California Energy Commission

CONSULTANT MEMORANDUM

Exploring Economic Impacts in Long-Term California Energy Scenarios: Technical Documentation

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ABBREVIATIONS:
CARB – California Air Resources Board
CEC – California Energy Commission
CGE – Computable General Equilibrium
CI – Carbon Intensity
DAC – Disadvantaged Community
GHG – Greenhouse gases
LTES – Long-term Energy Scenarios
RPS – Renewable Portfolio Standard
ZEV – Zero Emission Vehicle

Executive Summary

Introduction

As part of the state's path breaking commitments to a lower carbon future, the California Energy Commission is sponsoring a set of coordinated studies to assess the impacts 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 Strategy (LTES). This integrated policy framework is designed to accelerate Greenhouse Gas (GHG) 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.

Using a dynamic forecasting model of the California economy, Berkeley Economic Advising and Research conducted 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. While relatively technical, this research yielded four very general insights:

- Energy system investments are a potent catalyst for income and job growth.
- Technology adoption benefits can far exceed their direct costs.
- Energy savings from the implementation of the policies are substantial and induce broad based job creation.
- Statewide savings from averted mortality and morbidity are likely to be comparable to the direct costs of the energy system buildout.

More detailed and annotated results of this assessment are presented in a companion slide presentation, while this document contains summary results and technical documentation.

Project Purpose

The primary objective of this research was to improve visibility for public and private stakeholders regarding the comprehensive, long term net benefits of California's low carbon energy strategy. Because the state is presently reaffirming its climate commitments in the form of more aggressive medium term GHG mitigation, this is an opportune time to strengthen the basis of evidence supporting these policies in the public interest.

Until recently, the primary justifications for California "going it alone" on climate policy were more general, e.g. 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 entire state.

Project Process

The present research was carried out on an intensive production schedule spanning about three months. During that short time, the BEAR model's economic data were updated and information from leading energy experts was incorporated to include detailed and state-of-the-art energy system data from the larger "EPIC" project over the course of a full year. All of this information was synthesized and carried forward in the BEAR model to project 2030 and 2050 outcomes for the California economy.

Project Results

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

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

- Increase California real GSP 2% by 2030 and 9% by 2050
- Create over 500K additional FTE jobs by 2030 and 3.3M by 2050

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

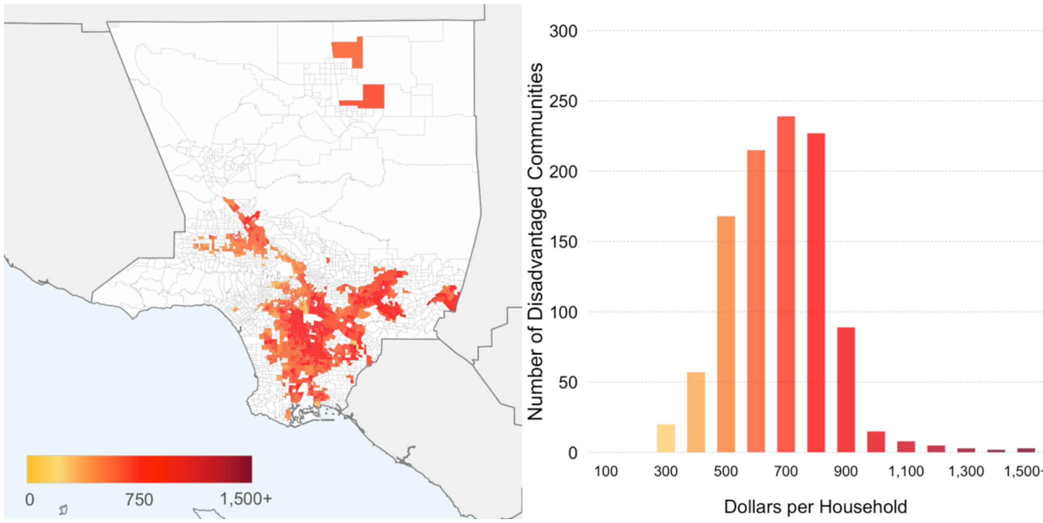
Two additional economic aspects of the new energy policies were also examined. Using very recent evidence on links between pollution mitigation and public health, BEAR was able to examine long term economic benefits from averted mortality and medical care attributable to California climate policy. We find that 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 in some quarters, could be justified on public health grounds alone.

Another primary contribution of this research is to elucidate economic and health impacts spatially across the state, with particular attention to Disadvantaged Community (DAC) populations. Our results forecast employment impacts across each of the state's 8,000 census tracts and 2,000 DACs.

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

DAC households are currently disproportionately burdened by high levels of criteria pollutant exposure (e.g., 25% higher PM2.5 levels on average according to CalEnviroScreen 3.0) and suffer from higher than average rates of associated diseases (e.g., 55% higher asthma rates [CES 3.0]). DACs would therefore greatly benefit from improvements in air quality that can reduce the mortality and morbidity costs they bear (see, e.g. Figure ES1).

Figure ES1: Medium Cost Scenario Health Benefits in 2030
(Los Angeles, $ per Household)



Source: Author's estimates utilizing data from Zhang et al 2017 (See Section 3.5 for details).

Benefits to California

This research demonstrates that the benefits of determined public and private investments in a new generation of energy production and use technologies can far outweigh their costs. Moreover, direct and indirect net benefits are distributed extensively across the state economy and its diverse population. Our results show net job creation and income growth, as well as valuable public health benefits, at all income levels and in all counties. Moreover, we find that average economic benefits are relatively greater in DACs because the primary job stimulus is in the construction and services sectors. More dramatically, average public health benefits are greater in **absolute** (dollar) terms for DAC than for non-DAC communities. Both these results suggest that climate policy benefits are not only inclusive but can contribute to reducing inequality.

It should be noted, however, these benefits among DACs are unevenly distributed across the state with DACs in Los Angeles benefitting more than DACs in the Central Valley, for example, because the sources of pollution in the Central Valley are less likely to be impacted by the policies considered here. More targeted policies could achieve different outcomes, both in terms of total benefits and their statewide distribution. Indeed, the very heterogeneity observed in initial conditions and our 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.

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1 Introduction

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), 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.

Using a dynamic forecasting model of the California economy, Berkeley Economic Advising and Research (BEAR) has conducted a detailed assessment of the implications of LTES for incomes and employment, across the state with more detailed attention to Disadvantaged Communities (DACs). 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 has the potential to:

- Increase California real GSP 2% by 2030 and 9% by 2050
- Create over 500K additional FTE jobs by 2030 and 3.3M by 2050

Expected additional gains from higher productivity and induced innovation will further amplify these net benefits, but we do not estimate these below. This assessment also takes a novel approach to estimating the economic benefits these policies would have from improved public health, and we find that 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 by averted health and mortality costs alone.

Our findings for Disadvantaged Communities are even more positive. LTES-induced job creation occurs in sectors and occupations that disproportionately employ people from Disadvantaged Community households, including construction, transportation and services. We estimate that this group (25% of state population) captures 30% of annual new jobs by 2030 and 29% by 2050.

DAC households are currently burdened by high levels of criteria pollutant exposure (25% higher PM2.5 levels on average according to CalEnviroScreen 3.0) and suffer from higher than average rates of associated diseases (55% higher asthma rates for example [CES 3.0]). DACs therefore benefit more in absolution terms than others, meaning their benefits are much greater in relative terms (30% of avoided deaths and costs in DACs, 25% of state population). DAC benefits are unevenly distributed across the state, however, with DACs in Los Angeles benefitting more than DACs in the

Central Valley, for example, because the sources of pollution in the Central Valley are less likely to be impacted by the policies considered here.

2 Macroeconomic Analysis

2.1 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 that models demand, supply, and resource allocation across the California economy, estimating economic outcomes annually over the period 2015–2030. This kind of Computable General Equilibrium (CGE) model is a state-of-the-art economic forecasting tool, using a system of equations and detailed economic data that simulate price-directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also included, with varying degrees of detail, to close the model and account for economy-wide resource allocation, production, & income determination.

BEAR is calibrated to a 2015 dataset of the California economy and it includes highly disaggregated representation of firm, household, employment, government, and trade behavior (Table 1). The model's 2015 – 2030 baseline is calibrated to the California Department of Finance economic and demographic projections. The model's baseline is recalibrated to incorporate the new data whenever new projections are released.

Table 1: **BEAR 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

For the LTES assessment the BEAR model was aggregated to 60 economic sectors (Table 2). The electric power sector was disaggregated by 8 generation types in order 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
A23TxtAprl	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

2.2 Scenarios

To take account of 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 the State'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 pre-existing state commitments to renewables, so each Reference case reflecting different cost assumptions with partial RPS adoption. The resulting scenarios are the following:

- Mit_Med Base cost (E3) or median mitigation scenario
- Mit_High: Higher cost alternative with lower assumed fossil fuel prices and higher capital financing rates.
- Mit_Low: Lower cost alternative with higher assumed fossil fuel prices and lower capital financing rates.

Reference Cases: Reflect pre-SB 350 policies (e.g. 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: Not included in E3 results but implicit in their 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 the extra spending to replace the existing durable goods stock with more energy efficient goods. Spending in industrial sectors includes both changes in fuel and stock spending. Changes in fuel occurs as different industries consume more energy from renewable sources. Changes in stock spending occurs 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 ICE vehicles to PHEV/BEVs.

A summary of the fuel and stock expenditures from the PATHWAYS model are shown in Table 3 (for 2030) and Table 4 (for 2050). Total net spending on stock and fuels are approximately $7.9 billion in 2030 and $25.2 billion in 2050.

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**

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**

In addition to the direct spending on stock and fuels, we also model the investment in new electric power generation in the state. To factor in these expenditures, we use the annual incremental change in electric power generation by source generated by PATHWAYS and multiply by the levelized capital costs for each technology. These investments are shown in Table 5 for 2030 and 2050. $7.1 billion and $10.3 billion in new electric power capacity investment will be required in 2030 and 2050, respectively. The bulk of this investment is in solar, storage, and wind technologies.

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**

2.3 Results

The LTES macroeconomic assessment results are presented below for two time horizons, 2030 and 2050. All results are presented as either percentage or level differences from the baseline scenario. The baseline scenario reflects pre-SB 350 policies such as the 33% RPS and historical energy efficiency goals.

There are three fundamental drivers of the macro results, growth-positive investment stimulus and fuel efficiency benefits, and growth-negative costs of technology adoption.

Their complex interplay determines the net outcome for the economy. Because these forces are countervailing, their aggregate impact 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 both 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, gross state product (GSP) and overall employment are both 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, ouptut, 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
(% and $billion difference from baseline 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)

Table 7 shows the key macroeconomic indicators for the LTES scenarios in 2050, relative to the baseline. As shown in the expenditure input tables (Table 4-5), 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, as well as continued electric power investments in solar, wind, and storage technologies. The economy-wide stimulus effects in the long run are generally about 4 times as large as the 2030 macroeconomic impacts. This makes intuitive sense as both the 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
(% and $billion difference from Baseline 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)

Employment Impacts by Occupation

One of the salient features of the BEAR model is the ability to forecast employment impacts by occupation. In Figure 1 and Figure 2 we present the employment impacts (relative to the pre-SB 350 baseline) 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 we find 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 much less direct such as office support, sales and marketing, and food processing and preparation.

Figure 1: Employment Impacts by Occupation (Mit_Med Scenario, percent change from Baseline)

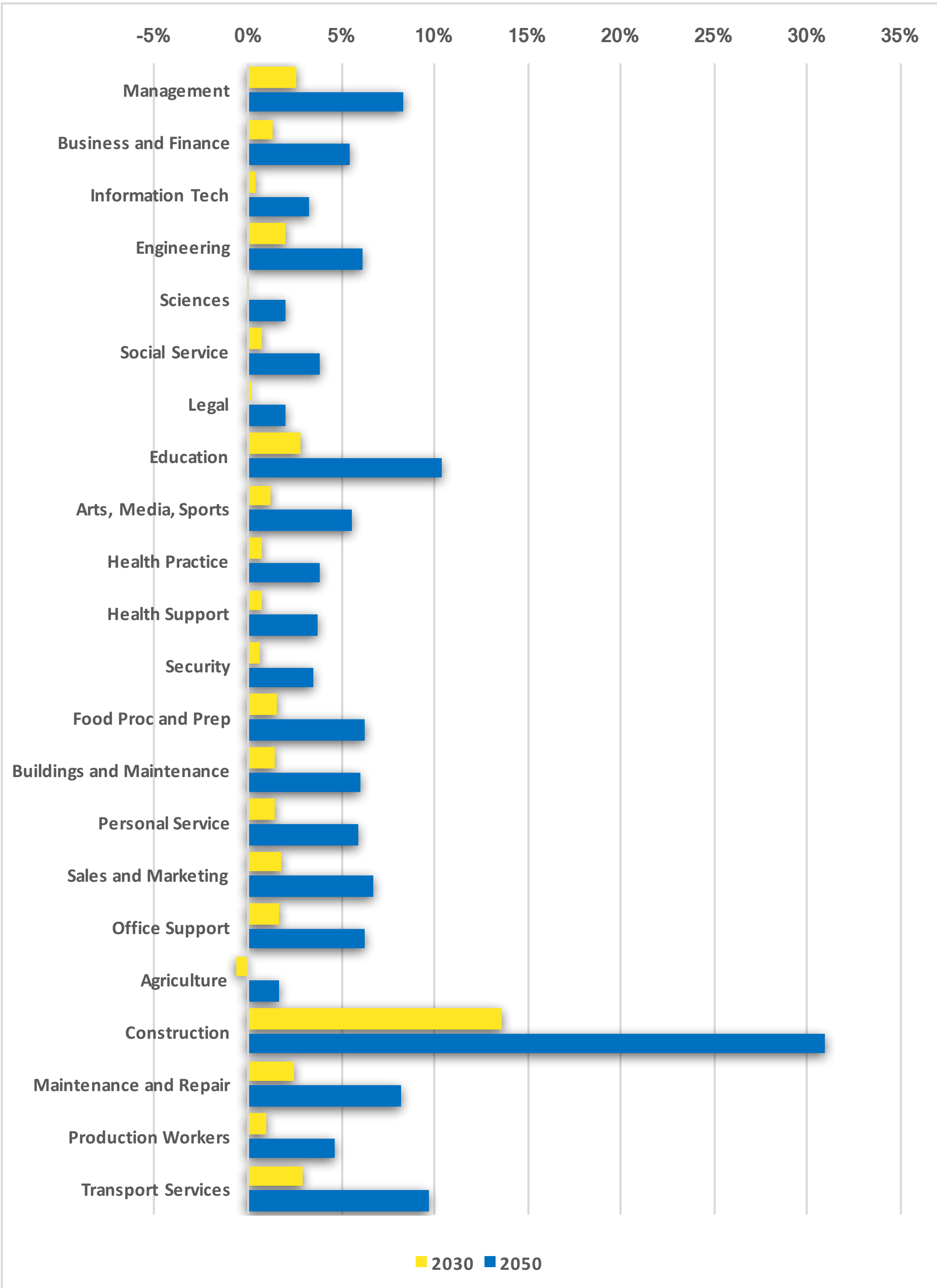
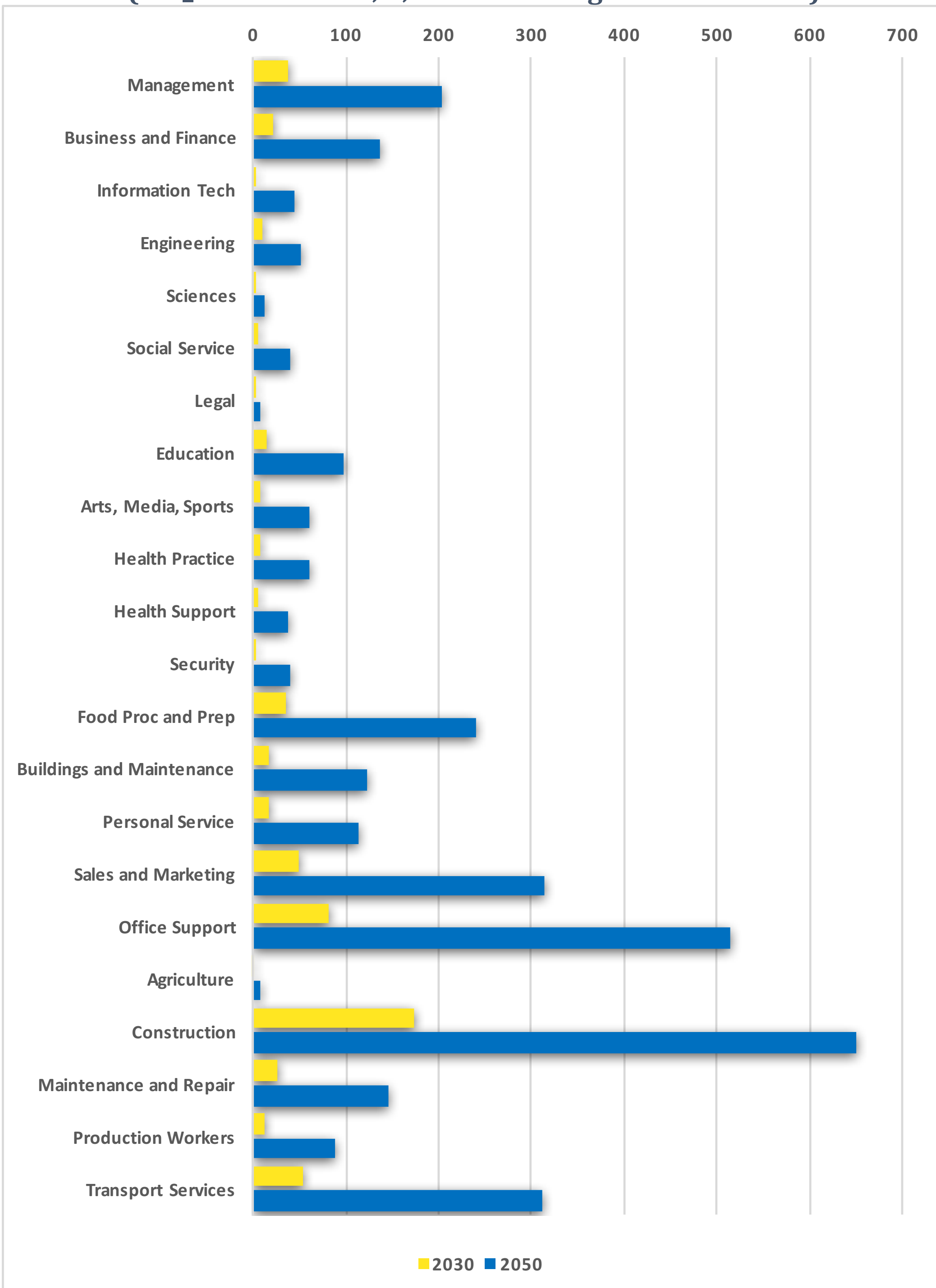


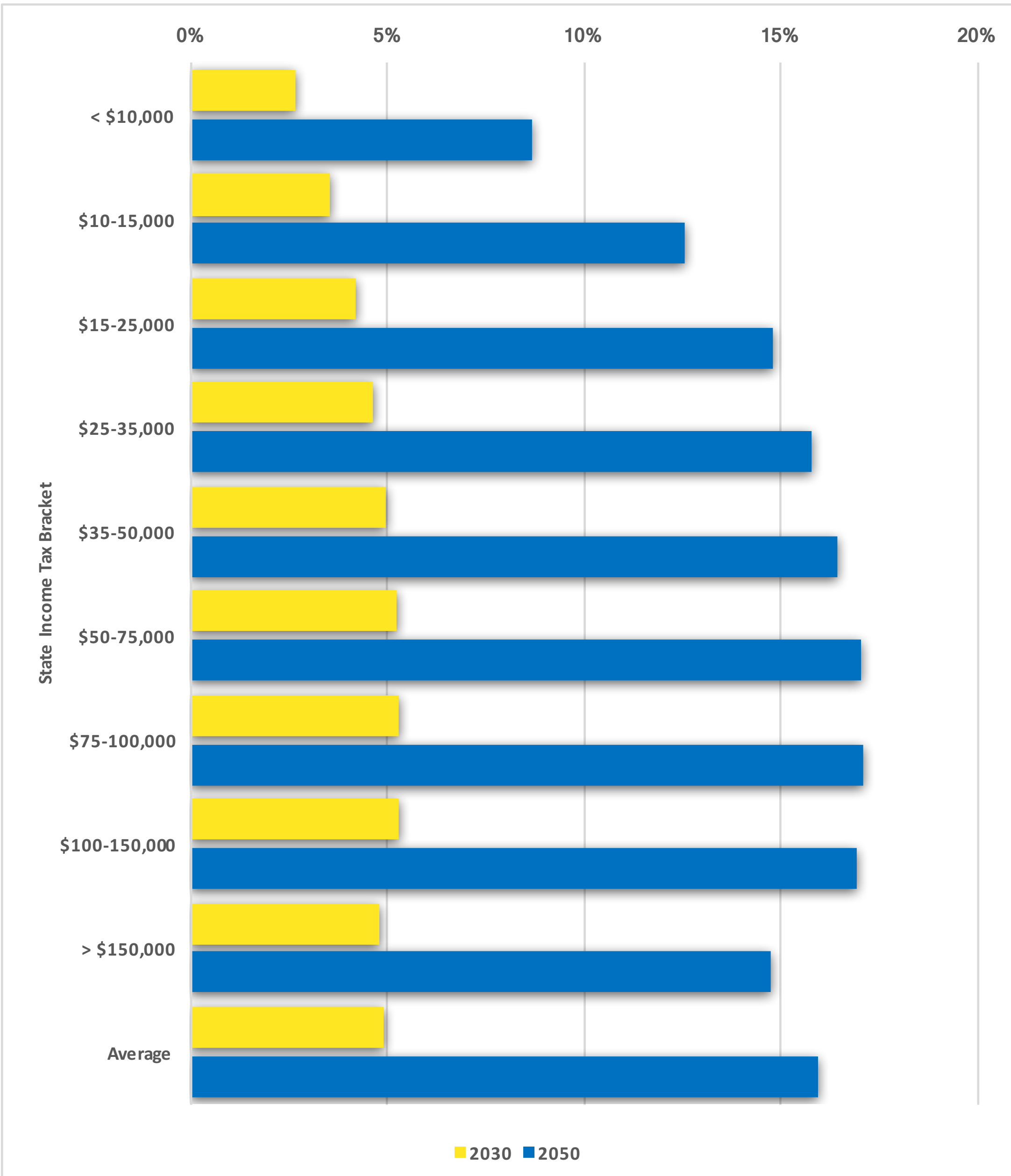
Figure 2: Employment Impacts by Occupation (Mit_Med Scenario, 1,000 FTE change from Baseline)



Impacts by Income Decile

The BEAR model has the ability to forecast results across state household income tax brackets. Given that the benefits from an 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 3.

Figure 3: Household Real Income Changes by Tax Bracket (Mit_Med, percent change from Baseline)



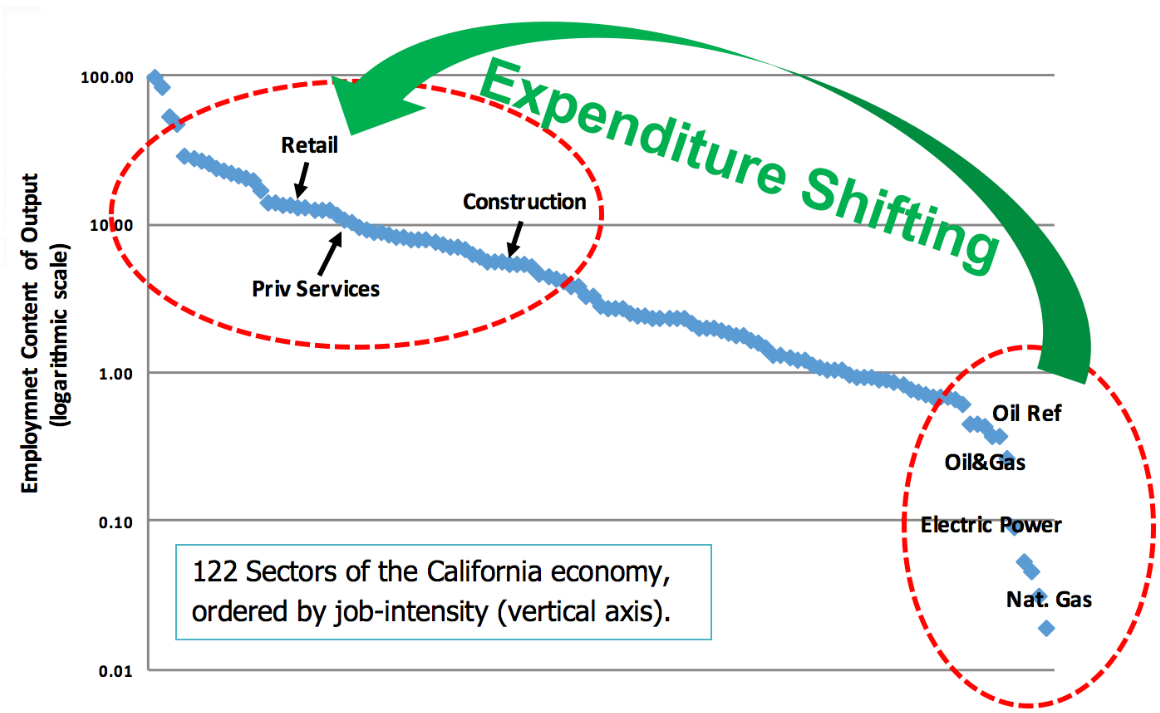
The difference in statewide income across all decides can be seen more clearly in Figure 3, which reports changes in 2050 household real incomes that would result with full implementation of LTES with median technology cost assumptions (Mit_Med scenario). Note however that these figures should not be 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 own 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 comprised of direct, indirect, and induced demand for workers, resources, and capital goods. Growth stimulus from energy saving is more subtle but also more pervasive. Promoting energy efficiency saves money for households and enterprises. These savings will be diverted to other expenditures, the majority of which go to in-state services:

- which employ workers of all skill levels and demographics
- which are non-tradable, 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 this expenditure 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 4 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 of revenue in the carbon fuel supply chain, for example, are 1-10% 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 4: Job Creation through Expenditure Shifting



3 Disadvantaged Community Analysis

3.1 Background

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 individual communities. In particular, the distributional component of costs and benefits will have broad implications with respect to policy impact and must be considered in order to ensure that vulnerable communities do not bear more than their share of the costs. Examples of past studies that directly considered policy impacts on disadvantaged communities include the Economic Assessment of SB350 commissioned by the California ISO (BEAR and Aspen 2016) and the Economic Analysis of the 2017 Scoping Plan developed by the California Air Resources Board (CARB 2017).

Here we use an approach to downscaling statewide economic impacts similar to the previous studies cited above. However, we advance the study of disadvantaged communities by incorporating an exploratory analysis of health benefits associated with reduced criteria pollutant concentrations resulting from a move toward cleaner energy sources. Moreover, in addition to income and employment effects, we also rely on detailed vehicle registration data from the DMV along with rebate data to examine adoption patterns of electric vehicles in both disadvantaged and non-disadvantaged communities. Lastly, we update the previously utilized methods by drawing on CalEnviroScreen 3.0 to identify disadvantaged communities (previous studies have utilized CalEnviroScreen 2.0 which weighted hazards differently) and by updating census tract level data from the American Community Survey (US Census Bureau; ACS 2016) used to calibrate community shares. We hope our approach will further develop the template for future analysis of environmental policy impacts on disadvantaged communities in California.

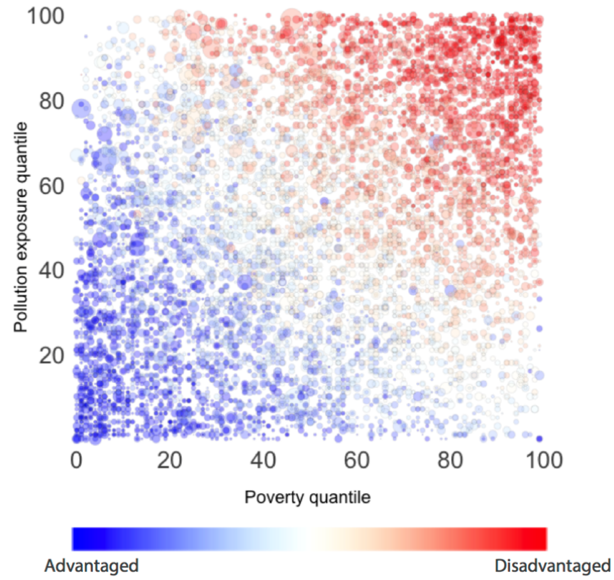
3.2 Identifying Disadvantaged Communities

In order to identify communities that are disadvantaged with respect to environmental policies, the California Environmental Protection Agency (CalEPA) worked with the Office of Environmental Health Hazard Assessment (OEHHA) to develop a tool called CalEnviroScreen (CES) that evaluates economic and environmental conditions of every census tract in California. The most recent version, CalEnviroScreen 3.0, was released in January 2017 and it 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. Disadvantaged Communities (DACs) are commonly defined using this tool as census tracts in the top 25^{th} percentile of CES scores. By this definition, there are currently 2,022 census tracts designated as disadvantaged communities in California.

The communities that are designated as disadvantaged using this approach are burdened by a combination of low income, high exposure to environmental hazards, and poor health. To illustrate the importance of this combination of factors,

Figure 5 highlights the relationships between pollution exposure, poverty, and CES score. Each point represents a census tract in California and the axes show poverty and pollution exposure. CES score is represented by color. DACs are concentrated in the upper right corner of the figure where both pollution exposure is high and income is low. The figure highlights the feature 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 5: The relationship between pollution exposure, poverty, and disadvantaged status.



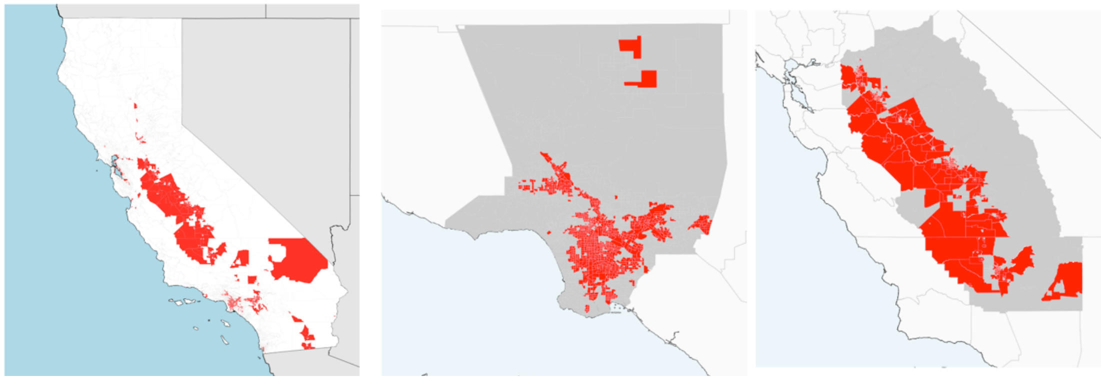
Note: The x-axis shows where the census tract ranks relative to other tracts with respect to poverty, the y-axis shows the pollution exposure rank, and the color shows the CES score rank. The size of the point is proportional to the census tract population.

3.3 Characteristics of Disadvantaged Communities

Spatial Distribution

The regional distribution of DAC communities is apparent from Figure 6. While there are disadvantaged communities throughout the state, they are highly concentrated in two region: the Central Valley and Los Angeles. In fact, approximately half of the disadvantaged communities are in Los Angeles County alone. This includes 51% of disadvantaged census tracts representing 46% of the disadvantaged population. Another 20% of disadvantaged communities are located 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 designated disadvantaged status for the purpose of 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 DAC population.

Figure 6: Collectively, Los Angeles and the Central Valley contain nearly 75% of all California DACs.



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

<u>Socioeconomic Status</u>

Naturally, disadvantaged communities are less well off than non-disadvantaged communities and these differences show up across the spectrum including lower income, lower level of education, and lower asset ownership. According to data from CalEnviroScreen 3.0 (CES), across the state, households in DAC communities average 53% lower per capita income than their non-disadvantaged counterparts and are 93% more likely to live below the poverty line.[1]

The CES data also reveal that DAC households are substantially more likely to be employed in the agricultural sector (4.3% vs 1.8%), however, this discrepancy is particularly stark in the Central Valley where more than 15% of DAC households are in the agricultural sector compared to less than 7% of non-DAC households. DACs also skew more heavily towards unskilled labor such as manufacturing (11.4% vs 9.3%), retail (12.0% vs 10.8%) and transportation (6.3% vs 4.2%).

While we do not observe energy usage for every census tract, we do observe the types of energy systems used for heating and cooling in the households sampled by the American Community Survey data (ACS; US Census Bureau 2016). We find that households in non-DACs communities are twice as likely to use solar energy for their heating and cooling needs while households in DACs are three times as likely not to have any heating or cooling systems in their homes.

[1] Source: author's calculations combining ACS 5-year average income estimates with CES 3.0 DAC designations.

Environmental Exposure

In addition to being less well off financially, by the CES 3.0 definition disadvantaged communities are also exposed to higher levels of many hazardous environmental exposures. For example, statewide emissions from diesel sources are 62% higher in DACs (27 compared to 17 kg of emissions day) and $PM_{2.5}$ exposure from all sources is 26% higher (12.3 compared to 9.7 ug\m^3). Pesticide use is 11% higher in disadvantaged communities (340 compared to 305 lbs. 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 and non-disadvantaged 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 non-disadvantaged counterparts (30 compared to 20 kg/day). Similarly, pesticide application is higher for both groups in the Central Valley, however, disadvantaged communities live in areas with 70% higher rates of pesticide application (845 compared to 498 lbs. per square mile).

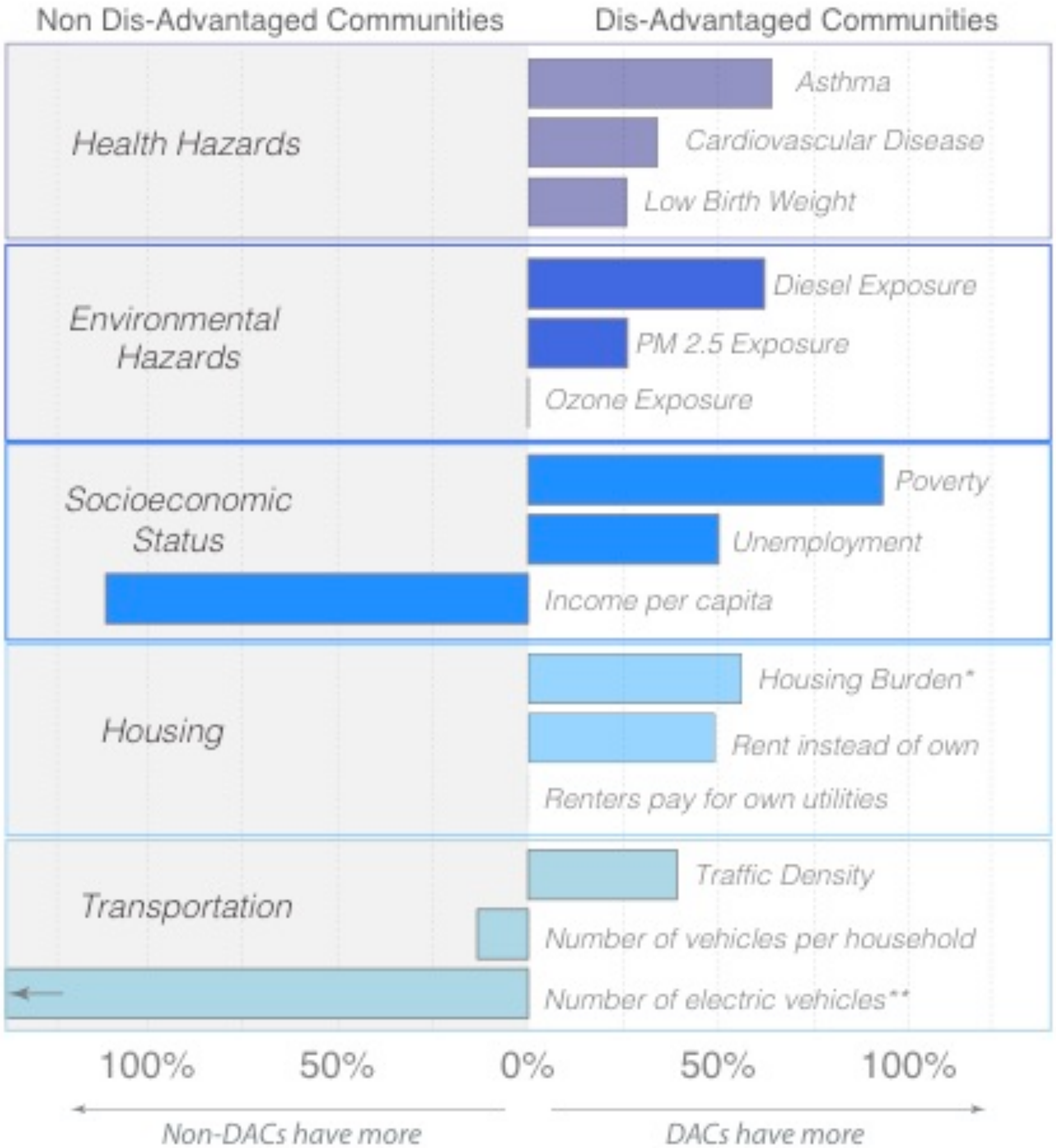
Health Burden

The high health and overall economic costs of exposure to these hazards is becoming increasingly clear (Zhang et al 2017; Zapata et al 2017; 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 DACs are disproportionately likely to be exposed to high amounts of these hazards, uniform reductions across the state stand to be particularly beneficial to these communities.

The combination of fewer resources to facilitate adaptation and higher exposure rates help contribute to a situation where disadvantaged households bare many of the overall health costs from poor environmental quality. For example, according to CES California households in DAC 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 since by the nature of being disadvantaged these communities are likely to be in poorer health overall. Nonetheless, the higher rates of disease incidence, and particularly asthma, indicate that improvements in air quality are likely to be particularly beneficial to disadvantaged communities.

It should also be noted that the source of pollution exposure in DACs vary geographically and 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. DACs in different regions are therefore likely to benefit more from different policies.

Figure 7: Overview of comparison between disadvantaged and non-disadvantaged communities



** A household has a "Housing Burden" if they pay more than 50% of their income for housing*
*** Non-DACs own more than 1,100% as many electric vehicles as DAC households*
**** It should be noted that 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 DACs 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. DACs in different regions are therefore likely to benefit more from different policies.

3.4 Methods

Directly modeling the economic impact of statewide policies at the disadvantaged community level using the BEAR model would require extensive data on economic activities for every census tract in California. Unfortunately, as far as we know, these data do not exist. We instead utilize state-wide impacts disaggregated to the census tract level and then highlight impacts in those census tracts designated as disadvantaged. The process of disaggregating statewide results to the census tract level is different for each outcome and these processes are described in detail below.

Downscaling BEAR Model Employment results

The BEAR model produces job impact estimates measured as total jobs by sector and by occupation. Jobs impacts are downscaled from the state to the census tract using occupational and sector employment information in the ACS. We use ACS 5-year estimates (2011-2015) of the share of number of households with residents employed in each sector and each occupation. We rely 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 inducted 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.

Caveats

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

Clean Vehicle Analysis

In order to downscale the impacts of clean vehicle use to the census tract level, we rely on vehicle registration data provided by the DMV as well as the Center for Sustainable Energy's Clean Vehicle Rebate Project data set. The Clean Vehicle Rebate Project (CVRP) is a publically 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 track level. While not all PEVs are captured in the database (as not every eligible vehicle owner applies to the CVRP), over the first five years of the program approximately 75% of eligible PEV purchases received CVRP rebates. Using this information on the location of clean vehicles in conjunction with DMV vehicle registration data allows us to model EV adoption and to downscale E3's statewide electric vehicle projections in order to examine the impacts on DACs. Currently, more than 93% of clean vehicles in California are owned by households in non-disadvantaged communities.

The data noted above is then used together with income data and detailed demographic information to model EV purchases. Next, we use BEAR model 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 impact of these changes on disadvantaged communities we rely on the American Communities Survey ("ACS") and calculate census tract level shares of households in each tax bracket using the 5-year averages covering the period 2011-2015. The census tract level shares of households in each tax bracket are 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 impact a particular community. Therefore, for any given census tract this approach is unlikely to accurately predict income change from the simulated policy. That being said, on average the statewide impacts within a tax bracket will impact the populations within that bracket so the statewide DAC vs non-DAC comparison are a reasonable best estimate.

In order to estimate average income per household we must first estimate the *number of households* in each census tract in 2030. To do so we use Department of Finance estimates of population growth by county. We assume 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, we can calculate household growth rates for each census tract and apply them to the current number of households in order to forecast the number of households in each census tract in 2030. These estimates of number of households are then used as the denominator in our income per household measure.

These predicted per-household income changes are then used to model EV purchasing patterns, which are in turn used to downscale the state-level electric vehicle forecasts generated by E3.

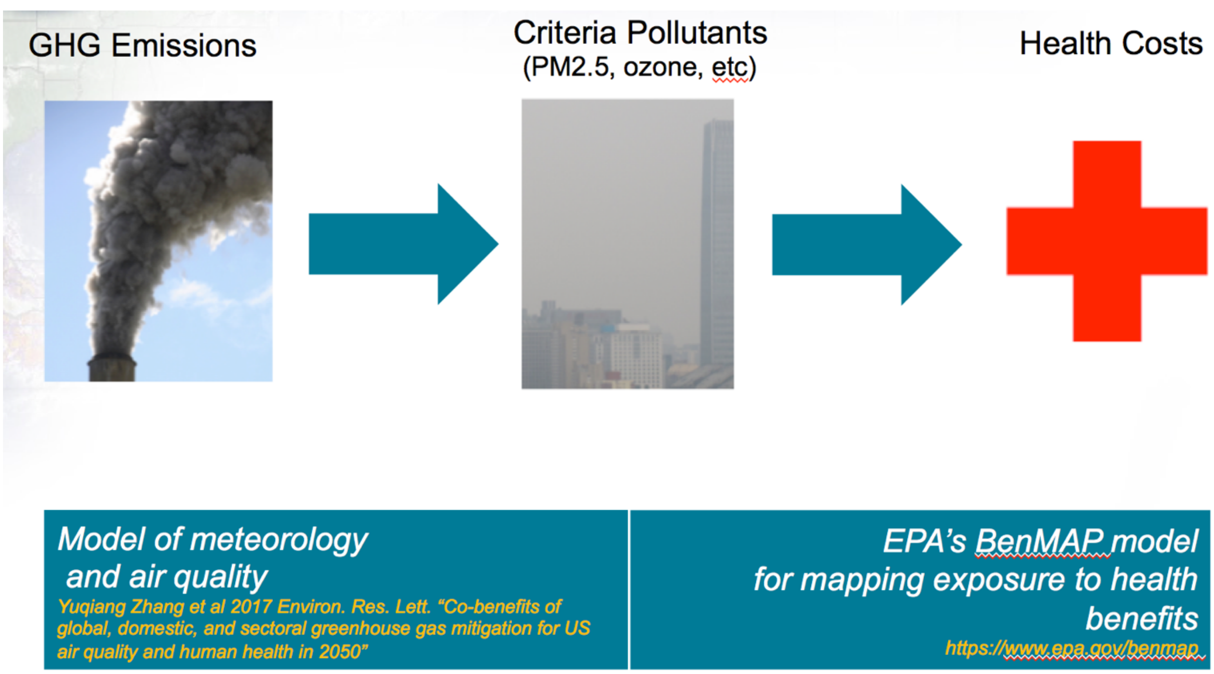
Caveats

Our approach allows purchasing patterns to vary by income but we do assume that household demographics are constant between now and the modeled years. While demographics do play an important role in predicting EV purchasing patterns (and we control for them in our model to try and isolate the role of income). Recent research has found that income is by far the most important predictor of EV purchases (CARB 2017b). We find that, at lower level incomes, additional income has an insignificant effect on the number of EVs purchased, however, at relatively high levels of income, new income does increase the number of EVs purchased. Additionally, while we allow EV purchasing patterns to vary by income, we are holding this relationship fixed into future.

3.5 Examining Health Benefits from Reduction in GHG Emissions

Poor air quality imposes substantial and unequal public health costs across the state. Conversely, averting such costs is an important co-benefit of reductions in GHG emissions and commensurate improvements in air quality. Moreover, the magnitude of benefits are thought to be large and likely to be realized in the near term.[2] As part of our medium and longer-term economic assessment of the state's future energy system, we present an exploratory analysis leveraging recent estimates of pollution health impacts to quantify the value of health benefits (i.e., avoided health costs) associated with a reduction in GHG emissions from LTES policies. We do this in four sequential steps.

Figure 8: Broad overview of health benefits analysis



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

[2] Recent work by Shindell et al estimates that lower emissions associated with global CO_2 reductions of 180GtC (to get to 2C warming) would lead to 153M fewer deaths by 2100, with 40% of benefits realized by 2050.

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

Unfortunately, we are not able to directly model how reductions in GHG emissions from California's LTES policies will specifically translate into lower criteria pollutant concentrations. Doing so would require an intensive modeling effort by physicists and environmental scientists and is far beyond the scope of the current project.[3] However, the authors of a recent study on the co-benefits of GHG mitigation in the U.S. (Zhang et al 2017) were kind enough to share their data with us,[4] which include ~50km x 50km gridded estimates of reductions in PM2.5 and Ozone associated with GHG emissions reductions in the domestic energy sector as well as associated avoided mortality estimates..Their model evaluates the RCP 4.5 ENERGY scenario[5] (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. The modeled emissions reductions come from changes in domestic electric power generation and energy extraction and transformation. [6] Benefits are modeled by Zhang et al in 2050 and we scale their estimates according to the share of 2050 GHG emissions reductions expected to be achieved by 2030.

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

As noted above, Zhang et al also provided their 50x50km gridded estimates for the number of avoided pre-mature deaths due to avoided PM2.5 exposure and the number of avoided pre-mature deaths due to avoided Ozone exposure. The avoided pre-mature deaths estimates were derived from the EPA's BenMAP model (BenMap 2017). This

[3] It should be noted that the CEC is currently supporting several other ongoing research efforts in this area.
[4] In the paper the authors model GHG emissions reductions in the energy, industrial, and residential sectors, however, we utilize their data for only the energy sector.
[5] The RCP 4.5 scenario is a midrange scenario associated with approximately 1.4C 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 (~2C warming by 2050) estimated annual benefits by 2050 of $11-20B from mortality alone (i.e., not including benefits from avoided morbidity).
[6] 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 we are capturing will inevitably be due to emissions reductions associated with activities other than power generation. CEC is also supporting more detailed assessments of California's energy sector that are currently underway.

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 PM2.5 and Ozone concentrations and output estimates for reductions in pre-mature deaths.

Step 3: Valuing mortality and morbidity

The standard approach for valuing the cost of an avoided pre-mature death is to use a concept known as the Value of a Statistical Life (VSL). We utilize the EPA's $7.6 for the Value of a Statistical Life,[7] which also represents a de facto consensus from legal actuaries in California. This value does not mean that the EPA places a dollar value on individual lives. It represents a survey based estimate of how much people are willing to pay for small reductions in their risk of dying from adverse health conditions that may be caused by environmental hazards. Willingness to pay for small risk reductions is then scaled up to represent the value of an avoided death.[8]

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

Directly estimating morbidity costs would require extensive information health costs incurred by cause, again outside this study and in many cases unavailable. We therefore rely on the EPA's regulatory assessment for the Review of the Particulate Matter National Ambient Air Quality Standards (NAAQS) to get an idea about the ratio of total health costs (mortality + morbidity) to mortality costs alone (Table 5-1, EPA 2006). In this regulatory assessment, the EPA estimated a range of total benefits, including mortality and morbidity, which we calculate to be 2.7x larger than their estimated mortality benefits alone. Scaling our benefits estimates by a factor of 2.7 we estimate the value of total health benefits in California associated with the volume of reductions in GHG emissions in 2030.

Step 4: Spatially Disaggregated (DAC level) Estimation

Because the data provided by Zhang et al are on a ~50x50km grid, we can match the avoided pre-mature deaths to individual communities and US census tracts (the geographic basis for DAC definition). We do this by taking the total avoided deaths in a grid cell and downscaling them across census tracts weighting by population. For

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

example, if 5 census tracts are contained within 1 grid cell and that grid cell predicts 10 avoided pre-mature deaths then each of the 5 census tracts will be assigned a fraction of the 10 deaths proportional to the population in that census tract. The census tracts designated as DACs by CalEnviroScreen 3.0 are identified and we estimate DAC and regional totals for the health benefits.

Caveats

This study utilizes modeled 50x50km gridded health benefits estimates from domestic GHG emissions reductions in the energy sector (Zhang et al 2017) and is intended to be illustrative of the potential magnitude of health benefits. However, studies devoted specifically to analyzing California policies at the local level have recently been published[9] or are underway (CEC is supporting several ongoing studies) and more of these types of studies are needed in order to illuminate highly localized effects.

The main caveats of our study are that GHG reductions from LTES policies are not being directly modeled and our estimates do not include benefits from emissions reductions in the transportation sector. Benefits are modeled from GHG reductions due to 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 our benefits estimates incorporate emissions reductions in neighboring states.[10] We are also assuming 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. We are thus underestimating benefits in places where LTES policies will reduce criteria pollutants in ways other than through electricity generation. Moreover, our analysis does not consider GHG emissions from the transportation sector which are likely to be extremely important to health benefits in California.

Another main assumption is that total health benefits and avoided pre-mature deaths conform to a 2.7 multiple relationship observed at the national level. This assumption is based on previous work by the EPA and takes averages from estimates in the EPA regulatory assessment for the National Ambient Air Quality Standards. It should be noted, however, that EPA estimates of morbidity costs in this study range widely and while we take the average, other estimates within the confidence interval would result in some variation of total avoided health cost estimates.

Additional assumptions include the following:

[9] Zapata et al 2017
[10] Zhang et al also estimate air quality changes associated with global emissions reductions. However, we utilize estimates of air quality changes associated with domestic emissions reductions only so our estimates do not incorporate benefits from emissions reductions in Mexico or Asia, which are expected to be substantial for Californians.

- value of a statistical life is $7.6M,
- BenMAP, a national assessment tool, appropriately estimates the number of avoided deaths from reductions in criteria pollutants[11],
- the total number of avoided deaths in a 50x50km area will be realized proportionately to population within that area

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

- The potentially large local environmental, health, and safety benefits from electrification of the vehicle fleet
- Productivity benefits from lower criteria pollutant concentrations (e.g. work and school attendance, performance, etc.)
- Local environmental and health benefits from rooftop solar[12]
- Benefits from avoided local temperature increases due to lower GHG emissions.[13]

These (and other) benefits would be additional to those estimated in this study.[14]

3.6 Results

If the recommended Medium Term Policies are implemented, Disadvantaged Communities (DACs) 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

[11] See https://www.epa.gov/benmap/how-benmap-ce-estimates-health-and-economic-effects-air-pollution for more details
[12] Some of the benefits from rooftop solar are implicitly included in our health benefits estimates insofar as rooftop solar helps reduce demand for other dirtier forms of electricity generation and therefor contributes to lower GHG emissions in the energy sector statewide. However, this process is not explicitly modeled and we cannot directly account for the location of potential solar expansion.
[13] Higher temperatures have been found to impact many outcomes including, but not limited to, agriculture, income, education, and crime (Carleton and Hsiang 2016).
[14] For more information on non-health co-benefits from reductions in GHG emissions, including examples of studies estimating damages to each of the mentioned outcomes (and more), see Carleton and Hsiang "Social and economic impacts of climate", Science 2016.

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

The following sections describe our results in more detail 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.

Job Creation

Our model results suggest that Base Cost policies stimulate the overall California economy, but that DACs experience relatively greater job creation. More specifically,

- By 2030
  - 170K more jobs created in DACs
  - 406K more jobs created in non-DACs
  - DACs (25% of state population), will take 30% of new jobs
- By 2050
  - 964K more jobs created in DACs, 29% of new jobs
  - 2.4M more jobs created in non-DACs

2030 Job Creation

Job growth statewide is driven by new jobs in construction, transportation, and service industries and these sectors happen to be sectors that disproportionately employ DAC workers. However, the benefits for this job creation will be experienced unevenly across the state and regions with employees in the noted sectors will benefit most. In Los Angeles, for example, 45% of the population lives in a DAC community and DAC workers are 55% more likely to be employed in service industries as well as 60% more likely to be employed in construction industries so more than half of the 161,000 forecast jobs in Los Angeles county in the base cost mitigation scenario are forecast to be created in DACs. Similarly, DAC workers in the Central Valley are more likely than non-DAC workers in that region to be employed in transportation and construction sectors. However, DAC and non-DAC workers are about equally as likely to be employed in Service Sectors in this region. Consequently, more than 32,000 of the

59,000 2030 jobs created in the Central Valley in the Base Cost Mitigation Scenario are forecast to be created in DACs.

Low cost mitigation means negative net cost but it also lowers demand stimulus so overall, we see positive but limited job creation by 2030. In DACs specifically, we see small positive job creation. This includes both Los Angeles, where 60% of DACs see at least 20 new jobs, and the Central Valley, where 47% of DACs 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 less profits to spur job creation so we see very limited job creation and even some job losses by 2030. Statewide nearly a third of DACs lose jobs in this scenario although the magnitude of job losses is relatively small (0-20 jobs lost). In Los Angeles nearly 40% of DACs lose jobs by 2030 but in the Central Valley the share of DACs with job losses is limited to 25%.

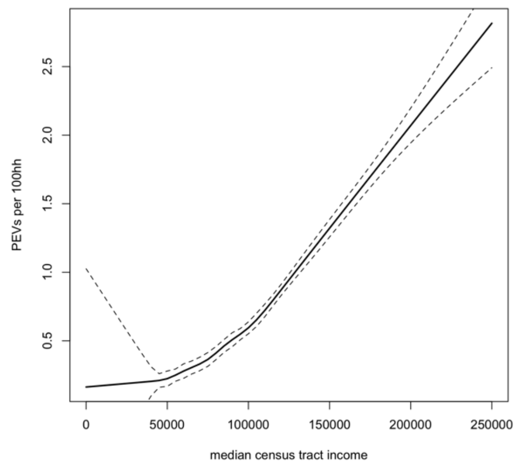
2050 Job Creation

Like 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 has includes 883,000 jobs generated across the state and more than 40% are generated in DACs due in large part to growth in the construction industry and service sectors. Both Los Angeles (192 jobs created per DAC) and the Central Valley (216 jobs created per DAC) experience substantial benefits. However, these benefits are significantly smaller than jobs generated in the Medium (Base) Cost Scenario where more than 3.3M new jobs are forecast to be generated statewide including 475,000 jobs in Los Angeles DACs and 344,000 jobs in Central Valley DACs. In the High Cost Scenario these numbers are reduced to 247,000 DAC jobs statewide and 120,000 and 49,000 jobs in Los Angeles and Central Valley DACs, respectively.

Electrical Vehicle Adoption

Relying on data from the DMV, electric vehicle rebate programs, and official sources on household income and demographic, we estimate patterns of EV adoption. Our approach is consistent with recent research (CARB 2017b) in that we find the most important predictor of EV adoption is income. In order to model future adoption, we assume stable demographics and use predicted changes in income from the BEAR model and we find the following results. For low-income households, in the absence of targeted programs[15], additional income generated by energy policies has a negligible impact on EV adoption. For relatively wealthy households we see a small but positive increase in adoption in the Base Cost scenarios.

Figure 9: Modeling the relationship between census tract income and the number of EVs purchased



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

Specifically, we estimate that:

- By 2030, there will be:
    - 180K new DAC EVs (6 additional EVs per 100 DAC hh)
    - 1.5M new non-DAC EVs (14 additional EVs per 100 non-DAC hh)
- By 2050, there will be:
    - 810K new EVs in DACs.
    - 11M new EVs in non-DACs.

Electric Vehicle adoption is likely to accelerate over the coming decades. Absent specific policies targeting DAC adoption, most new vehicles are likely to be purchased by non-DAC households. However, there is significant uncertainty around DAC adoption owing in large part to the unknown nature and effectiveness of potential incentive policies and future costs.

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

Health Benefits

While our analysis is exploratory in nature, our estimates are intended to provide insight on the potential order of magnitude of health benefits. It is quite clear that emissions mitigation policy will make highly valuable contributions to public health across California. Specifically, we estimate that:

- In 2030 alone, the economic value health benefits from GHG reductions in the energy sector will be $6.0 billion, of which:
  - $2.4B is due to averted mortality
  - $3.6B is due to averted medical (morbidity) costs

These benefits compare to about $8 billion in average annual direct costs of mitigation policy.[16] These large estimates are consistent with other emerging work on this issue including Zapata et al 2017 where the authors estimate the value of *avoided mortality alone* relative to the more extreme RCP 8.5 to be $11-20 billion by 2050. If total (mortality + morbidity) costs are 2-3 times as large as mortality costs alone then that would suggest total annual benefits under RCP 8.5 to be in the range of $20-60 billion by 2050. Our estimates represent health benefits associated with reductions in GHG emissions in the energy sector alone but do not quantify many of the other expected benefits that are known to be substantial. However, assuming uniform statewide emission reductions, these **benefits are higher for households in disadvantaged communities**. Moreover, we are underestimating the total benefits to DACs of these policies because we cannot fully account for the potential electrification of the transportation sector, which is likely to benefit DACs because of their proximity to transportation networks. [17]

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

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

[16] Our estimates are larger than the $1-2B estimated by CARB and cited in the 2030 scoping plan but congruent with several recent publications estimating substantially larger benefits (e.g., Shindell et al 2018, Zapata et al 2017, Saari et al 2015).

[17] 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.

Because DAC households have lower incomes, these gains are even more dramatic in relative terms. However, 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 co-benefits not estimated here include:

- Productivity benefits from lower criteria pollutant concentrations (e.g. work and school attendance, performance, etc.)
- Local environmental, health, and safety benefits from electrification of the vehicle fleet
- Local environmental and health benefits from rooftop solar
- Benefits from avoided local temperature increases due to lower GHG emissions. Higher temperatures have been found to impact many outcomes including, but not limited to, agriculture, income, education, and crime (Carleton and Hsiang 2016)

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

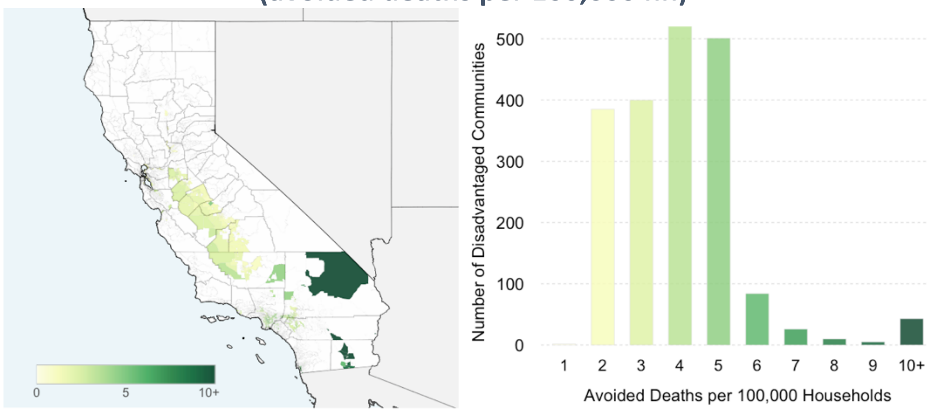
It should also be noted that our estimates of public health benefits are *not* directly linked to our EV analysis. In other words, we do not explicitly capture electrification of the vehicle fleet in our public health impact estimates and therefore cannot make any statements about the distributional impacts of health benefits from vehicle fleet electrification. Places like Los Angeles where a significant portion of emissions come from LDVs are more likely to benefit from new EV purchases than places like the Central Valley where HDVs are a larger contributor to emissions. Benefits from reductions in vehicle emissions would be *in addition to* the benefits estimated here. For more information on transportation networks and DAC exposure to pollution see CEC's 2017 IEPR.[18]

While most of the avoided deaths are a result of reductions in PM2.5, the primary source of this public health benefit in San Bernardino DACs is lower Ozone exposure. The census tracts in dark green (15-20 lives saved per 100,000 households) (see annex Section 5.3 maps and, e.g. Figure 9 below) are in the 93rd percentile of Ozone exposure statewide and the meteorological model from Zhang et al predicts a substantial reduction in Ozone exposure around San Bernardino.

[18] 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.

Figure 9: Medium Cost Scenario Avoided Pre-Mature Deaths

(avoided deaths per 100,000 hh)



3.7 Conclusions

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

Job Creation:

New job creation is largely in sectors and occupations that disproportionately employ people from Disadvantaged Community 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 (i.e., jobs generated through new investments) while service jobs are more related to indirect job growth (coming through savings induced spending).

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 non-DAC 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.

Pollution and health in DACS:

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

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

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

Transitions to cleaner energy sector and cleaner vehicle fleet are more likely to improve air quality (and thus benefit DACs) in areas like Los Angeles than in areas in the Central Valley. This is because much of the hazardous exposure that DAC households in the central valley face is due to diesel emissions from farm equipment, pesticide exposure, and other hazards that are less directly related to energy policies or vehicle emissions. That being said, due to 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 LA where most of the emissions are generated by sources covered by these policies.

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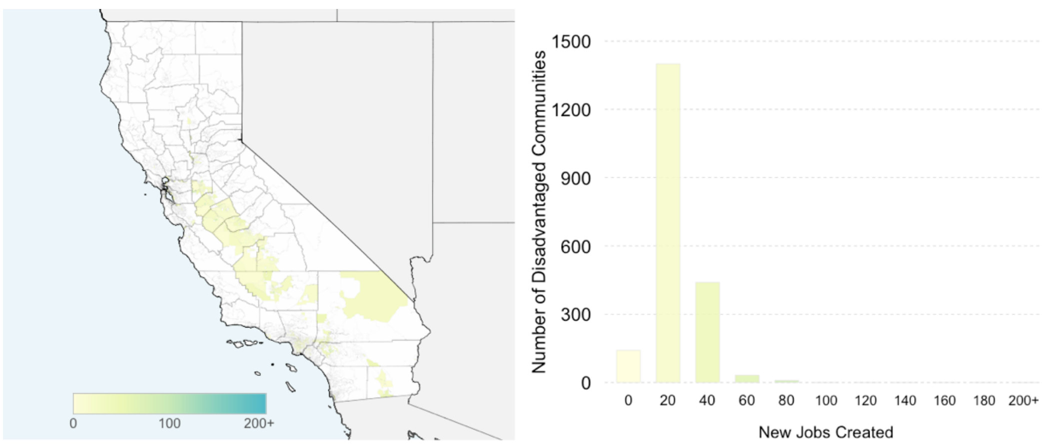
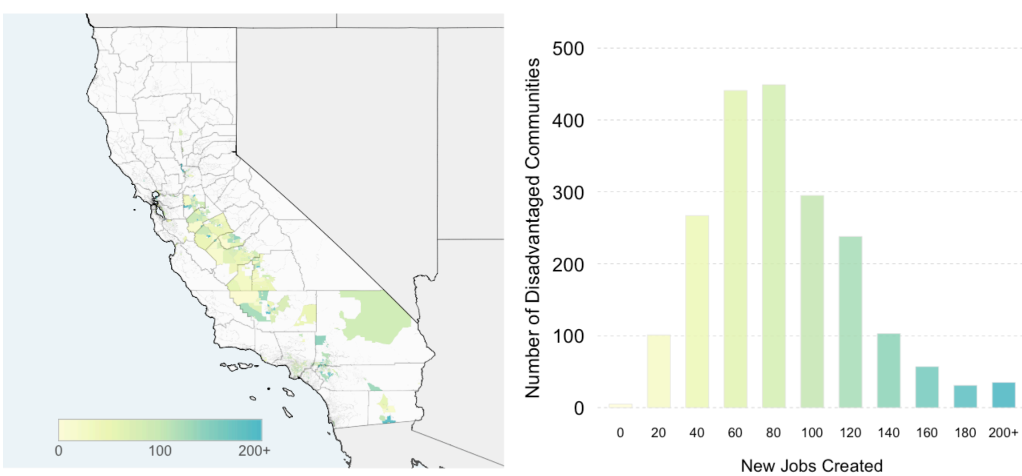
5 Results Appendix

5.1 Job Creation

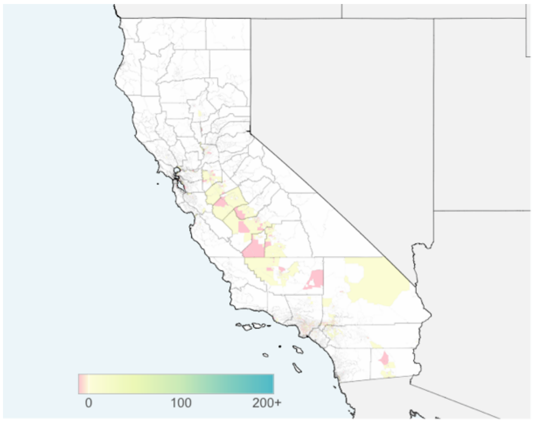
Job Creation - 2030 Low Cost Mitigation

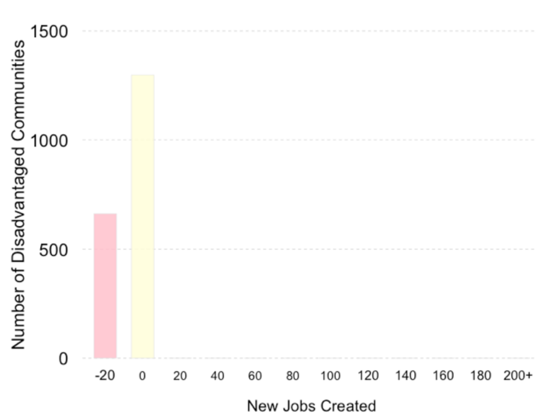


Job Creation - 2030 Medium Cost Mitigation

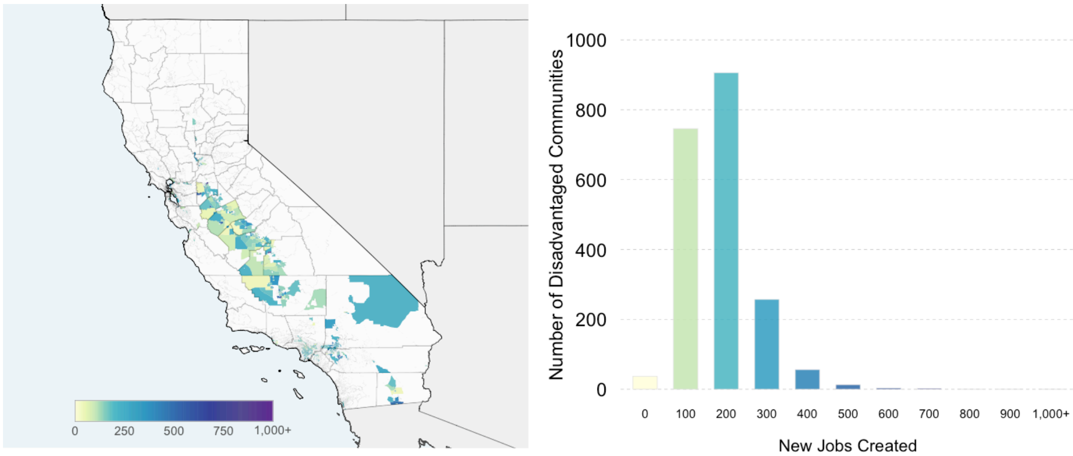


Job Creation - 2030 High Cost Mitigation

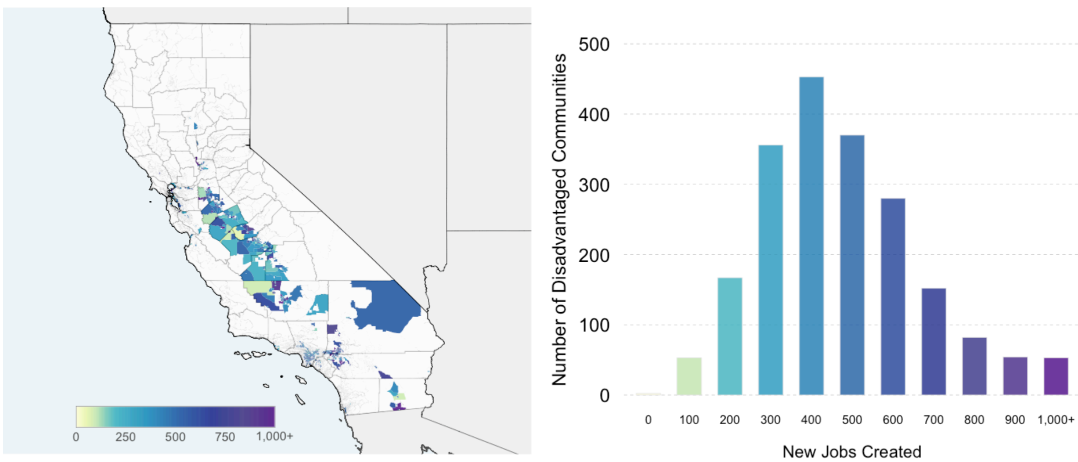

0
100
200+


Number of Disadvantaged Communities
1500
1000
500
0
-20
0
20
40
60
80
100
120
140
160
180
200+
New Jobs Created

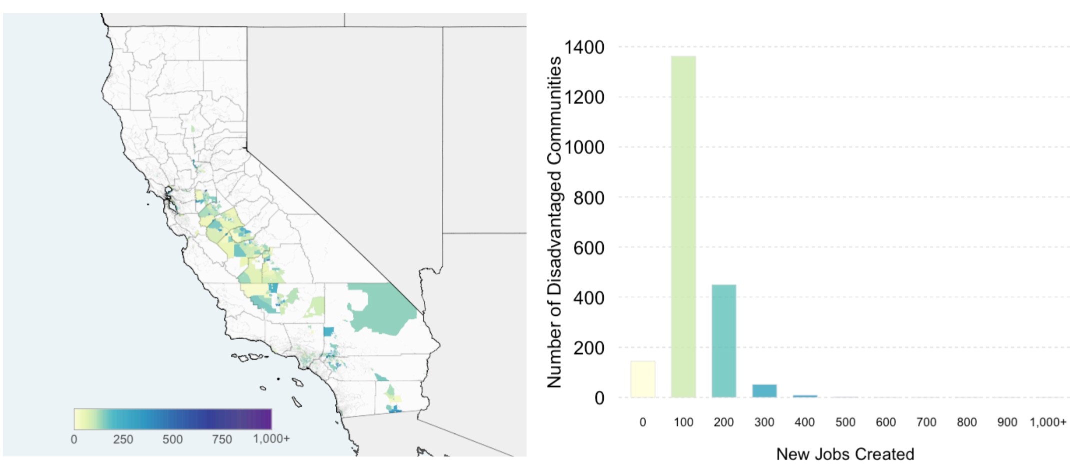
Job Creation - 2050 Low Cost Mitigation



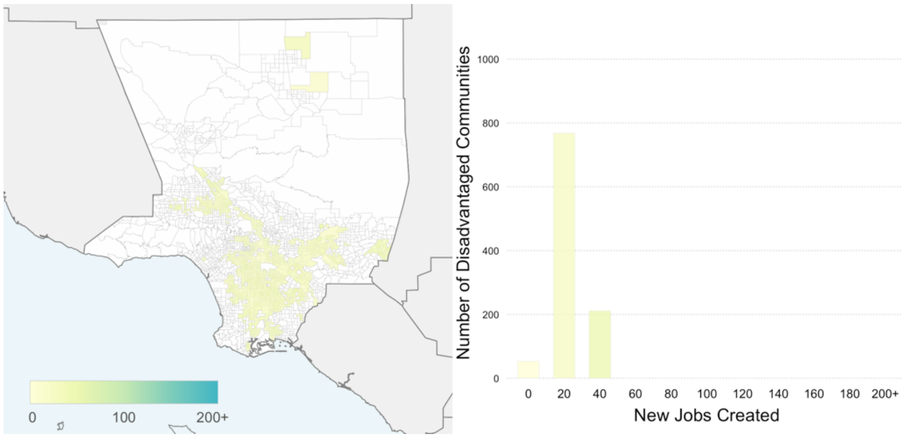
Job Creation - 2050 Medium Cost Mitigation



Job Creation - 2050 High Cost Mitigation



Job Creation - 2030 Low Cost Mitigation (Los Angeles)



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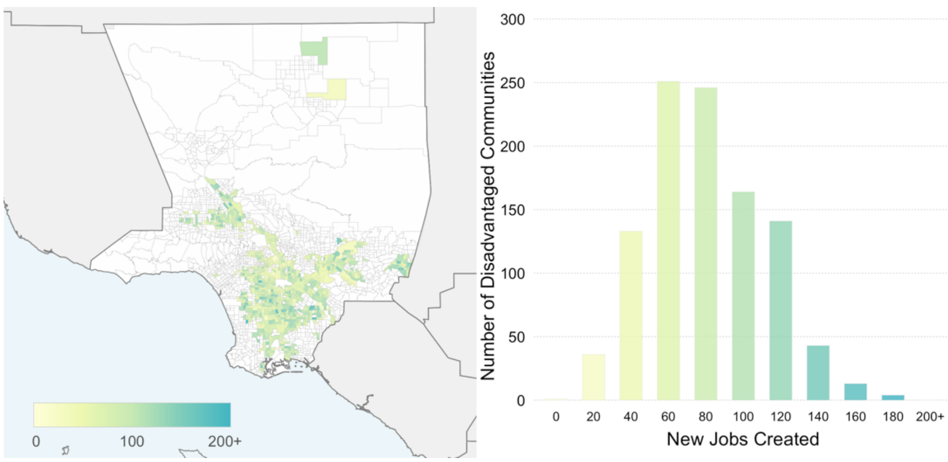

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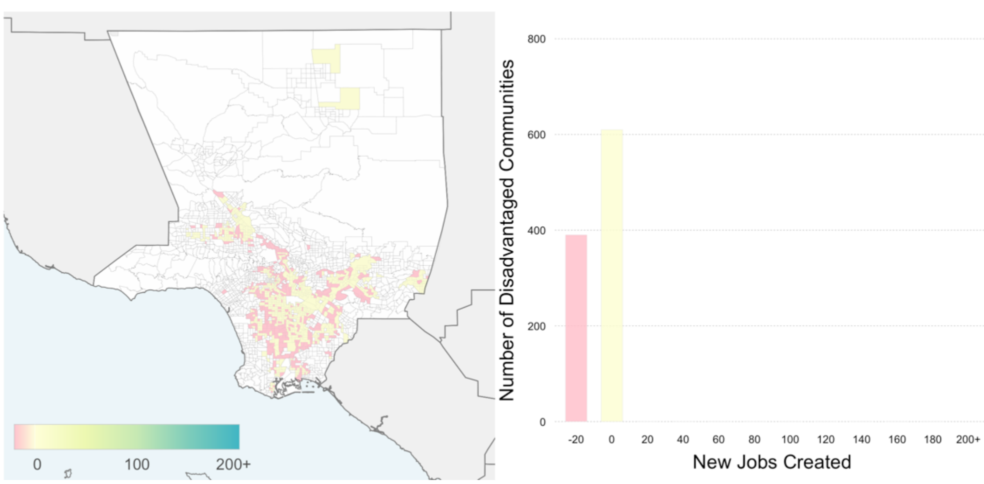
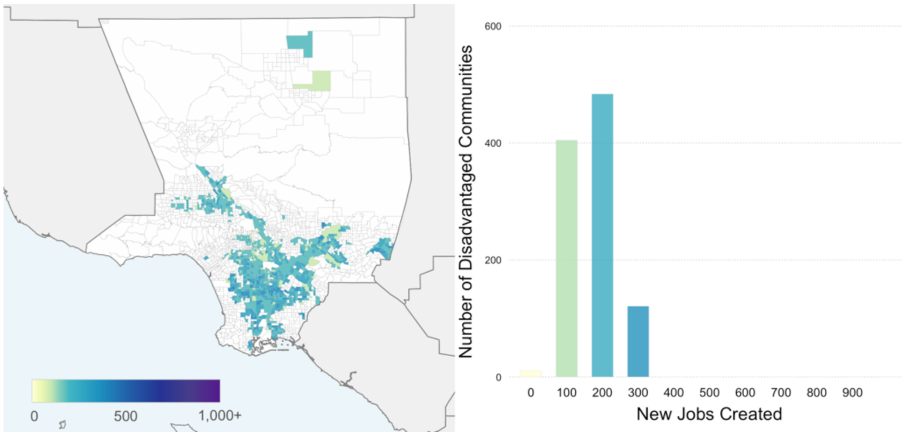


Job Creation - 2050 Low Cost Mitigation (Los Angeles)



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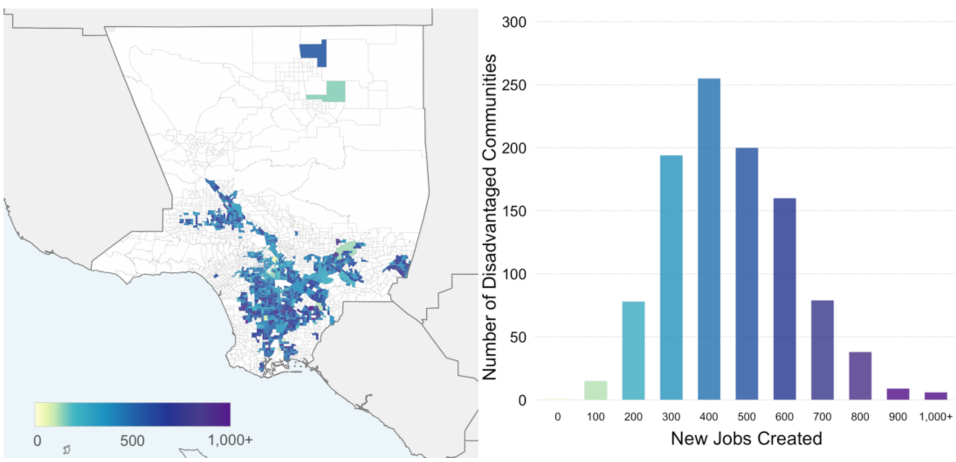
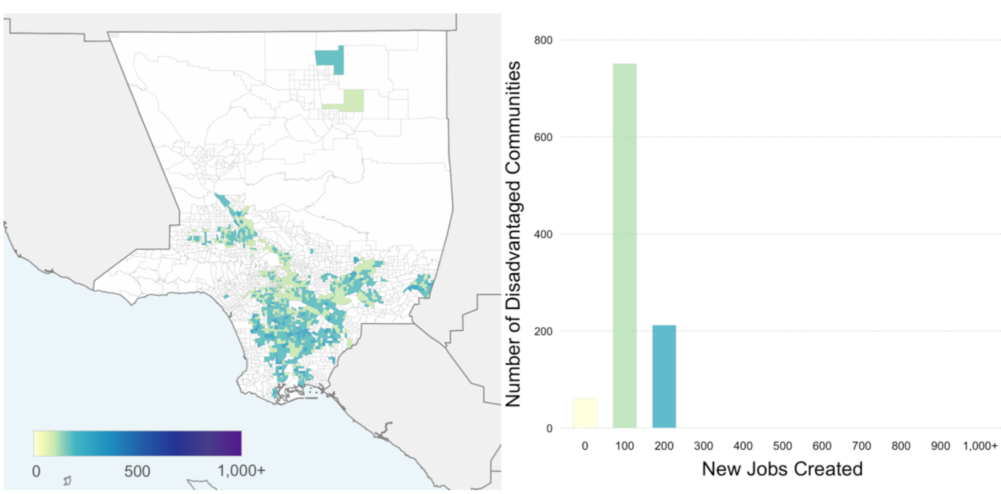
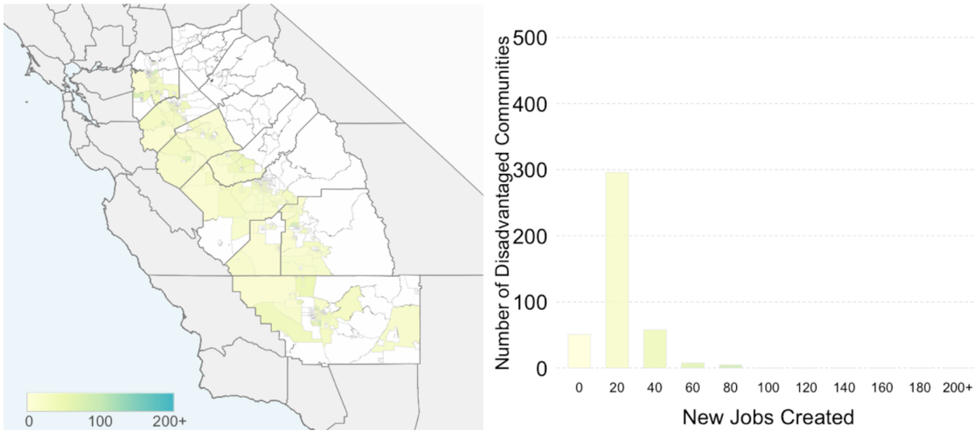


Job Creation - 2050 High Cost Mitigation (Los Angeles)



Job Creation - 2030 Low Cost Mitigation (Central Valley)



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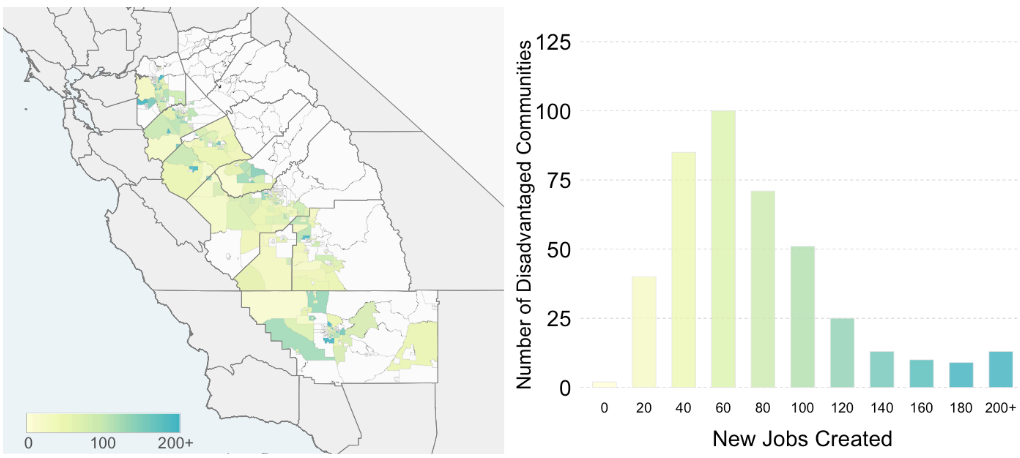
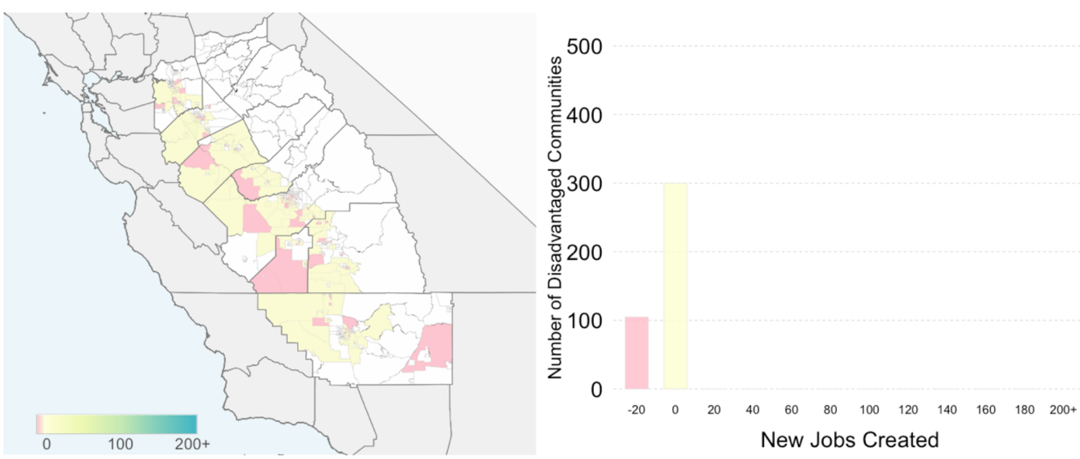


Job Creation - 2030 High Cost Mitigation (Central Valley)



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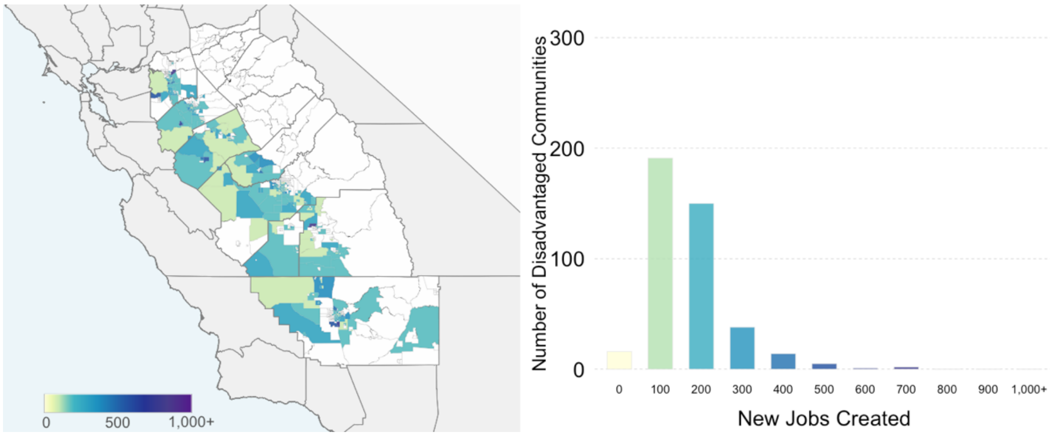

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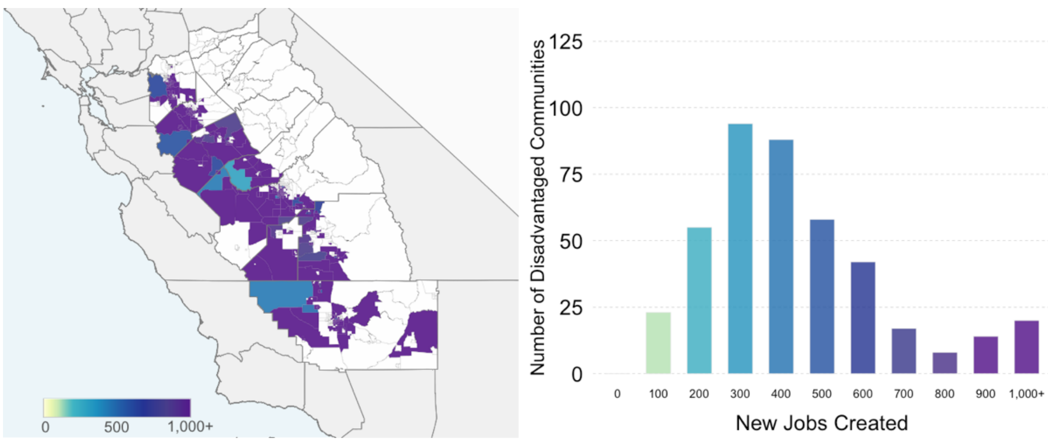

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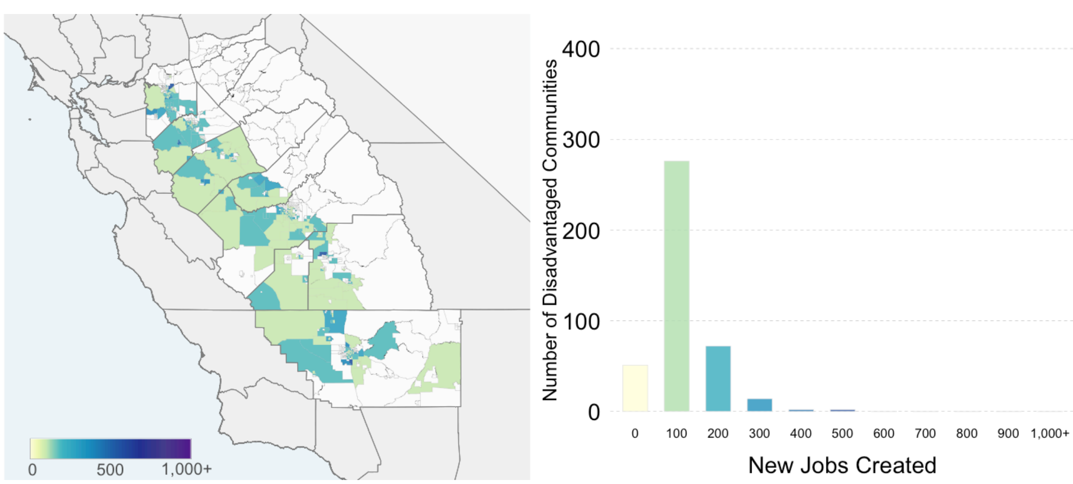
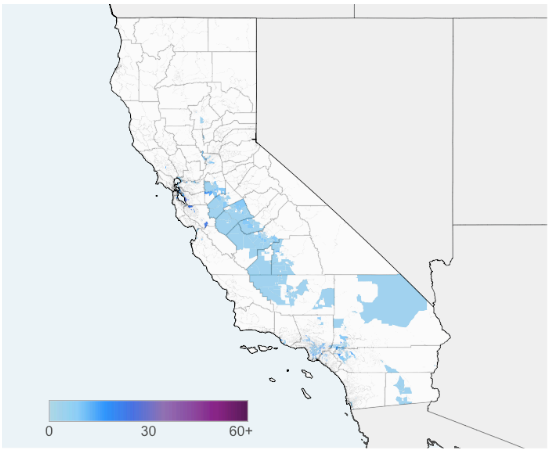
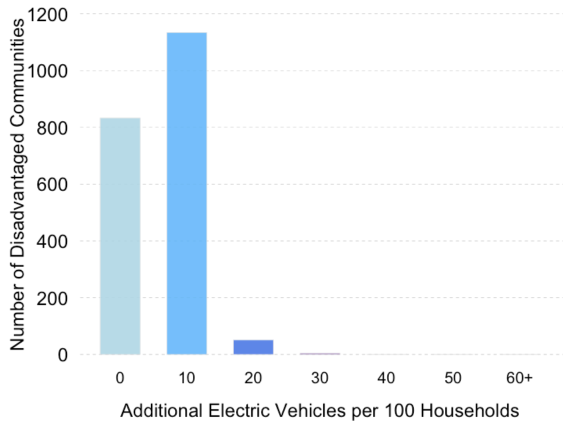


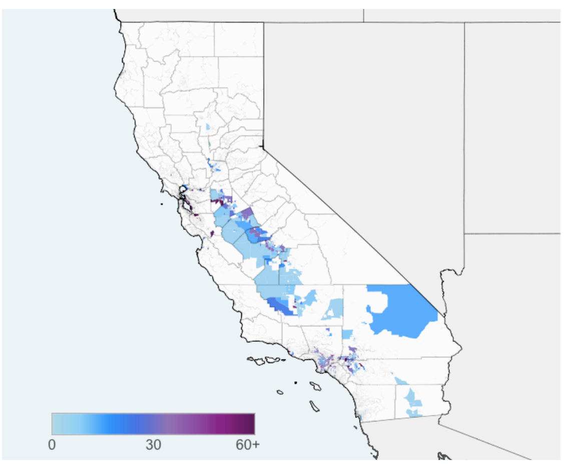
5.2 Electric Vehicle Adoption

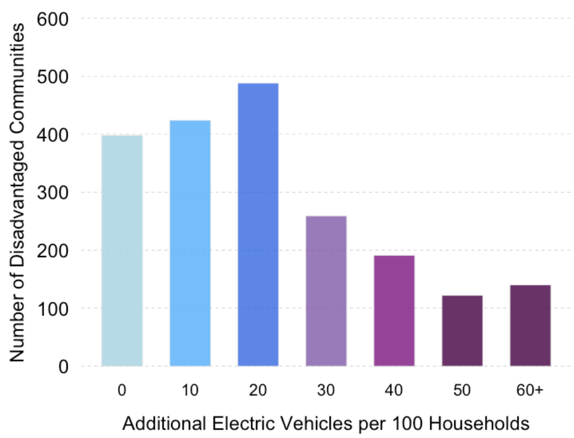
Additional Electric Vehicles - 2030



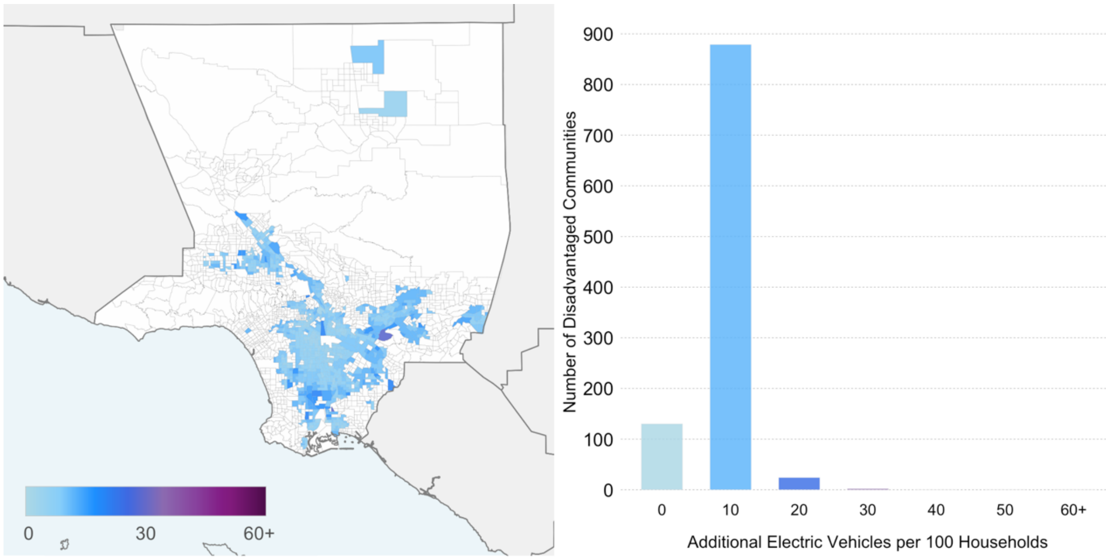


Additional Electric Vehicles - 2050

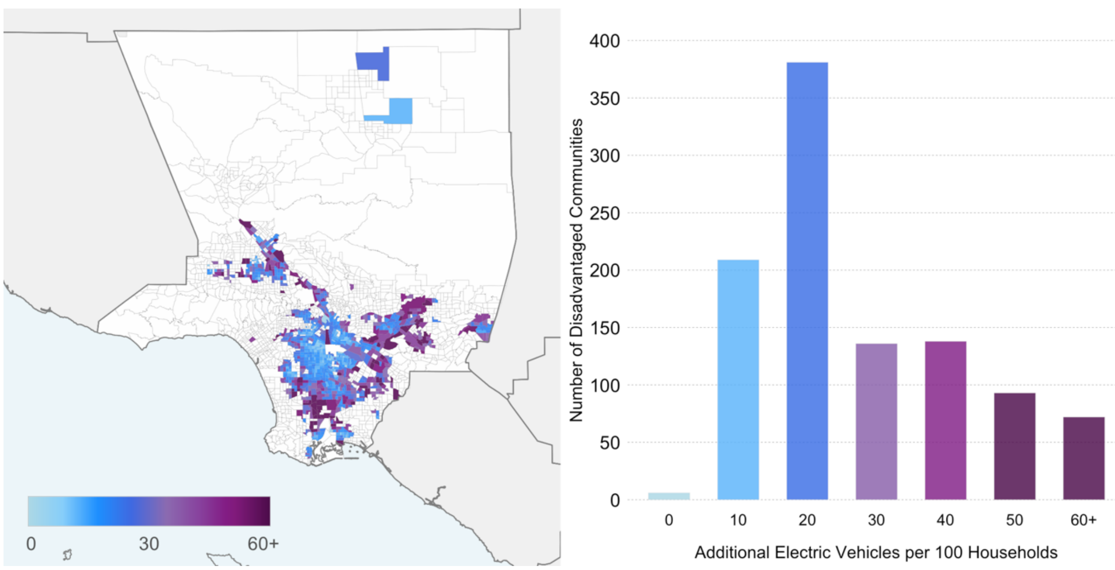




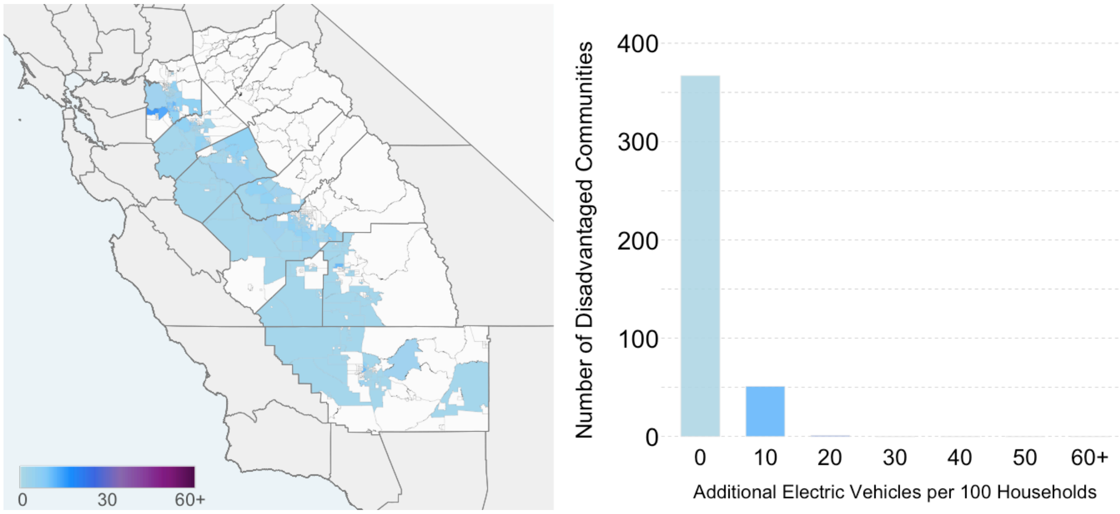
Additional Electric Vehicles – 2030 (Los Angeles)



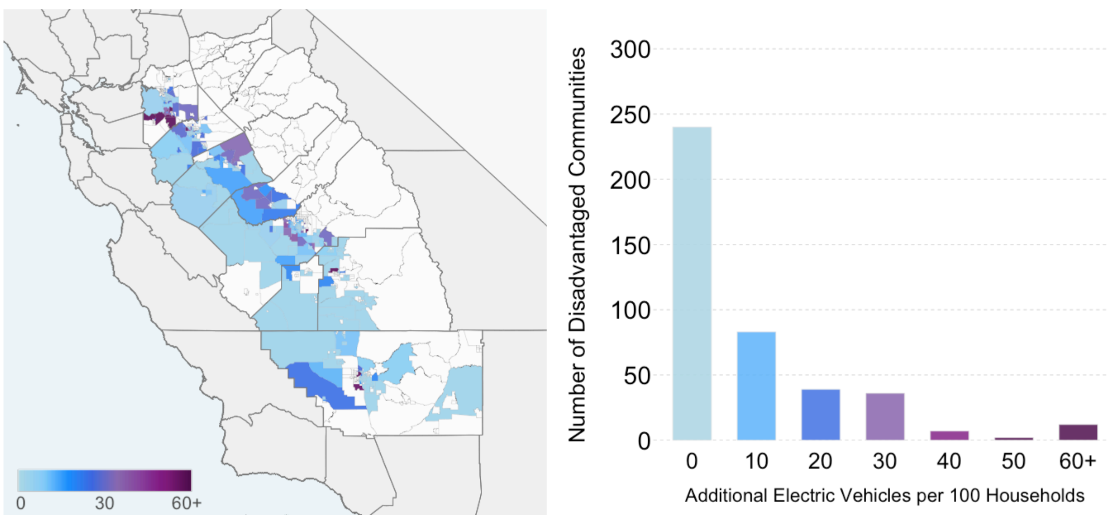
Additional Electric Vehicles – 2050 (Los Angeles)



Additional Electric Vehicles – 2030 (Central Valley)

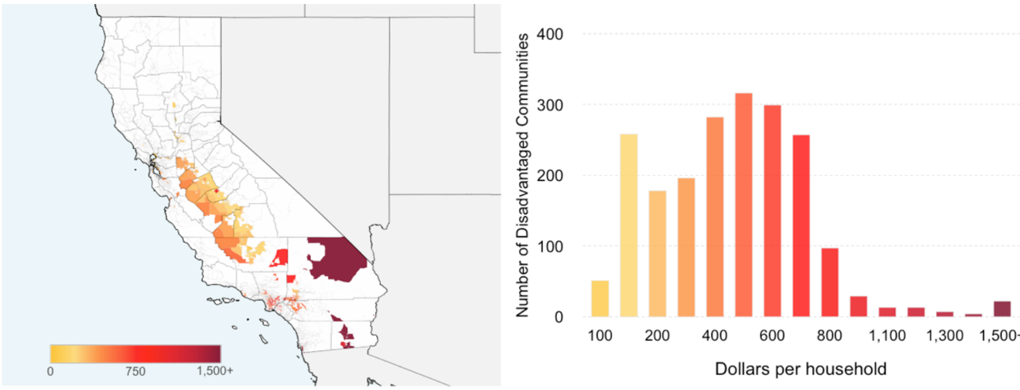


Additional Electric Vehicles – 2050 (Central Valley)

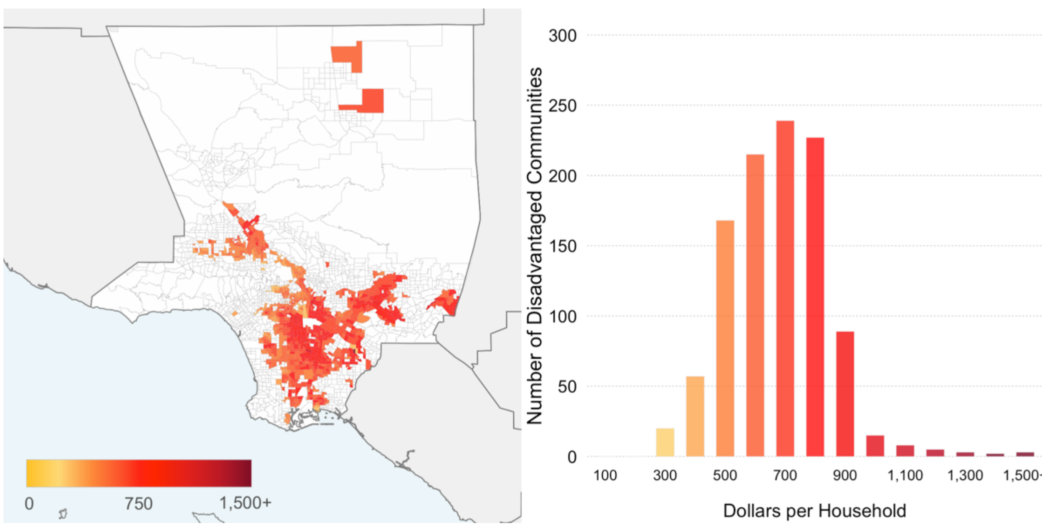


5.3 Public Health Benefits

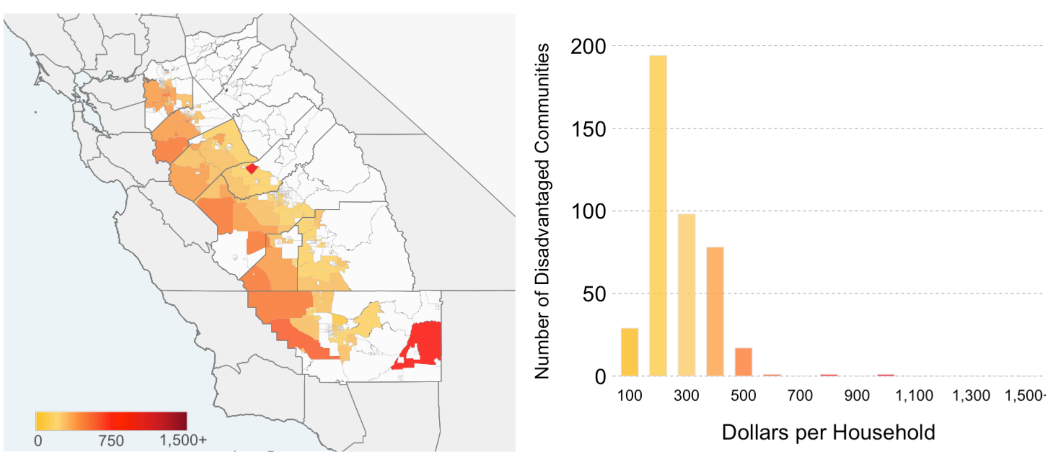
Medium Cost Scenario Health Benefits ($/hh)



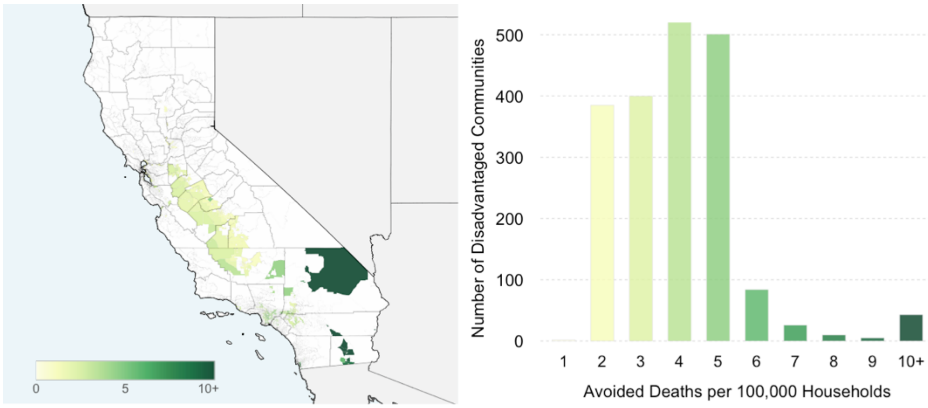
Medium Cost Scenario Health Benefits (Los Angeles, $/hh)



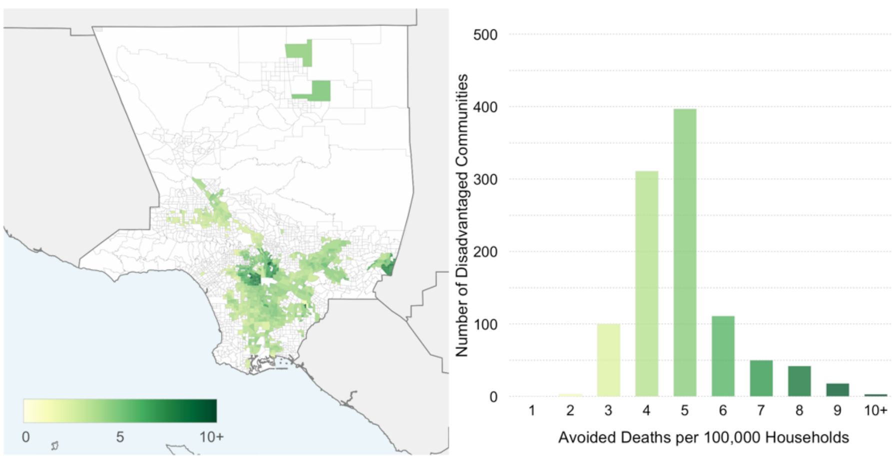
Medium Cost Scenario Health Benefits (Central Valley, $/hh)



Medium Cost Scenario Avoided Pre-Mature Deaths (avoided deaths per 100,000 hh)



Medium Cost Scenario Avoided Pre-Mature Deaths (Los Angeles) (avoided deaths per 100,000 hh)



Medium Cost Scenario Avoided Pre-Mature Deaths (Central Valley) (avoided deaths per 100,000 hh)