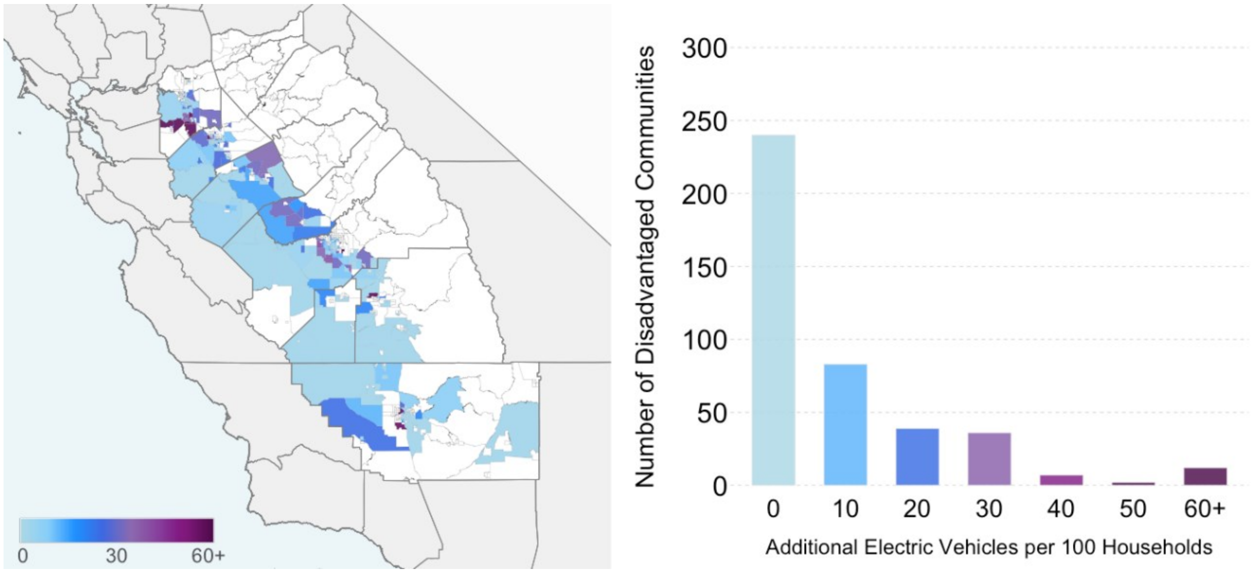
Source: Berkeley Economic Advising and Research

Figure A-23: Additional Electric Vehicles – 2030 (Central Valley)



Source: Berkeley Economic Advising and Research

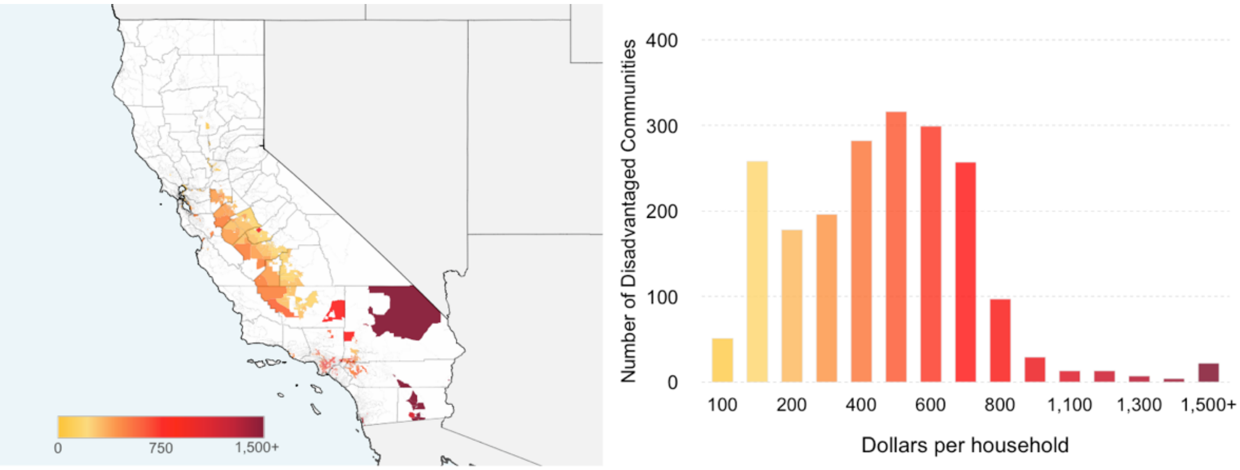
Figure A-24: Additional Electric Vehicles – 2050 (Central Valley)



Source: Berkeley Economic Advising and Research

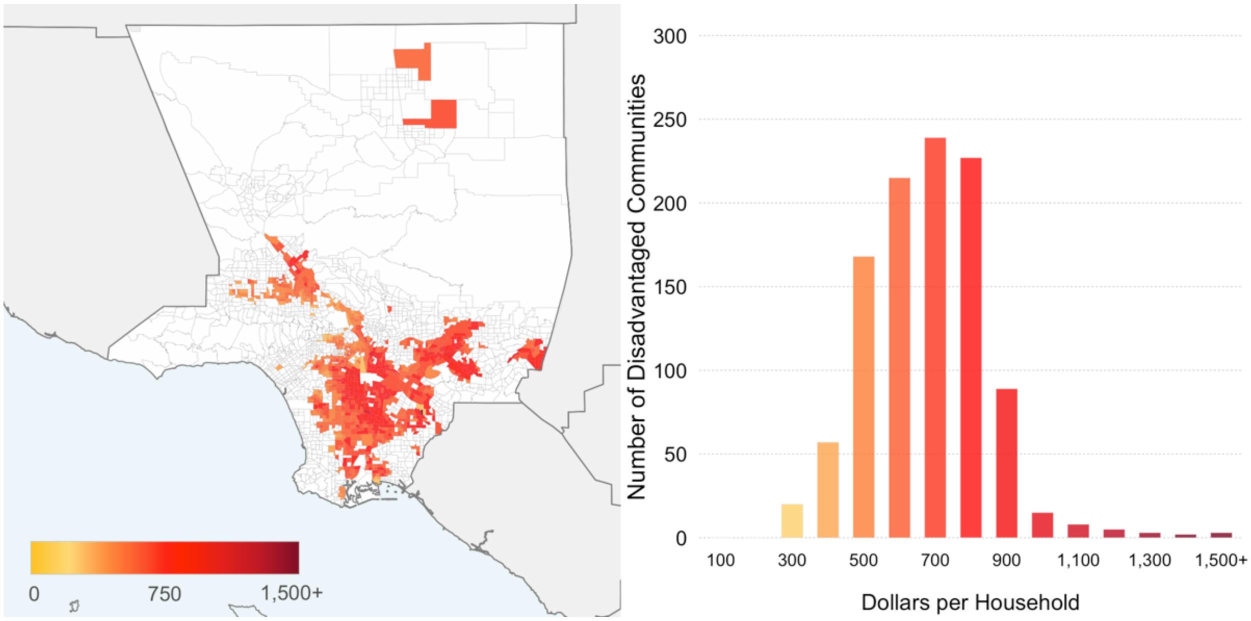
Public Health Benefits

Figure A-25: Medium-Cost Scenario Health Benefits ($/household), 2030



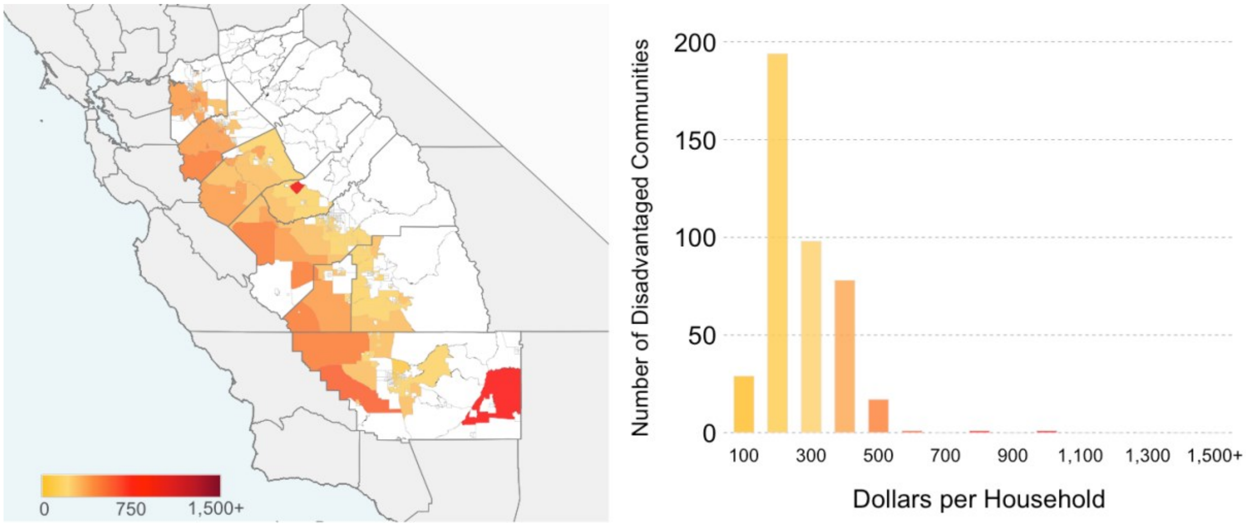
Source: Berkeley Economic Advising and Research

Figure A-26: Medium-Cost Scenario Health Benefits (Los Angeles, $/household), 2030



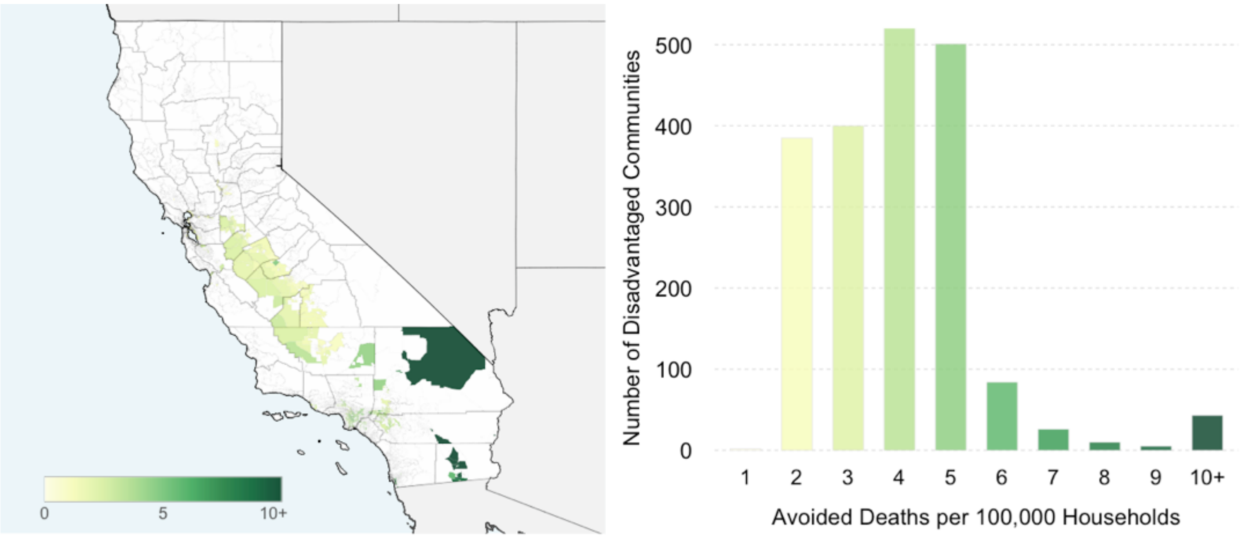
Source: Berkeley Economic Advising and Research

Figure A-27: Medium-Cost Scenario Health Benefits (Central Valley, $/household), 2030



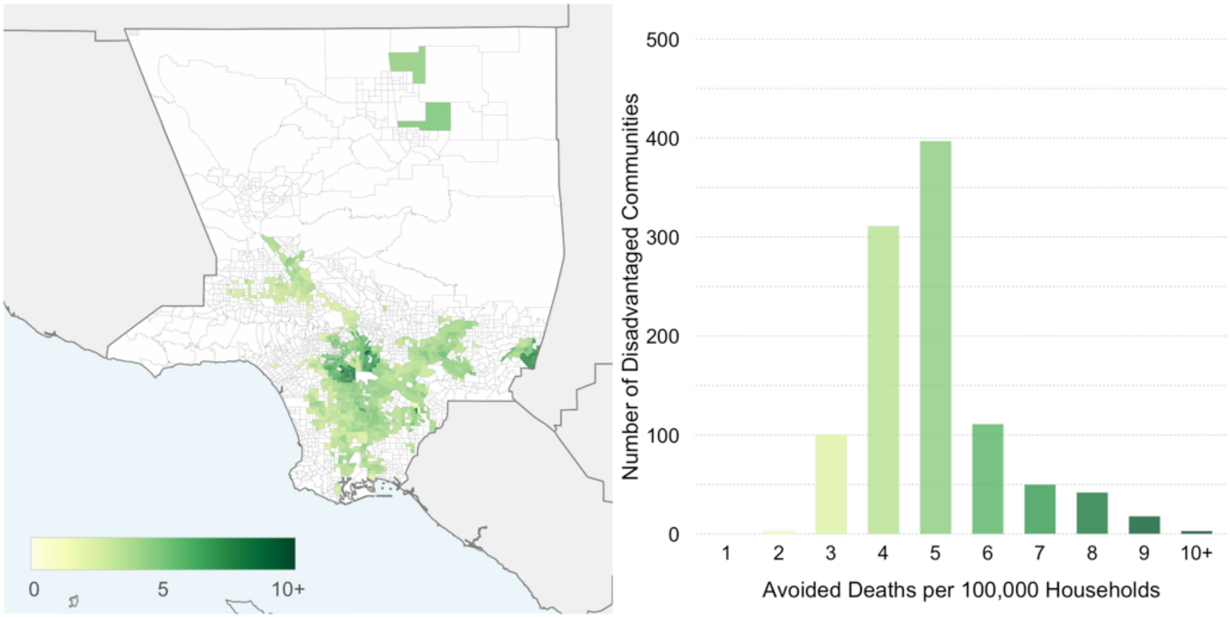
Source: Berkeley Economic Advising and Research

Figure A-28: Medium-Cost Scenario Avoided Premature Deaths (avoided deaths per 100,000 households), 2030



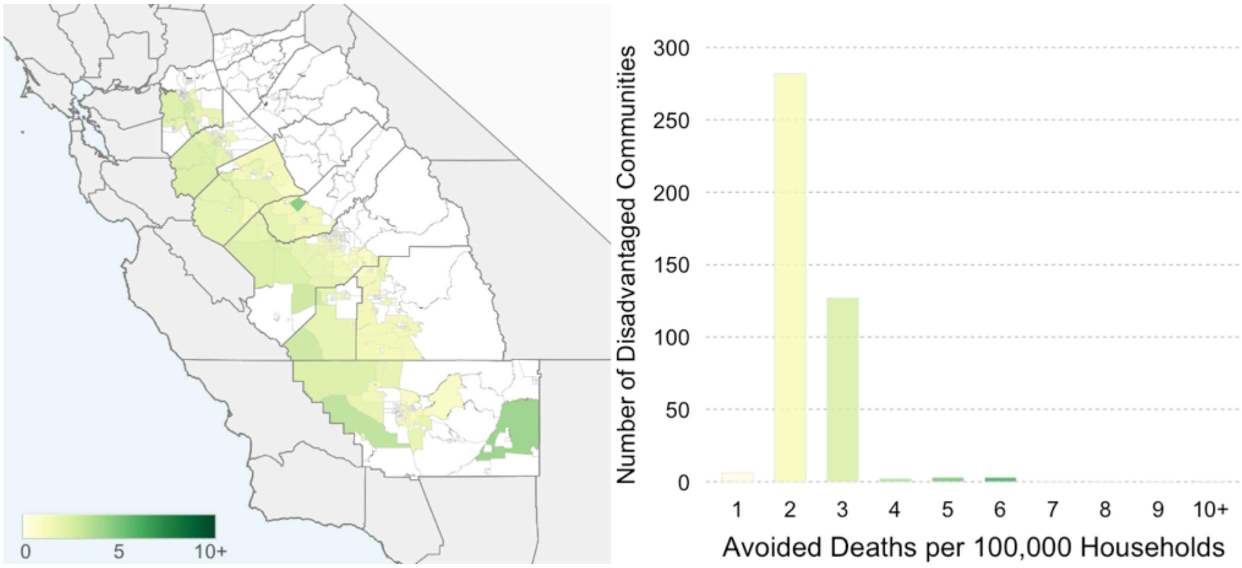
Source: Berkeley Economic Advising and Research

Figure A-29: Medium-Cost Scenario Avoided Premature Deaths (Los Angeles, avoided deaths per 100,000 households), 2030



Source: Berkeley Economic Advising and Research

Figure A-30: Medium-Cost Scenario Avoided Premature Deaths (Central Valley, avoided deaths per 100,000 households), 2030



Source: Berkeley Economic Advising and Research