Title

Emissions and Health Impact of Electric Vehicle Adoption on Disadvantaged Communities

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Publication Date
2023-12-01

DOI
10.7922/G29885BF

Data Availability
The data associated with this publication are managed by: California Air Resources Board, US EPA, and the California Office of Environmental Health Hazard Assessment

Emissions and Health Impact of Electric Vehicle Adoption on Disadvantaged Communities

December 2023

A Research Report from the National Center for Sustainable Transportation

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National Center for Sustainable Transportation
A USDOT University Transportation Center

UC DAVIS ITS Institute of Transportation Studies

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. NCST-UCD-RR-23-33	**2. Government Accession No.** N/A	**3. Recipient's Catalog No.** N/A
4. Title and Subtitle Emissions and Health Impact of Electric Vehicle Adoption on Disadvantaged Communities		**5. Report Date** December 2023 **6. Performing Organization Code** N/A
7. Author(s) Alan Jenn, Ph.D., http://orcid.org/0000-0003-4232-0697 Xinwei Li, Ph.D., http://orcid.org/0000-0002-6262-5343		**8. Performing Organization Report No.** UCD-ITS-RR-23-52
9. Performing Organization Name and Address Institute of Transportation Studies, UC Davis 1605 Tilia Street Davis, CA 95616		**10. Work Unit No.** N/A **11. Contract or Grant No.** USDOT Grant 69A3551747114
12. Sponsoring Agency Name and Address U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology 1200 New Jersey Avenue, SE, Washington, DC 20590		**13. Type of Report and Period Covered** Final Research Report (October 2021 – December 2022) **14. Sponsoring Agency Code** USDOT OST-R
15. Supplementary Notes DOI: https://doi.org/10.7922/G29885BF		

16. Abstract
Vehicle electrification has attracted strong policy support in California due to its air-quality and climate benefits from adoption. However, it is unclear whether these benefits are equitable across the state's sensitive populations and socioeconomic groups and whether disadvantaged communities are able to take advantage of the emission savings and associated health benefits of electric vehicle (EV) adoption. In this study, we analyze the statewide health impacts from the reduction of on-road emissions reduction (from reducing gasoline powered cars) and the increase in power plant emissions (from EV charging) across disadvantaged communities (DACs) detected by using the environmental justice screening tool CalEnviroScreen. The results indicate that EV adoption will reduce statewide primary PM2.5 emissions by 24.02-25.05 kilotonnes and CO2 emissions by 1,223-1,255 megatonnes through 2045, and the overall monetized emission-related health benefits from decreased mortality and morbidity can be 2.52-2.76 billion dollars overall. However, the average per capita per year air pollution benefit in DACs is about $1.60 lower than that in the least 10% vulnerable communities in 2020, and this disparity expands to over $31 per capita per year in 2045, indicating that the benefits overlook some of the state's most vulnerable population, and suggesting clear distributive and equity impacts of existing EV support policies. This study contributes to our growing understanding of environmental justice rising from vehicle electrification, underscoring the need for policy frameworks that create a more equitable transportation system.

17. Key Words Electric vehicles, emissions, health impacts, environmental justice		**18. Distribution Statement** No restrictions.	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 33	**22. Price** N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Disclaimer

Acknowledgments

This study was funded, partially or entirely, by a grant from the National Center for Sustainable Transportation (NCST), supported by the U.S. Department of Transportation (USDOT) through the University Transportation Centers program. The authors would like to thank the NCST and the USDOT for their support of university-based research in transportation, and especially for the funding provided in support of this project.

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Emissions and Health Impact of Electric Vehicle Adoption on Disadvantaged Communities

A National Center for Sustainable Transportation Research Report

December 2023

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EXECUTIVE SUMMARY

Vehicle electrification is an important policy initiative in California, as it has the potential to offer significant air-quality and climate benefits. However, it's crucial to ensure that these benefits are equitably distributed across the state's various communities, especially disadvantaged populations. In this study, we analyze the impact of EV adoption on disadvantaged communities (DACs) in California, as detected by the CalEnviroScreen environmental justice screening tool.

Our findings show that statewide adoption of EVs will reduce primary PM2.5 emissions by 20 kilo-tonnes and CO2 emissions by 1.2 giga-tonnes through 2045, resulting in monetized health benefits from reduced mortality and morbidity valued at $2.42-2.68 billion. However, our analysis also reveals that DACs will experience an average per capita per year air pollution benefit of $1.6 less than that of the least 10% vulnerable communities in 2020, and this disparity will widen to over $31 per capita per year in 2045. These results highlight the inequitable distributive impacts of current EV support policies and underscore the need for policy frameworks that create a more equitable transportation system.

Overall, our study contributes to our understanding of environmental justice in the context of vehicle electrification. By identifying the potential benefits and shortcomings of current policies, we hope to inform the development of more equitable transportation policies in California and beyond.

Introduction

Transportation electrification is a critical strategy for reducing greenhouse gas (GHG) emissions, air pollution, and associated health risks. With electricity becoming cleaner due to the increasing use of renewable resources and improving energy end-use efficiency, plug-in electric vehicles (PEVs) have become increasingly popular in the United States, with over 1.7 million sold since 2010 (*1*) and accounting for over 10% of light-duty vehicle sales in 2021 (*2*). California is leading the way in the transition to transportation electrification, with the largest share of EV adoption in the country. The state has set ambitious goals, including having 5 million zero-emission vehicles (ZEVs) on its roads by 2030 and requiring all new cars and passenger trucks sold in California to be ZEVs by 2035 (*3*). In light of this: what is the climate, air quality and health impacts of reaching the goal of electric vehicles adoption throughout the state?

However, questions remain regarding the climate, air quality, and health impacts of widespread EV adoption across the state. In particular, low-income and disadvantaged communities in the US suffer from disproportionate air pollution burdens, which can exacerbate existing health disparities. Recognizing this issue, California has been a leader in environmental justice initiatives, with legislation like SB115, which defined environmental justice and required the California EPA to conduct programs, policies, and activities to ensure the fair treatment of all people (*4*). Since then, a slew of legislation has been passed to support related issues. In the realm of zero-emission vehicles, there is direct support for individuals within lower income communities to adopt alternative fuel vehicles through programs such as the Enhanced Fleet Modernization Program. Participants in the San Joaquin Valley and other disadvantaged communities are provided strong monetary incentives for purchasing an electric vehicle. Part of the impetus of these programs is to promote a double benefit of electric vehicles in disadvantaged communities, where the benefit of reducing pollution is greater due to the lower level of air quality in these regions. Unfortunately, the vast majority of electric vehicles are not being sold to these regions, rather state-level rebates are primarily received by wealthier buyers in urban, affluent regions (see Figure 1). In fact, there may be secondary pollutant effects that run contrary to the goals of programs in disadvantaged communities. This is due to the fact that most of the air quality benefits of electric vehicle adoption are localized in the region where they operate, but the negative impacts are typically localized of vehicle charging are typically localized upstream, oftentimes in poorer, disadvantaged neighborhoods where fossil generation is often located (*5*, *6*).

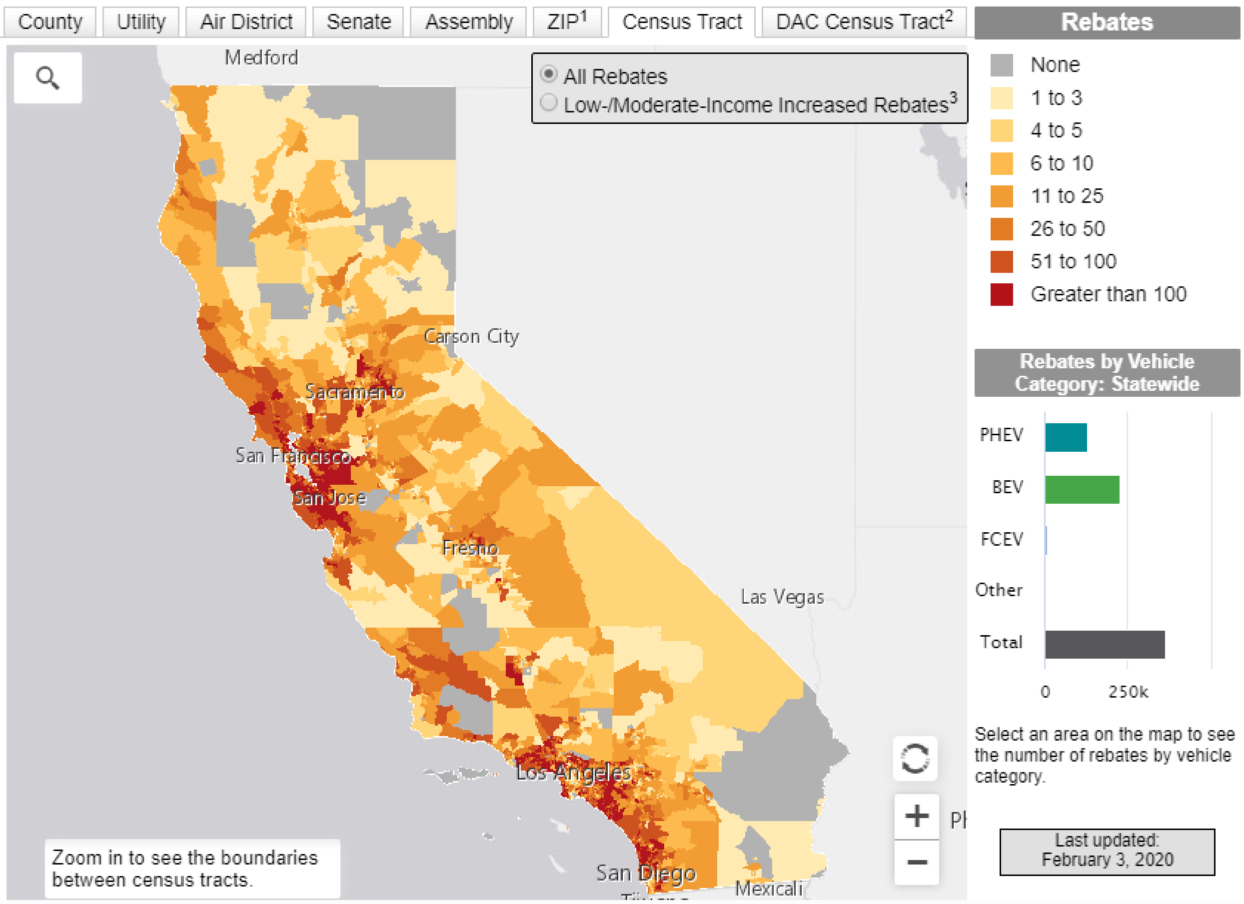

Figure 1. Number of Clean Vehicle Rebates disbursed by census tract in California through February 2020. Note: The vast majority of rebates are located in urban regions. Data from The Center for Sustainable Energy: https://cleanvehiclerebate.org/eng/cvrp-rebate-map

In this study, we investigate the climate, air quality and health impacts of adopting electric vehicles throughout California with a particular focus on disadvantaged communities and to understand whether the adverse impacts of increasing electricity demand from electric vehicles may lead to unintended consequences on these communities. The traditional benefits of electric vehicles have typically been focused on greenhouse gas emissions reductions (*7–10*), but these new technology vehicles also provide substantial air quality benefits by reducing tailpipe pollution. While the direct air quality benefits of reducing tailpipe emissions have been well studied (*11–13*), none of these studies consider the upstream air quality impacts of increasing electric vehicle adoption. However, the shift from on-road localized pollutants to upstream grid-based emissions results in a shift in pollutants that may impact communities throughout the state in fairly different ways in California. Requia et al. reviews 4,734 studies and find that the positive benefits of EVs for reducing GHG emissions and air pollutants depends on factors including source of energy generation, charging patterns and driving conditions (*14*).

To address the research gaps above, we design an integrated assessment approach with high spatial and temporal resolution (km and hourly) to quantify the air quality, public health and climate impacts of electric vehicles by leveraging electric grid and air quality model to measure the marginal impacts related to the use and charging of electric vehicles on disadvantaged communities in California.

Methods

As outlined in Figure 2, our overall modeling framework consists of four modules: travel demand, electric dispatch modeling, health damage estimation, and equity impact assessment. The travel demand module estimates the charging demand of electric vehicles at the sub-state level by combining data on vehicle ownership, travel patterns, and charging infrastructure availability. This information is then used to develop hourly load profiles for each sub-state region. The electric dispatch modeling module uses the Grid Optimized Operation Dispatch (GOOD) model (15) to simulate the electricity grid's response to the charging demand from electric vehicles. The GOOD model takes into account the real-time conditions of the electricity grid, such as the availability of different types of power plants, and determines the optimal way to meet the charging demand while minimizing costs and emissions.

The health damage estimation module uses a regression-based air pollution social impact model to estimate the health impacts of the increased pollutant emissions resulting from both on-road and grid-based sources. This model considers the location of disadvantaged communities and other vulnerable populations to determine the distribution of health impacts. The equity impact assessment module combines the results from the health damage estimation module with data on population characteristics from an environmental justice screening tool to identify the spatial distribution of disadvantaged communities and determine the monetary health impacts of electric vehicle use across all populations. This analysis helps to identify any potential disparities in the distribution of health impacts resulting from increased electric vehicle adoption.

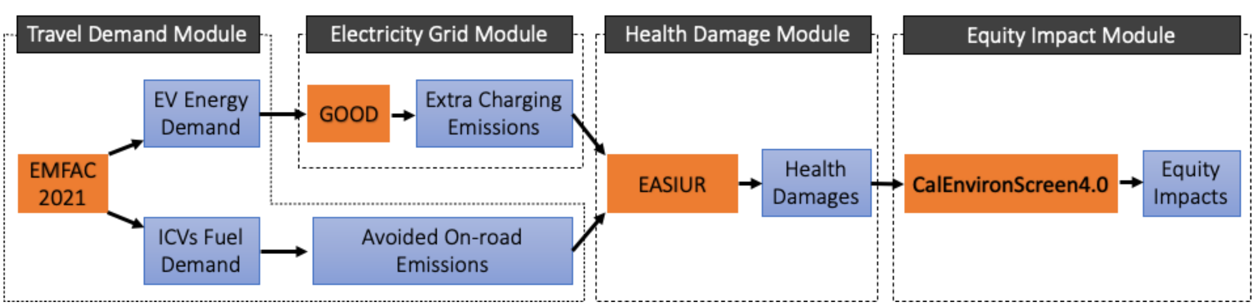

Figure 2. An integrated framework to quantify the air quality, health, and climate impacts of EV adoption to disadvantaged communities.

Travel and charging demand

It is important to accurately estimate the travel activity and energy consumption of electric vehicles in order to investigate the emissions and health impacts of EV adoption. To do this, the researchers collected activity and energy demand data from the California Air Resources Board's latest emission inventory model EMFAC2021 (16), which calculates emissions inventories for motor vehicles operating on California roadways and forecasts how the emissions will change in the future. Specifically, EMFAC2021 assumes that the ZEV market share in light-duty vehicle new sales accounts for 12% for the model year 2030 passenger vehicles. We focused on passenger vehicles and ran EMFAC2021 at a county level to generate the vehicle activity (eVMT) and the corresponding energy demand for battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). To estimate the avoided emissions from adopting electric vehicles, we also gathered emission factors for gasoline vehicles and multiplied them by the electrified miles within each region.

The daily energy demand of PEVs is then allocated into each hour of the day to form the hourly charging profiles. The charging pattern, based primarily on home charging but inclusive of other events, was extracted based on real-world charging data from the Electric Vehicle Miles Traveled (eVMT) project conducted by UC Davis, in which charging behavior of EVs are monitored over a full year and over 55,000 charging events are captured (17). This is called the "regular charging" pattern in the study (see Figure 3). With this charging probability pattern, the researchers were able to determine the hourly EV load contributing to the demand side into the grid operation dispatch model. To investigate the impact of charging behavior, a "smart charging" scenario was also defined, which assumes full flexibility by allowing the charging to be adapted according to real-time price changes in the electricity wholesale market and only constrained in the way that daily EV charging demand is satisfied by the end of the day. In this scenario, the optimized smart charging profile is an output from the grid simulation.

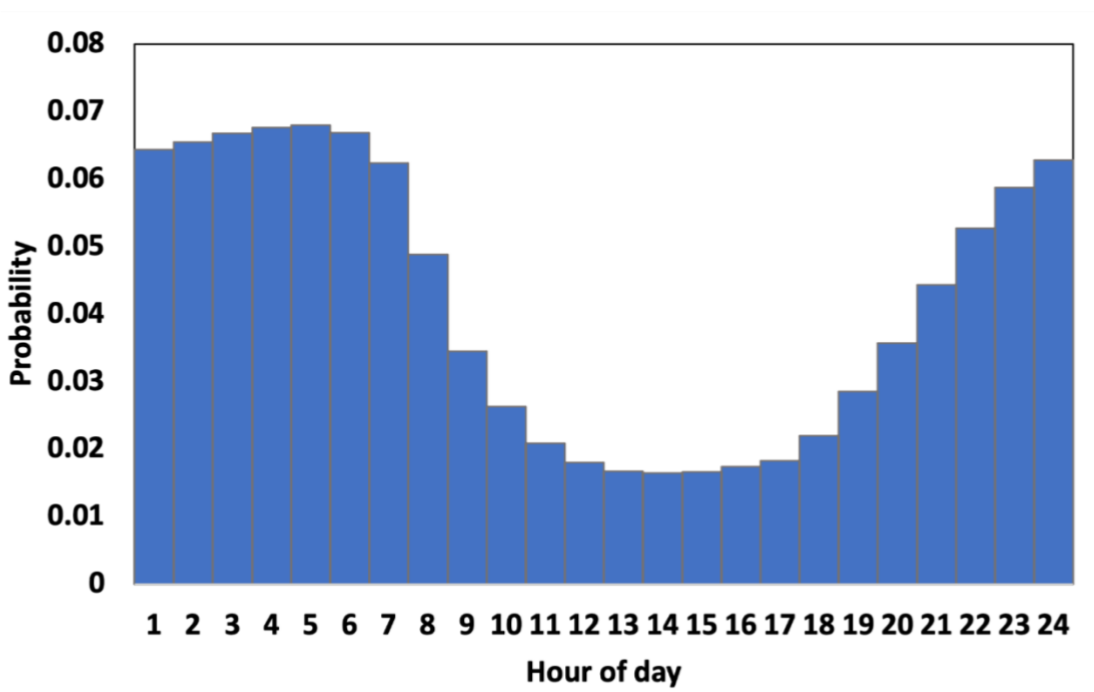

Figure 3. Probability of charging across a day (regular charging).

Electricity grid model

A consequential analysis of electric generation in California and surrounding regions will be modeled using an internally developed electricity grid dispatch model called the Grid Optimized Operation Dispatch (GOOD) model (15, 18). The GOOD model simulates the response of power generation assets throughout the Western Interconnect, subject to transmission constraints, to meet any load demand. The model functions as a system operator, dispatching power plants based on their marginal fuel costs, similar to the California Independent System Operator. The model dispatches the lowest bidding plants first, followed by higher bidding plants, until the system reaches the clearing price. The model also accounts for power flow between regions based on specific pairwise transmission constraints between every region in the model. Moreover, solar, wind, and other renewable resources are subject to constraints, such as the Renewable Portfolio Standard (RPS) in California, to produce power based on representative daily profiles in each region. Figure 4 displays the locations and capacities of generators in the Western Interconnect area.

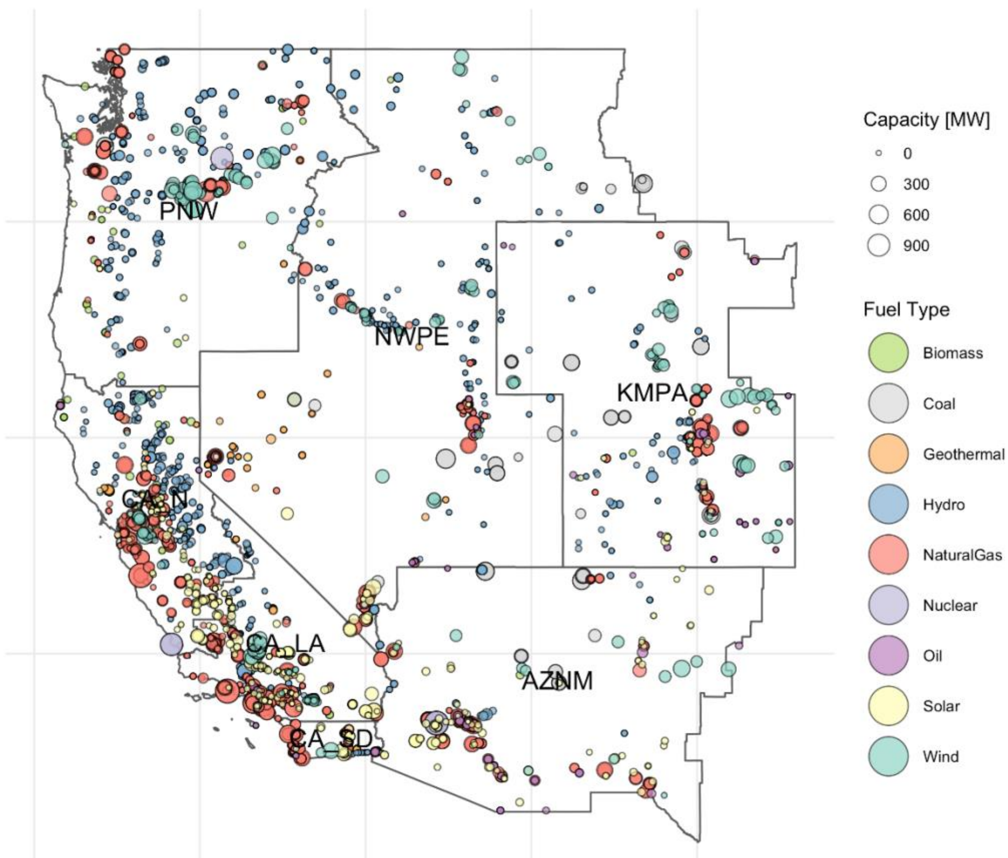

Figure 4. Locations and capacities of generators in the Western Interconnect area.

We run the model in two scenarios: one with regular charging demand and one with smart charging demand and additional PEV charging load determined as described in the previous section. The portion of PEV load in generation allows for the isolation of generation responding specifically to vehicle charging events. The pollution corresponding to electric vehicle demand is then derived based on the location and emission rates of the generators from the consequential analysis. Since pollutant emission rates are a function of the amount of fuel used (or energy provided), the dispatch model provides the input necessary in a straightforward secondary calculation to derive the quantity of upstream pollution associated with PEVs. The model allows for estimating local air pollutants (SO2, NOX, and PM2.5) and greenhouse gases (CO2, CH4, and N2O). The GOOD model is formulated as a linear programming problem, and the mathematical formulation of the model is described in the following section. We run it on an hourly basis from 2020 to 2045.

Table 1. Notations of Grid Optimized Operation Dispatch (GOOD) model.

Name	Type	Description
g	sets	Generators
gas_g	sets	Gas generators
t	sets	Time Period (hour)
d	sets	Time Period (day)
r	sets	Region
ca_r	sets	CA regions
$gtor_{g, r}$	sets	Generator to region mapping
r, o, p	sets	Alias sets of regions
$ttod_{t, d}$	sets	Hour to day mapping
$genCost_g$	parameters	Cost of generation [$ per MWh]
$demandLoad_{r,t}$	parameters	Baseload electricity demand [MWh]
$maxGen_g$	parameters	Capacity of dispatchable generation [MW]
$solarCap_r$	parameters	Capacity of solar generation [MW]
$windCap_r$	parameters	Capacity of wind generation [MW]
$solarCF_{r,t}$	parameters	Capacity factor of solar generation [unitless]
$windCF_{r,t}$	parameters	Capacity factor of wind generation [unitless]
$transCap_{r,o}$	parameters	Capacity of transmission line [MW]
$transCost_{r,o}$	parameters	Wheeling costs for transmission [$ per MW]
$percentRenew_r$	parameters	Renewable Portfolio Standards by region [unitless]
$windTransCost_r$	parameters	Wind transmission connection costs [$ per MW]
$storExisting_r$	parameters	Amount of storage from previous time period
$evHourlyLoad_{r,t}$	parameters	PEV hourly charging load [MWh]
$evDailyLoad_{r,d}$	parameters	PEV daily charging load [MWh]
transLoss	scalar	Transmission efficiency [unitless] /0.972/
storageLoss	scalar	Storage efficiency /0.85/
solarCost	scalar	Solar capacity cost [$ per MW] /80,000/
windCost	scalar	Wind capacity cost [$ per MW] /130,000/
storCost	scalar	Storage capacity cost [$ per MWh] /13,000/
importLimit	scalar	Transmission import limit [MWh] /80,000,000/

Name	Type	Description
$generation_{g,t}$	positive variable	Generator operation [MW]
$trans_{r,t,o}$	positive variable	Transmission operation (from region r to o) [MW]
$evFlexibleLoad_{r,t}$	positive variable	PEV hourly charging load with smart charging [MWh]
$solarNew_{r}$	positive variable	New solar capacity built [MW]
$windNew_{r}$	positive variable	New wind capacity built [MW]
$storSOC_{r,t}$	positive variable	The storage state of charge [MWh]
$storIn_{r,t}$	positive variable	The input energy to and from the storage [MWh]
$storOut_{r,t}$	positive variable	The output energy to and from the storage [MWh]
$storCap_{r}$	positive variable	Storage capacity installed [MW]

Objective function: Minimizing total system cost

$$\begin{aligned} systemCost = & \sum_{g,t}\left(generation_{g,t} \cdot genCost_{g}\right) + \sum_{r,t,o}\left(trans_{r,t,o} \cdot transCost_{r,o}\right) \\ & + \sum_{r}(solarCost \cdot solarNew_{r} + (windCost + windTransCost_{r}) \cdot windNew_{r} \\ & + (storCap_{r} - storExisting_{r}) \cdot storCost) \end{aligned} \tag{1}$$

Constrain 1a: Generation should meet total load, including regular EV charging load

$$\begin{aligned} \sum_{g \in gtor(g,r)} & generation_{g,t} + (solarCap_{r} + solarNew_{r}) \cdot solarCF_{r,t} \\ & + (windCap_{r} + windNew_{r}) \cdot windCF_{r,t} \\ & + \left(\sum_{o} trans_{o,t,r} \cdot transLoss - \sum_{p} trans_{r,t,p}\right) - storIn_{r,t} + storageLoss \\ & \cdot storOut_{r,t} - \left(demandLoad_{r,t} + evHourlyLoad_{r,t}\right) \geq 0 \end{aligned} \tag{2}$$

Constrain 1b: Generation should meet total load, including smart EV charging load under smart charging

$$\begin{aligned} \sum_{g \in gtor_{g,r}} & generation_{g,t} + (solarCap_{r} + solarNew_{r}) \cdot solarCF_{r,t} + (windCap_{r} + windNew_{r}) \\ & \cdot windCF_{r,t} + \left(\sum_{o} trans_{o,t,r} \cdot transLoss - \sum_{p} trans_{r,t,p}\right) - storIn_{r,t} \\ & + storageLoss \cdot storOut_{r,t} - \left(demandLoad_{r,t} + evFlexibleLoad_{r,t}\right) \geq 0 \end{aligned} \tag{3}$$

Constrain 2: Smart EV charging load should match daily charging demand

$$\sum_{t \in ttod_{t,d}} evFlexibleLoad_{r,t} - evDailyLoad_{r,d} = 0 \tag{4}$$

Constrain 3: Renewable generation requirement under California's Renewable Portfolio Standards (RPS)

$$\sum_t \Big((solarCap_r + solarNew_r) \cdot solarCF_{r,t} + (windCap_r + windNew_r) \cdot windCF_{r,t} \Big) \cdot (1 - percentRenew_r) - percentRenew_r \cdot \sum_t \left(\sum_{g \in gtor_{g,r}} generation_{g,t} \right) \geq 0 \quad (5)$$

Constrain 4: Real-time energy balance of the grid storage

$$storSOC_{r,t} - storSOC_{r,t-1} - storIn_{r,t-1} \cdot storageLoss + storOut_{r,t-1} = 0 \quad (6)$$

Constrain 5&6: The charging/discharging energy per hour of storage is limited to be below 25% of the total capacity of the grid storage device according to the performance of current lithium-ion batteries.

$$storCap_r \cdot 0.25 - storIn_{r,t} \geq 0 \quad (7)$$
$$storCap_r \cdot 0.25 - storOut_{r,t} \geq 0 \quad (8)$$

Constrain 7: Storage capacity limit

$$storCap_r - storSOC_{r,t} \geq 0 \quad (9)$$

Constrain 8: Net balance for all storage

$$\sum_{r,t} \left(storIn_{r,t} - storOut_{r,t} \right) = 0 \quad (10)$$

Constrain 9: Import limit into CA

$$importLimit - \sum_{r,t,ca} trans_{r,t,ca} \geq 0 \quad (11)$$

Health implications from pollution outcomes

Using the local pollutant outcomes derived from the electric grid module, health impacts can be determined at a high resolution using the Estimating Air Pollution Social Impact Using Regression (EASIUR) model (19). The model uses a regression model to derive results from Comprehensive Air Quality Model with Extensions (CAMx), a state-of-the-art chemical transport model. EASIUR is a grid-based model that estimates the corresponding social costs of pollutant emissions (for both mortality and morbidity) with a spatial resolution of 36 × 36 km at three stack heights: ground-level area emissions, point emissions at 150m, and 300m.

For the monetized health damages, EASIUR assumes a value of a statistical life (VSL) of $8.8M in 2010 USD. Since the GOOD model generates pollutants at exact power plant coordinates, we regard them as the point emissions at 300 m for the input into the EASIUR model. To assess the health benefit from shifting internal combustion engine vehicles (ICEVs) to electric vehicles, we also run the EASIUR model with ground-level transport emissions estimated from the transport module. These models include baseline emissions (which we marginally affect through changes in air quality from the transport/grid models), which allows for cumulative damages to be accounted for. The final outcome is a spatially resolute measurement of both the marginal and aggregate electric vehicle impacts.

Health impact to disadvantaged communities

To measure the health implications from EV adoption to disadvantaged communities specifically, we combine spatial data on health impacts and population characteristics from the most recent CalEnviroScreen 4.0 tool developed by the California Office of Environmental Health Hazard Assessment (OEHHA) (20). CalEnviroScreen produces an aggregated score for each census tract in California based on its state percentile values for 21 indicators to characterize both pollution burden and population characteristics. Pollution burden consists of eight exposure indicators (Ozone and PM2.5 concentrations, diesel PM emissions, drinking water contaminants, children's lead risk from housing, high-hazard, high-volatility pesticides, facilities toxic releases, and traffic impacts) and five environmental effect indicators (toxic cleanup sites, groundwater threats, hazardous waste, impaired water, and solid waste sites).

Population characteristics are the average of the three sensitive population indicators (asthma emergency department visits, cardiovascular disease, and low birth-weight infants) and five socioeconomic factor indicators (education attainment, housing-burdened low-income households, linguistic isolation, poverty, and unemployment). The spatial distribution of the population characteristics index is shown in Figure 5 below. The three sensitive population indicators and five socioeconomic factor indicators can be found in Appendix Figure A1. Higher population characteristics scores mean the communities are more vulnerable to pollutants. To eliminate the impacts from other pollution burdens, we only use the population characteristics index, which reflects the population's vulnerability to environmental impacts from EV adoption.

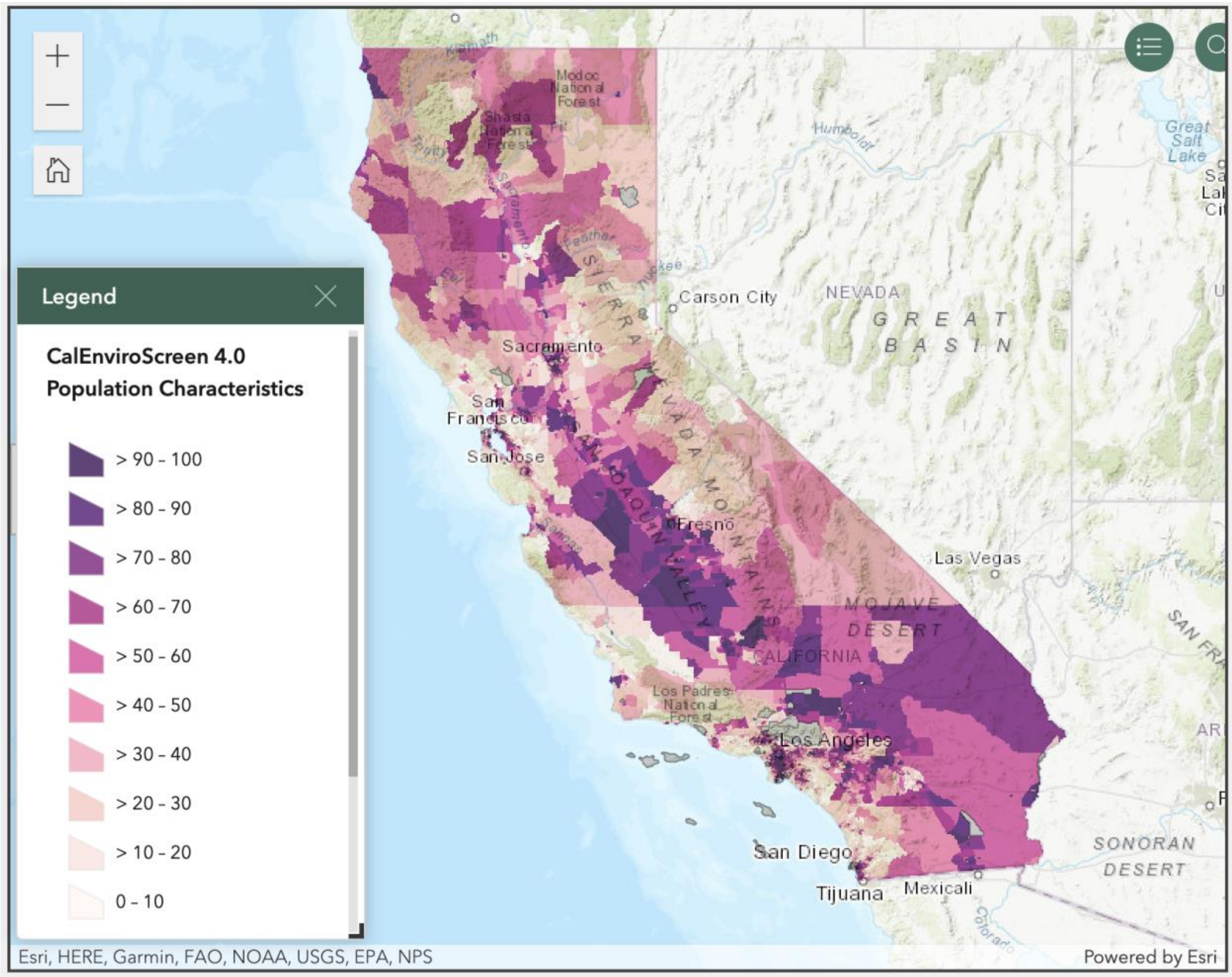

Figure 5. Population Characteristics disbursed by census tract in California. Note: data from California Office of Environmental Health Hazard Assessment: https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40

Results

Charging demand is unevenly distributed across regions

As depicted in Figure 6, the travel demand from light-duty PEVs in California is expected to rise from 6 billion miles/yr in 2020 to 362 billion miles/yr in 2045, with BEV travel demand accounting for 93.7% of total eVMT in 2045, up from 73.1% in 2020. The total statewide energy consumption from EV adoption is projected to increase from 6 GWh/day in 2020 to 380 GWh/day in 2045. However, the top five counties account for 52% of energy demand for charging in California (Los Angeles, San Diego, Orange County, San Bernardino, and Riverside), as shown in Figure 7. This has substantial implications for the distribution of air quality benefits across the state.

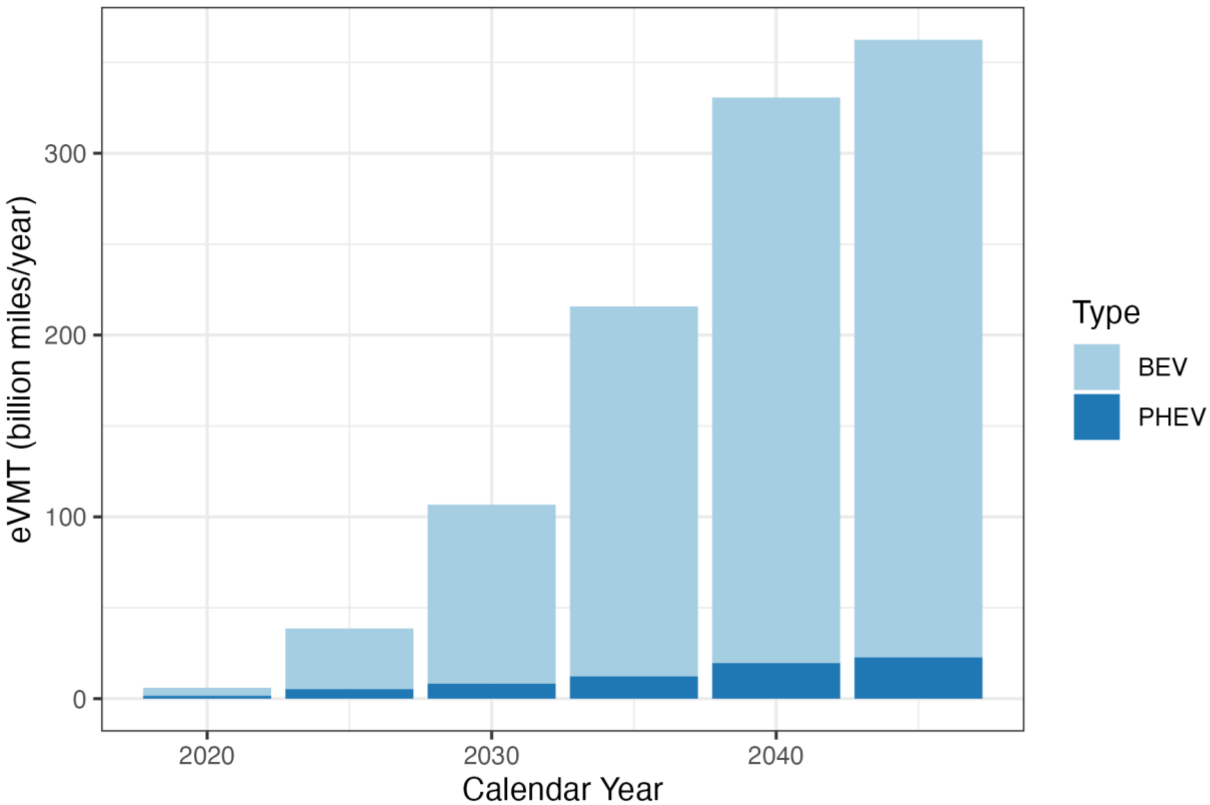

Figure 6. Travel demand estimation for PEVs through 2045 in California.

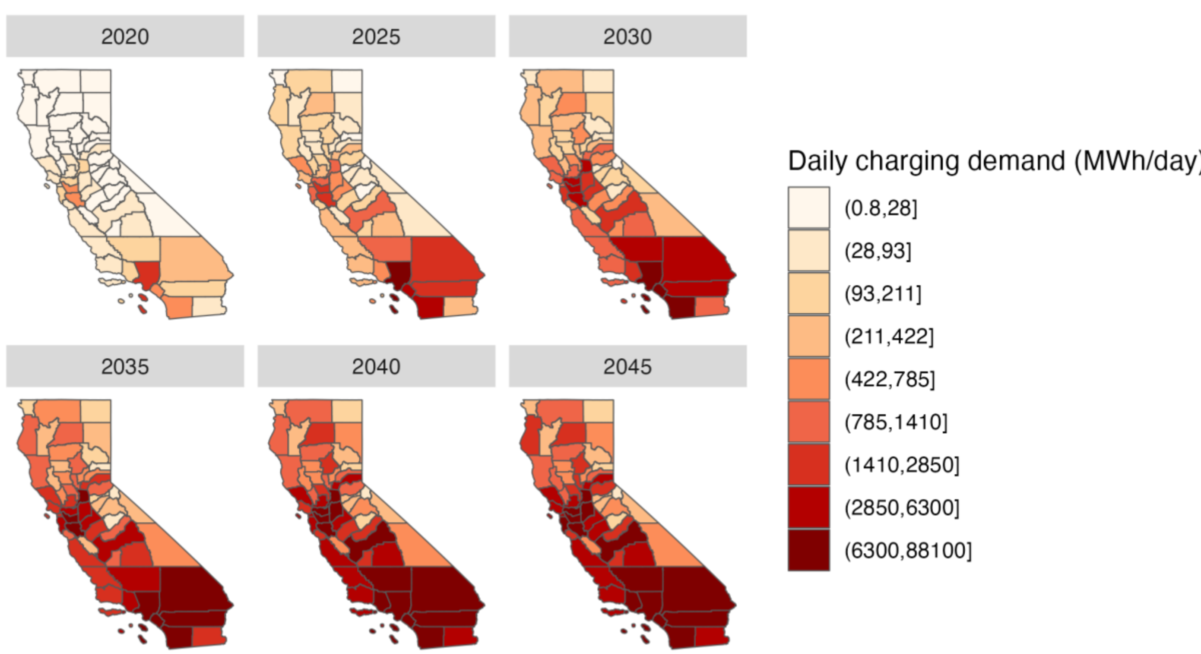

Figure 7. Charging demand spatial distribution.

Renewable generation amplifies the emission benefits of electric vehicles

The EV charging demand is combined with the baseline electricity load and fed into the electricity grid dispatch model. Two scenarios are examined: a "regular charging" strategy that replicates the current charging pattern of PEV drivers, and "smart charging" in which charging activities are adapted according to real-time price changes in the electricity wholesale market. The analysis focuses on the environmental effects, including which generators will be utilized to charge the EVs and the resulting production of pollutants.

Figure 8 shows the spatial distribution of CO2 and primary PM2.5 from power plants throughout the Western Interconnect for electricity demand and California's EV charging load under the regular charging scenario. The amount and location of environmental impacts largely depend on the generation mix (see Appendix Figure A2). Thanks to the growth of renewable generation, the grid emission rates of CO2 and PM2.5 decline by 60% and 47% in the regular charging scenario from 2020 to 2045 and decrease by 58% and 48% in the smart charging scenario. Charging patterns significantly affect the environmental outcome of the extra EV charging load. Table 2 shows extra emissions from EV adoption by pollutant and year. Generally, emissions from EV charging in the smart charging scenario are much lower than those under the regular charging scenario since the former allows charging activities to optimally occur during periods when electricity prices are the lowest, which commonly align with more wind and solar generation. The emissions from charging electric vehicles peak in 2040 under regular charging and decrease after 2040 as higher penetration of wind and solar offsets the impact from increasing charging demand. Smart charging technology brings the peak to 2035 since it allows flexibility in charging and accommodates higher solar generation.

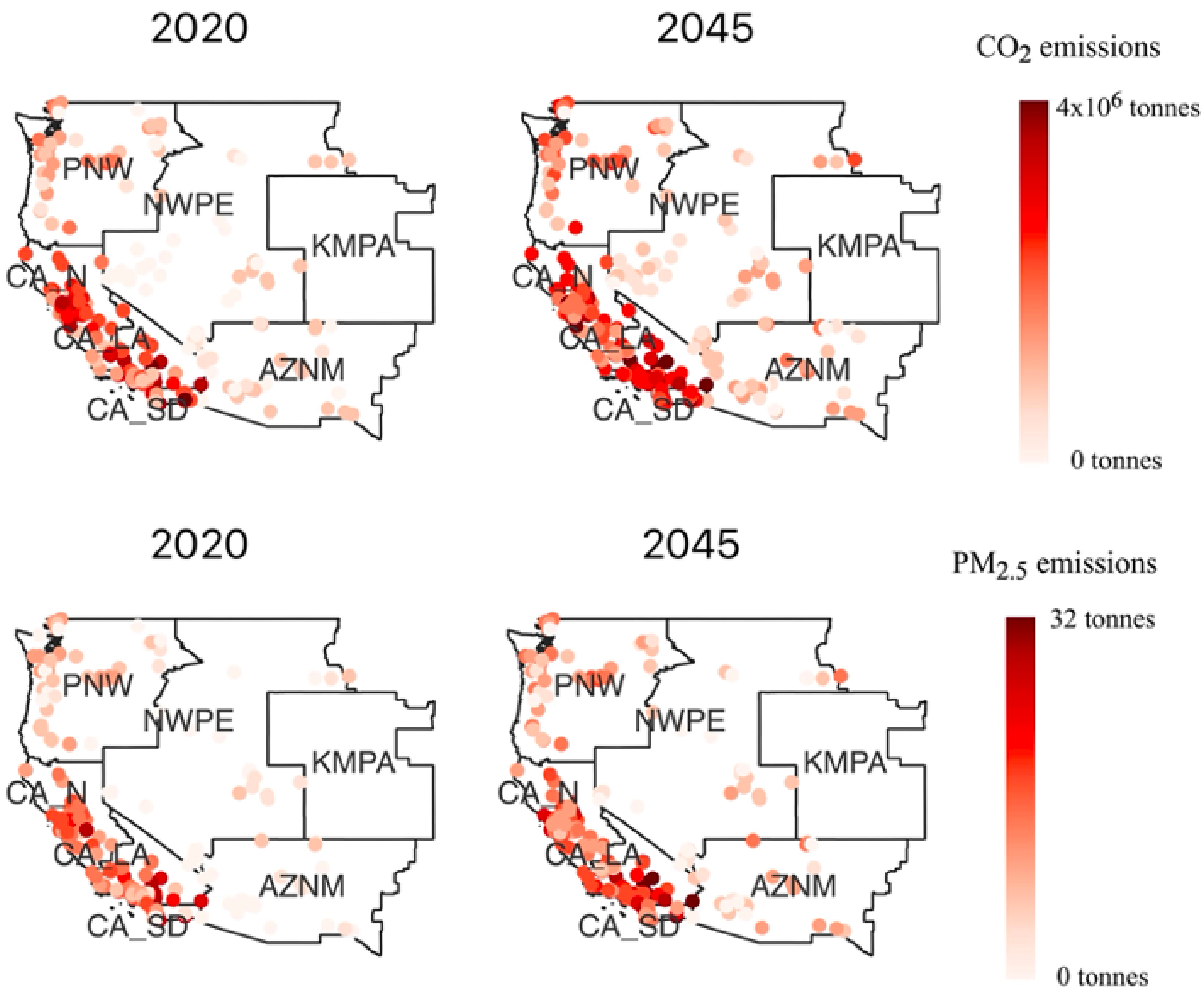

Figure 8. Emissions from EV charging among power generators throughout the Western Interconnect under regular charging scenario.

Table 2. Annual emissions from extra EV charging load.

	Year	Air pollutants (tonnes/yr)			Greenhouse gases (tonnes/yr)		
		SO_2	NO_X	$PM_{2.5}$	CO_2	CH_4	N_2O
Regular charging	**2020**	173	380	38	628,497	46	7
	2025	1,113	2,365	244	3,982,698	299	43
	2030	2,653	5,611	581	9,444,275	725	104
	2035	4,325	9,363	1,013	15,867,050	1,213	173
	2040	5,147	12,082	1,294	19,942,340	1,464	209
	2045	2,668	4,987	505	7,995,037	689	99
Smart charging	**2020**	155	298	28	460,297	40	6
	2025	785	1,403	140	2,115,576	201	29
	2030	1,339	2,373	269	3,872,830	351	51
	2035	1,887	3,457	405	5,554,882	506	73
	2040	1,228	2,214	253	3,714,170	332	48
	2045	1,158	2,320	256	3,493,796	323	47

Table 3 shows the avoided on-road emissions by substituting ICEVs with EVs. Compared to the extra emissions from the grid (see Table 2), adopting electric vehicles will decrease the total primary PM2.5 emissions by 93.9% and total CO2 emissions by 98.1% in 2045. Enabled by smart charging, the total emissions from adopting EVs will drop by 96.9% and 99.2% for PM2.5 and CO2 in 2045, respectively.

Table 3. Annual avoided emissions from replacing ICEVs with EVs.

Year	Air pollutants (avoided tonnes/yr)			Greenhouse gases (avoided tonnes/yr)		
	SO_2	NO_X	$PM_{2.5}$	CO_2	CH_4	N_2O
2020	93	5,508	177	9,408,022	597	411
2025	541	20,424	1,055	54,708,410	2,369	1,816
2030	1,359	37,715	2,731	137,496,500	4,736	3,977
2035	2,572	55,835	5,218	260,211,400	7,290	6,910
2040	3,792	70,556	7,710	383,603,500	9,068	9,728
2045	4,075	68,098	8,285	412,230,500	8,756	10,144

EV adoption brings benefit overall but expands disparity

To assess the monetized health impacts to different communities across California, we only consider local air pollutants (SO2, NOX, and PM2.5) since marginal damages for them are sensitive to the location and height of emission sources, while marginal damages of greenhouse gases are irrelevant to location and their impacts are considered constant globally. We compare the on-road benefit from avoided gasoline vehicle usage, and extra damage from grid side attributed to the additional charging demand with regular charging for passenger vehicle electrification in Figure 9. We find that the air pollution related health benefit of electric vehicles is 6-10 times greater relative to gasoline vehicles in 2020 and the benefit expands to 14-36 times as the adoption level increase in the future. The damage from electricity production will increase from 2020 to 2040 as the more charging demand is required but higher wind and solar penetration offsets the trend and decrease the grid damage since 2040.

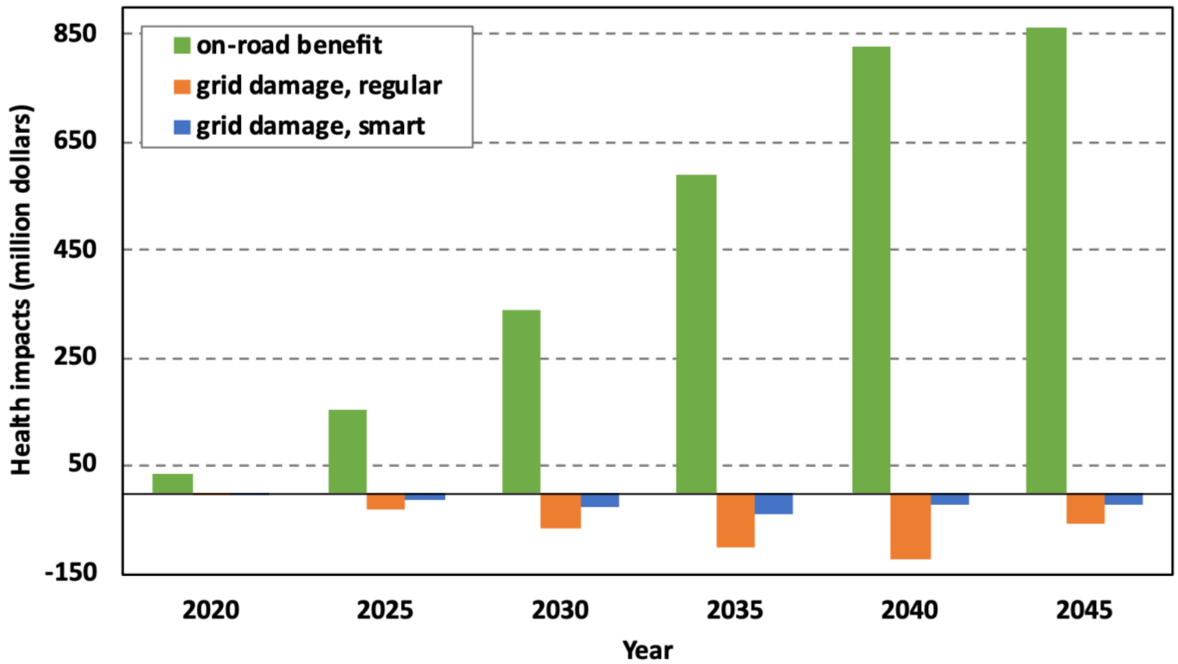

Figure 9. Total on-road benefits and grid damages compare from vehicle electrification.

Even though the total net impact from transportation and the grid is absolutely beneficial to the state as a whole, we still notice that some areas will suffer from damages since there are fossil fuel generators nearby as shown in Figure 11. The areas with higher EV adoption, such as Los Angeles, Santa Clara, and their surrounding areas will gain the most health benefits. As the share of wind and solar generation increases to 85.7% in 2045, the health impact from adopting electric vehicles is positive in all regions of California. We examined separate scenarios with "regular charging" and "smart charging", the latter of which allows for flexibility in aggregate charging loads to meet the needs of the electric grid. We find that allowing for smart charging increases the benefits from reduced emissions, but more impactfully helps to reduce negative outcomes related to EV charging within DACs—particularly as renewable generation increases over time. Starting in 2020 through 2040, the number of locations experiencing negative outcomes is halved when switching from regular charging to smart charging.

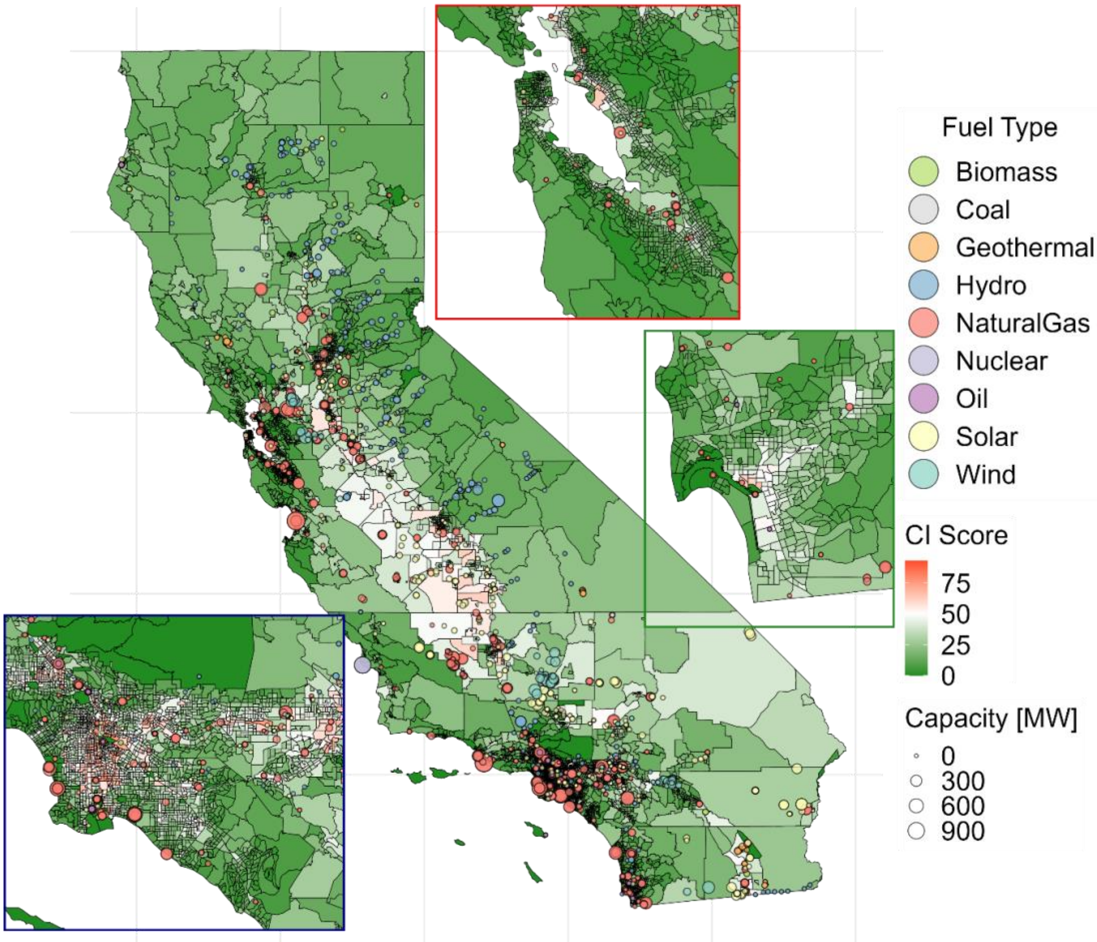

Figure 10. Disadvantaged Community classification (by percentile) from CalEnviroScreen 4.0 relative to power plant locations in California

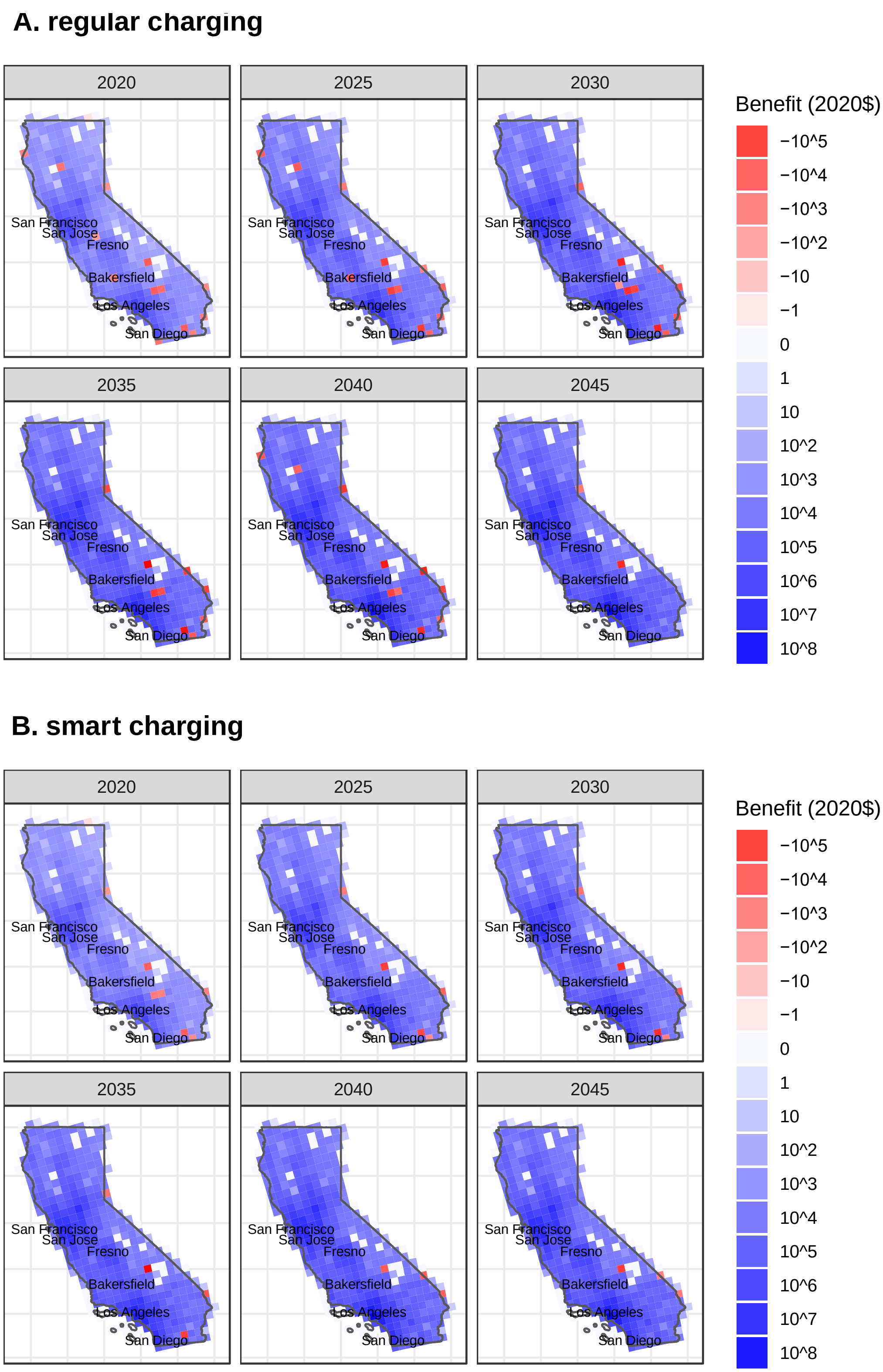

Figure 11. Spatial distribution of health impact from EV adoption in California.

To evaluate the benefits from EV adoption across all communities in California, we match the per capita benefit with the population characteristics index for each census tract and plot smooth local regression lines in Figure 12. We find that the overall benefit from EV adoption generally increases from 2020 to 2045, but there is substantial disparity across populations. Census tracts with more vulnerable communities experience lower per capita benefit than less vulnerable communities. The average difference is $1.50 - $1.60 per capita per year in 2020 but increases to over $31 per capita per year in 2045. This finding may be attributable to the fact that the electric vehicles are more adopted in the regions where people are wealthier and less vulnerable, and the fossil fuel plants are more concentrated in areas near disadvantaged communities, as well as the location of roadway infrastructure. The difference between the benefits of regular and smart charging is relatively small, due to the large amount of absolute benefit from electrification.

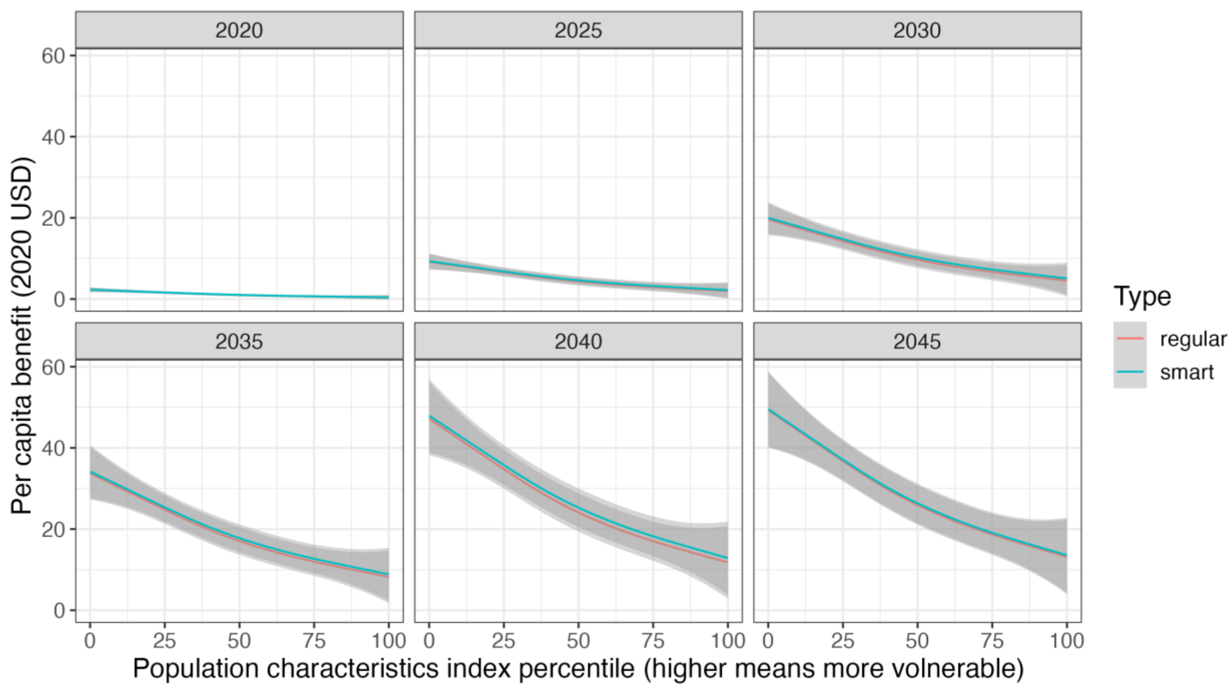

Figure 12. Smooth curves (by using the "loess" method) of the per capita per year benefit in census tracts in California from 2020 to 2045.

Discussion

In this study, we analyze the emissions and health implications of adopting electric vehicles to disadvantaged communities in California under the state's goals of EV adoption and renewable generation. We quantify the transportation-related emissions co-benefits of renewable integration targets by leveraging a grid optimized operational dispatch model. We estimate the monetary health impact by utilizing a state-of-the-art integrated air quality assessment model for both avoided on-road transport emission and extra point emissions from electricity generation. The results show that EV adoption will lead to a decrease in total primary PM2.5 by 94% and CO2 emissions by 98% in 2045 compared to a business-as-usual scenario with gas cars.

Smart charging technology could expand the benefit due to the flexibility of optimally distributing charging loads into periods when electricity prices and emission rates are lower with more wind and solar generation. We also find that the total health benefit is disproportionally distributed towards wealthier and less vulnerable communities and some communities near fossil fuel plants suffer negative impact when renewable generation is not high enough. The average per capita per year air pollution benefit in disadvantaged communities is at least $1.50 lower than the communities with the highest benefit in 2020 and this disparity expands to over $31 per capita per year in 2045.

Our study only focused on the health and equity impacts within California and did not consider the impact from extra grid emissions to other Western Interconnect territories outside of California. Future research will consider expanding the study to the rest of the United States.

Conclusions

California is leading the revolution towards transportation electrification in the US and the world, and aggressively reaching the goal of having 5 million ZEVs on California roads by 2030. Given that the air-quality and climate benefits of EV adoption have been cited as reasons for public support, we sought to understand how these benefits will change over time, and whether they are equally distributed to all communities.

One important finding of this study is that while the whole state of California will benefit from increasing EV adoptions, people in disadvantaged communities benefit less and the magnitude of this disparity doubles from 2020 to 2045. This effect is a result of electric vehicles being more widely adopted in the regions where people are richer and less vulnerable and because fossil fuel plants are more concentrated in the areas near disadvantaged communities. This study is the first in the literature to quantitatively assess the disparity in health benefits from air pollutant reductions from EV adoption among different communities in California. Our result reveals the significance of improving EV adoption in disadvantaged communities and create equitable EV access to all people. Our study underscores the need for policy frameworks that create a more equitable, environmentally friendly and sustainable transportation system.

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Data Summary

Products of Research

The data collection efforts are relatively minimal as most of the data that has been used in this study is publicly available: the activity and energy demand data of electric vehicles are from the California Air Resources Board (CARB)'s latest emission inventory model EMFAC2021; the generators data for building the GOOD model are from the US EPA's emissions & generation resource integrated database eGrid 2020; the population characteristics indicators data are from the most recent CalEnviroScreen 4.0 tool developed by California Office of Environmental Health Hazard Assessment (OEHHA). Other data, for example the regular charging profile, is based on other research efforts at the UC Davis Electric Vehicle Research Center.

Data Format and Content

All the data used in this project is in csv. file.

Data Access and Sharing

EMFAC2021: https://arb.ca.gov/emfac/

eGRID: https://www.epa.gov/egrid

CalEnviroScreen 4.0: https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40

Reuse and Redistribution

No restrictions on reuse and redistribution of data.

Appendix A

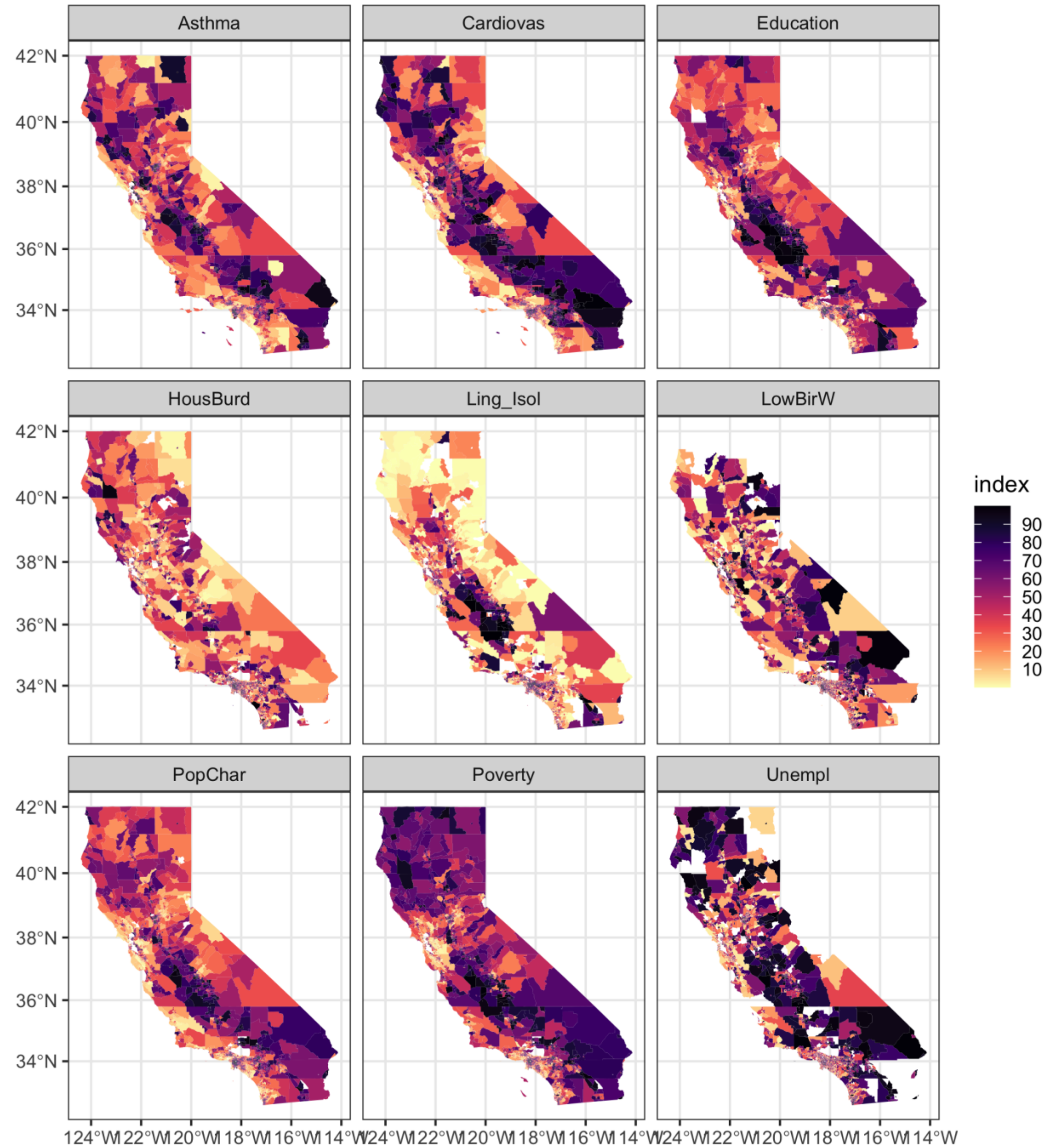

Figure A1. Spatial distribution of sensitive population and socioeconomic factor indicators in CalEnviroScreen 4.0.

Figure A2. Generation mix by region under (a) regular charging and (b) smart charging scenarios through 2045.