IMPACTS OF GREENHOUSE GAS EMISSION LIMITS WITHIN DISADVANTAGED COMMUNITIES: PROGRESS TOWARD REDUCING INEQUITIES

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Message from the Secretary

Thank you for reading this report which examines how California's efforts to reduce carbon pollution has affected air quality in disadvantaged communities. It is critical to gather and analyze data as a way to track our progress and refine our approach to advancing equity and environmental justice.

This second report by CalEPA's Office of Environmental Health Hazard Assessment (OEHHA), focuses on facilities subject to the Cap-and-Trade Program; and initiatives to reduce pollution from heavy-duty vehicles. The report highlights that between 2000 and 2019, disadvantaged communities experienced health benefits from reductions in particulate matter and air toxics from these sources. For heavy-duty vehicles, the reduction has been greater than 75% since 2000. The reductions highlighted in the report are not a result of a single, isolated effort, but are from a combination of government regulations, rules, and incentives, as well as local zoning decisions. The report also illustrates how Governor Newsom's 2045 heavy duty zero emissions mandate will substantially improve the air in these communities.

The report also focuses on the need to significantly expand our efforts to transition to both zero emission transportation and less polluting facilities. Residents of disadvantaged communities and people of color continue to experience the highest pollution levels of particulate matter and air toxics. It is our job at all levels of government – state, federal and local - to reduce harmful air pollutant exposures in communities across the Golden State.

California is committed to doubling down on our efforts to equitably address greenhouse gas emissions and air pollution. Governor Newsom seeks to allocate over $37 billion to advance climate efforts that will most benefit disadvantaged communities. There is a strong focus on cleaning up heavy-duty vehicles, moving to zero emissions light and medium duty vehicles and electrifying ports. Reducing pollution from these sources will substantially improve community air quality.

We must also enforce existing air pollution laws, with particular attention to facilities affecting disadvantaged communities. We are strengthening our partnership with communities, tribal nations, local air districts and the federal government to this end.

Moving forward, we will continue to monitor our progress with reports like this one from OEHHA and other tools. OEHHA's report lays out ways to improve future analyses. While data have improved since the previous OEHHA report in 2017, there are still significant gaps, and the current report outlines ways we can do a better job measuring emissions and improving our understanding of the impacts of our climate change and air quality policies and programs on California's communities.

We will only be successful in bending the emissions arc towards carbon neutrality if at every step we integrate equity and community health into all our decisions.

Jared Blumenfeld
California Secretary for Environmental Protection

Executive Summary

This report is the second examination by the Office of Environmental Health Hazard Assessment (OEHHA) of the impacts on disadvantaged communities in California from emissions associated with the climate change policies and programs mandated by the Global Warming Solutions Act of 2006, Assembly Bill 32 (AB 32) (Nunez, Statutes of 2006), and related legislation. The California Air Resources Board (CARB), along with other state agencies, administer these policies and programs, which are aimed at reducing greenhouse gas (GHG) emissions. Since 2015, OEHHA has been tasked with analyzing and reporting on the benefits and impacts of the GHG emissions limits adopted by CARB under AB 32.

OEHHA's first report on this subject (2017) focused solely on emissions from industrial facilities that were subject to the Regulation for the California Cap on Greenhouse Gas Emissions and Market-Based Compliance Mechanisms, known as the Cap-and-Trade Program (CARB 2019a). This report builds on that work, while also evaluating another significant contributor of GHGs, namely localized co-pollutants in the form of emissions from heavy-duty vehicles (HDVs). A range of federal, state and local laws and regulations over the years have led to significant air quality improvements throughout California. In addition to emission reductions from those efforts, important co-pollutants like air toxics and particulate matter may be reduced when climate policies are implemented, especially when they result from fuel combustion.

This report's major findings include the following:

1. Both HDVs and facilities subject to the Cap-and-Trade Program have reduced emissions of co-pollutants, with HDVs showing a clearer downward trend when compared to stationary sources. These emission reductions have major health benefits, including a reduction in premature pollution-related deaths.
2. The greatest beneficiaries of reduced emissions from both HDVs and facilities subject to the Cap-and-Trade Program have been in communities of color and in disadvantaged communities in California, as identified by CalEnviroScreen (CES). This has reduced the emission gap between communities with high and low CES scores, but a wide gap still remains.
3. The transition to zero-emission HDVs will expedite further emissions reductions.
4. While the progress observed is encouraging, inequities persist and federal, state, and local climate and air quality programs must do more to reduce emissions of

GHGs and co-pollutants in order to reduce the burden of emissions on disadvantaged communities and communities of color.

Heavy-Duty Vehicle Emissions

We found that diesel particulate matter (DPM) concentrations have decreased across California for the last 20 years, with the greatest benefits accruing to high-scoring communities identified by CES as having high levels of both pollution and vulnerability to its effects. DPM has decreased in these communities three times more than it has in low-scoring communities.

We also found taking certain actions to transition from HDVs to zero-emission vehicles by 2045 could significantly reduce statewide emissions of fine particulate matter (PM2.5) associated with HDVs by an estimated 58%, when compared to business as usual. These reductions have the potential to avoid an estimated 3,800 premature deaths over 25 years, two thirds of which would benefit people of color. These benefits would be felt in California's most impacted communities, with a third of the avoided premature deaths would be located in high-scoring CES communities.

Emissions from Cap-and-Trade Covered Facilities

We found that facilities subject to the Cap-and-Trade Program are three times more likely to be located in or near disadvantaged communities and communities of color. As a result, these communities also have the potential to benefit most from reductions in co-pollutant emissions. We evaluated the change in emissions from Cap-and-Trade-covered facilities in 2017 compared to 2012 and found a 45-fold greater reduction of PM2.5 exposure in high-scoring versus low-scoring communities. We also found that the majority (68%) of health benefits from reductions in emissions from facilities subject to the Cap-and-Trade Program have been for people of color. Although we observed statewide reductions in GHGs, PM2.5, and air toxics, the relationship between facility emissions of GHGs and co-pollutants is variable by sector, pollutant, and year.

While significant improvements have been made in disadvantaged communities and communities of color, which may be attributed to a range of federal, state and local programs and policies, they continue to be overburdened. We found that Black Californians in particular experience twice the PM2.5 exposure from facilities covered by the Cap-and-Trade Program than White Californians do. Furthermore, we found that Black Californians experience three times greater exposure from refinery emissions than all other stationary source sectors covered by the Cap-and-Trade Program combined.

To comply with requirements under the Cap-and-Trade Program, entities may surrender a specified number of offsets to fulfill part of their compliance obligation, in addition to emission allowances. For entities subject to this Program, we evaluated emission trends, the use of offsets, and the location of their associated facilities. We found that four of the top five entities that use the most offsets own petroleum refineries, and refineries contribute more to PM disparity by CES score and race/ethnicity than any other sector. However, despite the use of offsets by entities that own refineries, Black Californians experienced a four-fold greater reduction in PM2.5 exposure from these sources compared to White Californians for the periods that were compared.

Approach to the Analysis

We conducted our analysis by evaluating GHG and co-pollutant emissions from HDVs and facilities subject to the Cap-and-Trade Program, modeling the associated primary and secondary PM2.5 concentrations and estimating health effects due to exposure changes to PM2.5. For HDVs, we examined historical trends (2000-2019) for DPM and modeled projected PM2.5 concentrations for 2020-2045. For our analysis of facilities subject to the Cap-and-Trade Program, we examined emission trends from pre-Cap-and-Trade implementation (2011) to the most recent year emission data was available (2018). We then modeled PM2.5 exposure concentrations using 2012 and 2017 PM2.5 and precursor emissions. While data from 2011 to 2018 was available to us, we used the emissions from 2012 and 2017 for modeling and health analysis because these two years were used for the National Emissions Inventory. Consequently, the emissions data was subject to more rigorous quality checking than other years in the study period. These analyses were facilitated by work since the last report such as the Pollution Mapping Tool (CARB 2018).

We paid particular attention to communities already disproportionally burdened by environmental, socioeconomic and health issues, as identified by CES. We defined communities as disadvantaged and overburdened if they scored in the top 25% of communities statewide when ranked by CES score. We examined emissions, exposure, and health benefits by high (top 25%) and low (bottom 25%) scoring CES communities and by race/ethnicity.

Future Work

OEHHA will continue to provide updates, and seek new and improved data to evaluate emission trends and impacts in disadvantaged communities associated with emissions sources affected by California's climate change policies and programs. OEHHA staff will work to better inform our future research efforts with input and partnerships from those who live in impacted communities. While emissions reductions have narrowed the air quality gap between communities with high and low CES scores, there continue to be inequities. Similarly, while additional data has become available since the previous report, there are still significant gaps in available data.

Efforts that would facilitate future analyses include:

1. Collecting granular, community-level data for mobile sources.
2. Improving data accessibility for criteria pollutant and air toxics emissions data.
3. Adding finer scale criteria pollutant and air toxics emissions reporting for the oil and gas sector.
4. Implementing statewide data standards for all emission sources.
5. Increasing transparency regarding offset entity information.
6. Creating environmental and health equity benchmarks.

Introduction

California leads the nation in seeking to mitigate risks associated with climate change. With the passing of the landmark Global Warming Solutions Act of 2006 (Nunez, Statutes of 2006), the state established numerous policies and programs to reduce California's greenhouse gas (GHG) emissions. In 2015, the Office of Environmental Health Hazard Assessment (OEHHA) was directed to prepare and periodically update a report analyzing the benefits and impacts of the GHG emission limits adopted by the California Air Resources Board (CARB) within disadvantaged communities.[1]

In 2017, OEHHA released its first report on this subject, which focused on emissions from facilities covered by the Cap-and-Trade Program. That report found that a significant proportion of facilities regulated under that Program were located in close proximity to disadvantaged communities. Moreover, the previous report also found a positive relationship between GHG and co-pollutant emissions, indicating that GHG reductions were likely to result in reductions of co-pollutants in some sectors (OEHHA 2017).

The transportation, industrial, and electricity sectors are the largest contributors to GHG emissions in California (Figure 1) and present the largest opportunities for GHG reductions (CARB 2021d). Thus, we focus on sources targeted to reduce the risk of climate change in communities: heavy-duty vehicles (HDVs) and stationary sources subject to the Cap-and-Trade Program. Additionally, these sources contribute to both statewide GHG emissions and localized emissions of particulate matter and air toxics, and there is data about them available for analysis. In this second report, we quantify changes in GHG and co-pollutant emissions from covered facilities and evaluate corresponding health impacts, with an emphasis on communities that are disproportionately burdened by environmental, socioeconomic, and health issues.

[1] The full text of the directive can be found on the OEHHA website, here: https://oehha.ca.gov/media/downloads/environmental-justice/report-general-info/govdirective12032015.pdf.

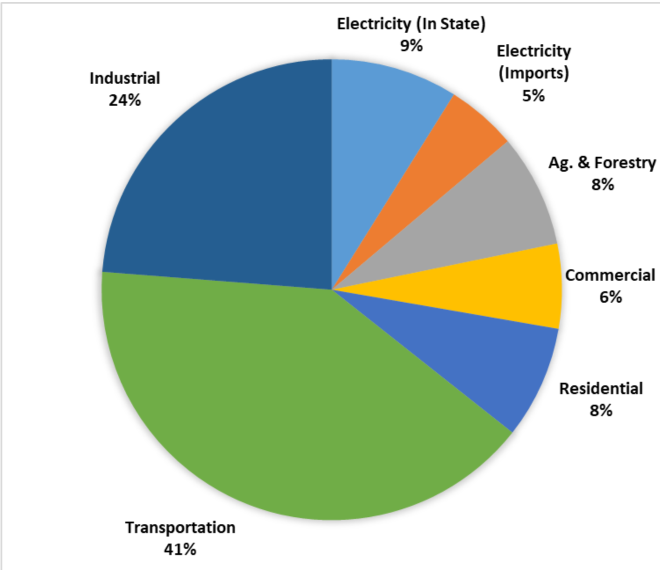

Figure 1. Greenhouse Gas Emissions in 2019 by Economic Sector[2](CARB 2021d)

This report is organized around two research questions:

1. What are the historical and projected benefits and impacts from emissions changes from heavy-duty vehicle sources in disadvantaged communities?
2. What have been the benefits and impacts from emissions changes at facilities subject to the Cap-and-Trade Program in disadvantaged communities?

The report approaches these questions through an environmental and health equity lens. As such, we use the CalEnviroScreen tool to help identify California communities where people are the most affected by multiple sources of pollution and where people are especially vulnerable to their effects. As a way of understanding health and equity impacts, we analyzed emissions, exposure, and health outcome by race/ethnicity and CalEnviroScreen (CES) 4.0 scores (OEHHA 2021). In this report "benefits and impacts" are defined as:

- Changes in emissions of GHGs, fine particulate matter (PM2.5), and air toxics.
- Expected health benefits resulting from changes in PM2.5 based on modeled PM2.5 concentrations, specifically avoided premature mortality.

For the HDV analysis, we evaluated trends in HDV primary PM2.5 concentrations from 2000 to 2019, also known as diesel PM (DPM). We also assessed projected primary and secondary PM2.5 concentrations from HDVs resulting from a complete transition (100% new and accelerated turnover of existing fleet) to zero emission HDVs from 2020 to 2045. We focused on HDVs because of the public health risk from exposure to DPM, which is a toxic air contaminant.

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[2] Figure 1 shows 2019 GHG emissions by sector but this report includes GHG emission data up to 2018.

DPM is a subset of PM2.5 and is thought to cause the same adverse health effects as PM2.5 (CARB 2020a). Other mobile sources such as off-road and light-duty vehicles may be analyzed in future evaluations.

For facilities covered by the Cap-and-Trade Program, we evaluated emissions of GHGs and co-pollutants from 2011 to 2018. We covered significantly more years of data than have been covered by previous analyses conducted by OEHHA or other researchers (Cushing et al. 2018; OEHHA 2017). Data from all stationary facilities covered by Cap-and-Trade were used in this analysis, excluding entities classified as transportation fuel suppliers, suppliers of natural gas, and electricity importers. We did not include them in this analysis because they are not easily linked to local emissions.

The report begins with a brief background on California's climate policy, with a focus on policies targeting emissions from HDVs and stationary sources covered by the Cap-and-Trade Program. The section on data sources and methods includes an overview of the analytical framework. The section on results presents findings from the two research questions. In the last section, we summarize our findings and discuss the limitations of the available data and analytical methods, and outline future work. Additional methods are provided in the appendix.

Background

California's authority to reduce GHG emissions and curb climate change stems from AB 32. This act sets a statewide goal to reduce GHG emissions from all sources within the AB 32 GHG inventory in California to 1990 levels by the year 2020. It required CARB and other state agencies to adopt rules and regulations to achieve maximum technologically feasible and cost-effective GHG emission reductions. CARB responded by issuing a first Scoping Plan and subsequent updates, outlining specific actions to achieve GHG reductions using a range of strategies, and targeting a wide variety of emission sources (2008, 2014, 2017b).

This report focuses on the environmental and health equity resulting from trends in emissions from sources subject to heavy-duty emissions measures and stationary sources subject to the Cap-and-Trade Program. It expands on OEHHA's initial, 2017 report on this subject, which focused on the environmental and health equity of facility emissions subject to the Cap-and-Trade Program using a limited dataset (OEHHA 2017).

Since the enactment of AB 32, several legislative and executive initiatives have continued to enhance California's climate change policies. In 2016, California set a new target to achieve a 40% reduction in emissions from 1990 levels by 2030 (Pavley, Statutes of 2016). Additionally, AB 197 (Garcia, Statutes of 2016) requires CARB to consider the social costs of carbon and to protect the state's most impacted and disadvantaged communities from these effects. In 2017, AB 398 included provisions to continue the Cap-and-Trade Program through 2030, while AB 617 required more frequent reporting of criteria air pollutant and air toxics emissions data, and established the Community Air Protection Program to target pollution reduction in California communities most impacted by poor air quality, using community-level air pollution monitoring and clean technology incentives (C Garcia, Statutes of 2017; E Garcia, Statutes of 2017). Recent executive orders outline a path to carbon neutrality by 2045 (B-55-18 2018) and require all new cars and passenger trucks sold in California to be zero-emission vehicles by 2035 (N-79-20 Executive Order 2020).

In response to AB 32, CARB develops Scoping Plans to ensure statutory GHG reduction targets are met. The Scoping Plan outlines a number of strategies that target the diverse sources of GHG emissions, ranging from industrial sources, to transportation and electricity (CARB 2017b). The Scoping Plans also leverage existing policies to reduce harmful local air pollution with co-benefits for GHG emissions reductions. Despite arising from the same emission sources, pursuant to state and federal regulations, GHGs are regulated at the state scale and co-pollutants are regulated at local and regional[3] scales. Measures focused on GHGs do not incorporate specific targets to reduce emissions of PM2.5 or air toxics like benzene. These co-pollutants, which are emitted from many of the same pollution sources as GHGs, affect local air quality and pose known risks to public health, such as the risk of asthma and cardiovascular disease. For stationary sources, these harmful pollutants are regulated via local rules and regulations that are reflected in permits for stationary sources and are enforced by local air districts.

Despite statewide and regional scale improvements to air quality, disparities in community-scale air pollution and health inequities remain (Apte et al. 2019; Morello-Frosch et al. 2011; OEHHA 2017; Propper et al. 2015). Community-level impacts from local emissions can be significant, even in areas that meet regional air quality standards. Apte et al. (2019) have shown that the top two sources of PM2.5 exposure in California are on-road vehicles and industrial activity, which also contribute most to PM2.5 concentration disparity by race/ethnicity.

The importance of striving for environmental and health equity in climate policies is clear. It is important to ensure that statewide policies do not leave some communities behind, while other communities reap the benefits of emission reductions. An Environmental Justice Advisory Committee (EJAC) was created under AB32 to advise CARB on Scoping Plan development for this reason.

Some environmental justice concerns remain over policies that target the reduction of emissions from the two sectors evaluated in this report, namely HDVs and stationary sources. Specifically, HDVs remain the largest source of DPM emissions and one of the largest sources of oxides of nitrogen (NOx) in the state, and pose significant equity concerns in regions of the state with persistent truck traffic, such as goods movement corridors (Houston et al. 2014).[4] California policies adopted by CARB[5] under the Clean Air Act have effectively reduced DPM and NOx emissions statewide, with the greatest reduction of DPM coming from HDVs (Schwarzman et al. 2021). Despite these regional reductions, low-income communities and communities of color still do not enjoy the same benefits because of their proximity to several concentrated emissions sources like ports, railyards, and highways. Similarly, historical land use practices of siting facilities in communities of color, along with residential redlining, have contributed to the

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[3] California develops State Implementation Plans to reduce criteria pollutants like PM2.5 under the Clean Air Act.
[4] Goods movement refers to networks of highways and city and local streets that trucks use to move freight and other goods from its origin to its destination.
https://ww2.arb.ca.gov/resources/fact-sheets/california-air-resources-board-appointments-qualifications-terms

exposure disparities from large stationary sources that we see today (Pastor et al. 2001). Facilities subject to Cap-and-Trade existed before the establishment and implementation of the Program in 2013. The Cap-and-Trade Program is one of the more recent set of regulations among the many that affect emissions from these facilities.

The transportation sector[6] is the largest emitter of GHGs in the state, responsible for 41% of GHG emissions in 2019. This sector also emits the majority of DPM and NOx, which is a significant precursor to ozone and PM2.5 (CARB 2020d). Emissions data from rail, ships, aircraft, HDVs, and passenger vehicles are all captured under the transportation sector (CARB 2020d). Our analysis of HDV emissions uses data from all sources of diesel fuel, including conventional and alternative diesel fuels. Diesel fuel represents 17% of total fuel sales, while gasoline is the most used transportation fuel in California (California Energy Commission 2021a, b). Alternative diesel fuels, such as biodiesel and renewable diesel, are part of a growing market in California, and displaced over 568 million gallons of diesel fuel in 2018 (CARB 2019c). It is important to note that the use of alternative diesel leads to lower PM emissions in diesel engines than conventional diesel fuel does (Xue et al. 2011).

Air pollutant emissions from mobile sources have disproportionate impacts on vulnerable populations and California's communities of color (CARB 2017b). Diesel-fueled vehicles traveling on California's freeways and major roads expose nearby residents to DPM, a toxic air contaminant that is linked to lung cancer, premature death, hospitalizations and emergency department visits for chronic heart and lung disease (CARB 2020a; Kagawa 2002). Nearly all DPM is in the PM2.5 size range (CARB 2021b). Furthermore, recent findings show that Black Californians have 19% higher PM2.5 exposure from vehicle emissions than the state average, and the census tracts with the highest PM2.5 pollution burden from vehicle emissions have a high proportion of people of color (Reichmuth 2019). This suggests that reducing emissions from diesel vehicles can improve health outcomes for certain communities of color that are disproportionately exposed to DPM from heavy-duty vehicles.

The Cap-and-Trade Program is a market-based regulation to reduce statewide GHG emissions that was implemented in California beginning in 2013. The Cap-and-Trade Program covers approximately 80% of the State's GHG emissions from transportation fuels, electricity generated and consumed in state, industrial, agricultural, waste, residential, and commercial

[6] Fuel suppliers, covered by the Cap-and-Trade Program as of 2015, supply gasoline, diesel fuel no. 1 and no. 2, liquefied petroleum gas, and natural gas to California customers. GHG emissions are estimated based on the amount of fuel sold and a fuel specific GHG emission rate.

sources that emit over 25,000 metric tons of carbon dioxide equivalent[7] (MTCO2e) annually[8] (CARB 2017b). The Cap-and-Trade Program sets a statewide emissions limit, or “cap,” that decreases annually.

To comply with the Cap-and-Trade Program, entities submit state-issued emission allowances or a combination of allowances and offset credits equal to their reported and verified GHG emissions (CARB 2019a, d). This feature of the Program allows entities to determine the most cost-effective approach to compliance, which can include using direct emission reductions, purchasing or trading allowances, or applying offset credits. Offset credits can be used to meet up to eight percent of an entity’s compliance obligation through the 2020 emissions year. Per AB 398 (E Garcia, Statutes of 2017), entities can meet up to four percent of their compliance obligation using offset credits for emissions years 2021–2025, and six percent for emissions years 2026 –2030. Offset usage is reported at the entity level, and an individual entity may control one or more stationary facilities.

Emissions from large stationary facilities have significant impacts on nearby communities (Apte et al. 2019). Stationary sources are subject to both local air district permits for criteria air pollutants and air toxics, and the state’s Cap-and-Trade Program for GHG reductions, in addition to other federal and state rules and regulations. Reducing GHG, criteria air pollutant and air toxics emissions from large stationary sources is a priority for environmental justice activists and community members. In the development of the Scoping Plan for achieving statewide GHG reduction targets, members of the Environmental Justice Advisory Committee expressed concern that the Cap-and-Trade Program, by design, does not mandate emission reductions at each and every facility (Environmental Justice Advisory Committee 2017). OEHHA (2017) and others have meanwhile shown that covered facilities are disproportionately located near disadvantaged communities, and that covered facilities near communities with high proportions of people of color tend to emit more air pollution (Cushing et al. 2018). Thus, it is important to evaluate the benefits and impacts of facilities covered by the Cap-and-Trade Program on the health of California residents, especially in low-income communities and communities of color.

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[7] The unit of measurement for GHG emissions is: metric tons of carbon dioxide equivalent (MTCO2e). The unit CO2e represents an amount of a GHG whose atmospheric impact has been standardized to that of one unit mass of carbon dioxide (CO2), based on the global warming potential (GWP) of the gas. CO2e values are calculated using the IPCC Fourth Assessment Report 100-year GWP values.

[8] The Cap-and-Trade Program analysis in this report does not include all the sectors listed here. Specifically, transportation fuel suppliers and electricity imports are not included in the analysis because they are not associated with known, distinct, point locations.

Data Sources and Methods

Our goal in this report is to track and analyze the benefits and impacts within California's disadvantaged communities from policies designed to reduce GHG emissions from HDV and large stationary source sectors. This section provides an overview of the data and methods used in the analysis. The appendix contains detailed methods for dataset construction and analysis. We used R (version 4.0.4) to conduct statistical analyses, and created plots using *ggplot2* (version 3.3.3) (R Core Team 2021; Wickham. H 2009). ArcGIS© Pro version 2.8.0 was used to conduct spatial analysis and to create maps (Esri Inc. 2021). More information and datasets are available upon request.

CalEnviroScreen and Population Demographics

We used CalEnviroScreen 4.0 (CES) as a framework for evaluating the environmental and health equity of California's climate policies (OEHHA 2021). CES is a screening methodology developed by OEHHA that is used to help identify California communities that are disproportionately burdened by multiple sources of pollution. CES calculates an overall cumulative burden score for each census tract and ranks them in percentiles. Census tracts with the highest scores have higher cumulative burdens and vulnerabilities to the health effects of pollution compared to census tracts with lower scores. We derived demographic variables such as race/ethnicity from the U.S. Census Bureau American Community Survey (ACS) 5-year estimates 2014–2018. Following ACS practices, White survey respondents were defined as those who identified themselves and household members as non-Hispanic White. People of color were those who identified themselves as members of all other race/ethnicities that were not non-Hispanic White.

We grouped the CES percentile scores for each census tract into four quartiles: $<25^{th}$ percentile, $25–<50^{th}$ percentile, $50–<75^{th}$ percentile, and $75–100^{th}$ percentile for our environmental and health equity analysis. The most vulnerable group was the top quartile ($75–100^{th}$), representing the top 25% CES communities. The top 25 % CES communities, and communities with high pollution and low population, were designated by the California Environmental Protection Agency's (CalEPA) as disadvantaged communities in 2017 pursuant to Senate Bill No. 535 (CalEPA 2017). The 2021 draft designation of disadvantaged communities using CES 4.0 was released after we completed our analysis. The draft designated communities include the highest scoring 25% of census tracts, census tracts in the top 5% of the Pollution Burden indicator score, census tracts designated as disadvantaged using CES 3.0 and areas within federally recognized tribal boundaries in California (CalEPA 2021). Figure 2 shows a map of statewide communities organized by CES scores, grouped into the four quartile ranges. The same methodology was applied to group communities in census tracts into four quartiles for race/ethnicity variables, and percent people of color based on based on data from the ACS 5-year estimates.

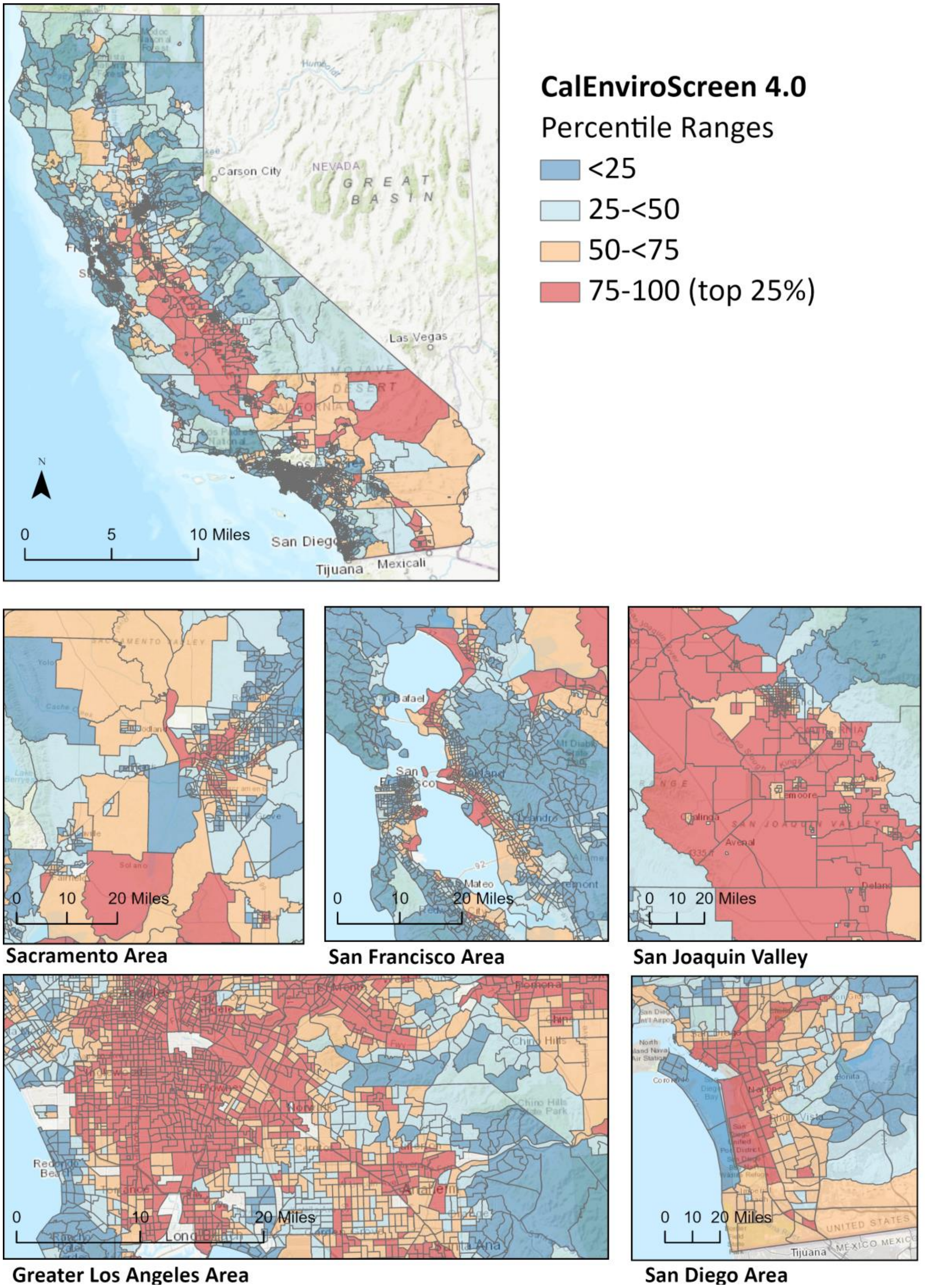


Figure 2. Map of California Showing Statewide CalEnviroScreen 4.0 Quartiles

Mobile Source Sector Data

Estimated Diesel PM Concentrations

To estimate the primary PM2.5 concentration from diesel sources or DPM at stationary monitor locations, we used the method described in Propper et al. (2015) where NOx concentrations are used as a tracer for DPM. In brief, the ratio of DPM to NOx emissions is used as a factor to convert NOx concentrations to DPM concentrations. That factor is called Alpha. We calculated Alpha for every air basin and every year from 2000 to 2019. In December 2020, we obtained the ambient air quality data from CARB's regulatory monitoring network. We calculated annual mean concentrations of NOx for each monitor that met the completeness criteria for each year from 2000 to 2019. Following U.S. Environmental Protection Agency (US EPA) guidance, a 75% completeness criterion was applied to each monitored pollutant to calculate annual average concentrations US EPA (US EPA 2017a). We evaluated the completeness criterion of each pollutant using the R package *openair* (Carslaw and Ropkins 2012) to assess the frequency of valid samples for a given time period. Monitors were then assigned the CES quartile of the census tract where the monitor was located. Annual concentrations at each monitor were then compared across CES quartiles.

Statewide Diesel Emissions Data

Statewide annual emission estimates for primary PM2.5, precursors to secondary PM2.5 formation (NOx, sulfur oxides [SOx], and reactive organic gases [ROGs]) were acquired from CARB in January 2021. We received processed emission shapefiles in a 1-kilometer (km) grid of California for 2018. The emission estimates were calculated by CARB using the EMission FACtor 2017 (EMFAC2017) model version 1.0.2 which estimates emission inventories (CARB 2021a, b). The emissions were allocated to a 1-km grid using an Emission Spatial and Temporal Allocator (ESTA) (CARB 2019a). We also received projected mobile source emission data from 2020 to 2045. Emission projections received were modeled using Mobile Emission Toolkit for Analysis (META) (CARB 2021b). The projected datasets were used as input into two subsequent models to estimate average population-weighted PM2.5 concentrations using InMAP and then avoided premature mortality using US EPA's Benefits Mapping and Analysis Program (BenMAP).

Large Stationary Source Sector Data

Facility Data

We compiled information on all facilities that report GHG emissions to CARB within the industrial and in-state electricity sectors subject to the Cap-and-Trade program. We used data for seven sectors that are covered by the Cap-and-Trade Program—cement plant, cogeneration, electricity generation, oil and gas production, hydrogen plant, other combustion source, and refinery (Figure 3). We excluded electricity importers and suppliers of transportation and natural gas fuels, because they are not easily linked to local emissions.

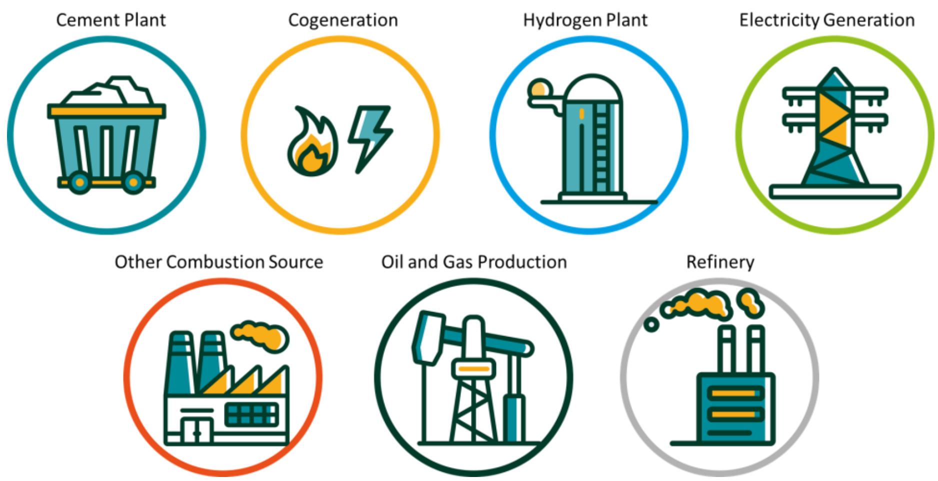


Figure 3. Seven Sectors Covered by the Cap-and-Trade Program and Included in OEHHA Analysis of Large Stationary Sources

We obtained information regarding facility status under the Cap-and-Trade Program (i.e., covered or not covered) and operating status of large stationary sources from CARB. Stationary facilities were included in this analysis if the facility was covered by the Cap-and-Trade Program for at least one year during the period 2013 to 2018. We used facility-level data on emissions of GHGs, criteria air pollutants, and air toxics for reporting years 2011–2018. These reporting years were used for our analysis because GHG emissions prior to 2011 were calculated differently and emission data was not available beyond 2018 when we began our analysis. Facility GHG emissions were derived from Mandatory Reporting Regulation (MRR) data, downloaded from the CARB website in August 2020 (CARB 2020b). Facility data for criteria air pollutants and air toxics emissions, derived from the California Emissions Inventory Development and Reporting System (CEIDARS), were obtained in December 2020 via request to CARB. Facility locations were downloaded from the Pollution Mapping Tool in March 2020 (CARB 2018). Additional coordinates for oil and gas production facilities were obtained via request from CARB and supplemented by data obtained from researchers at University of California, Berkeley (April 2019).

Facility CalEnviroScreen Score and Demographic Data

Facility locations were used to categorize facilities based on CES and ACS 5-year demographic estimate (2014–2018) variables of nearby census tracts (OEHHA 2021; US Census Bureau 2019). Specifically, each facility was assigned the maximum non-zero CES score of a census tract within a given distance of the facility. Facilities were grouped into quartiles based on the assigned CES percentile, and we evaluated facility locations and emission trends across CES quartiles. We employed a similar method to assign ACS demographic variables to evaluate trends across quartiles for race/ethnicity profiles of residents. Over 95% of facilities included in our analysis were assigned the CES score or race/ethnicity variables of the census tract within 0.5 miles from the facility point location. Facilities near a census tract where CES variables were not calculated due to low population were assigned values from census tracts within 1.0 mile (11 facilities) or within 2.5 miles (two facilities). Race/ethnicity variables were derived from the census tracts within 0.5 miles for all except four facilities that were assigned variables from the census tract within 1.0 mile. The buffer distances used in this report are consistent with other research in this field (Cushing et al. 2018; Pastor et al. 2010).

We obtained CEIDARS stack-level criteria air pollutant emissions data for reporting year 2012 and 2017 for Cap-and-Trade covered facilities from CARB in December 2020. We used 2012 and 2017 data because these years of data have undergone extensive quality control measures by CARB due to the use of data from these years in the National Emissions Inventory (personal communication with CARB) and because they were during our study time period. Further, it allowed us to examine the potential influence of the Cap-and-Trade Program on facility emissions as these years represent emissions from pre-Cap-and-Trade (2012) and post Cap-and-Trade (2017) implementation. These data were used as input into Intervention Model for Air Pollution (InMAP), described in more detail in the section 'Modeling Methodology.'

Odds Ratio

To compare the distribution of facilities with respect to census tracts with different CES scores and relative percentage people of color, we used an odds ratio approach. Census tracts were assigned their respective quartile values for CES and for people of color. Then, census tracts that were within 2.5 miles of a facility were categorized as being near a facility while tracts beyond 2.5 miles were not. We evaluated the odds of a high-scoring census tract (75^{th}-100^{th}percentile) being located near a facility compared to a low-scoring census tract (<25^{th} percentile) for both CES score and percentage people of color.

Entity Compliance Obligation and Offset Data

Offset credit issuance tables and compliance reports were downloaded from CARB's website in February 2021 for two compliance periods (2013–2014 and 2015–2017) (CARB 2021c). Offset credit issuance tables detail available offset projects, while the compliance reports provide entity-level data on how compliance obligations are met through the use of allowances and/or offset credits. Compliance obligation data are summarized at the entity-level and given a unique identification number. An entity is a company that may operate several regulated facilities under the Cap-and-Trade Program. Offset usage is reported by entity, while emissions are reported by facility.

Using a unique identifier for each entity, facilities and associated GHG and PM2.5 emissions were joined to their parent entity. Since the first compliance period was two years in duration and the second three, cumulative emissions from facilities were summed at the entity level and annualized by compliance period. We then ranked each entity on the total amount of offset credits used in a compliance period. We also calculated the percentage of offsets each entity used to meet their compliance obligation, with eight percent being the maximum allowed under the Program for those years. If an entity used offsets, then all of the associated emissions for that entity were summed and compared to emissions associated with entities that did not use offsets. For the spatial analysis, only stationary facilities associated with entities were included and fuel suppliers and electricity importers were omitted.

Modeling Methodology

This analysis used two models, Intervention Model for Air Pollution (InMAP) and the Environmental Benefits Mapping and Analysis Program (BenMAP) to estimate population-weighted average PM2.5 concentrations and avoided premature mortality due to changes in these concentrations, respectively. Out of all the co-pollutants we chose to evaluate PM 2.5 because of data availability, model capabilities, and significant associated health effects.

InMAP estimates annual average concentrations of PM2.5 from emissions of primary PM2.5 and secondary PM2.5 from oxides of nitrogen (Tessum et al. 2017). The model domain for the state of California includes portions of neighboring states and consists of 21,705 grid cells, ranging from 1 km^2 to 2,304 km^2. A Source-Receptor Matrix previously created using InMAP was used to estimate PM2.5 concentrations in this study (Apte et al. 2019).

BenMAP version 1.5.8 was used to approximate health benefits (US EPA 2021). We modeled the number of avoided premature deaths resulting from changes in PM2.5 concentrations, using the data obtained from InMAP modeling. BenMAP uses four key sources of data (1) modeled or monitored air quality changes, (2) population characteristics, (3) baseline incidence rates, and (4) an effect estimate. BenMAP uses beta coefficients, which represent the associations between air pollution exposure and a health outcome reported in epidemiologic studies, to construct health impact functions to estimate the counts of air pollution-related deaths and illnesses (Sacks et al. 2018). We used the health impact function established by Krewski et al. (2009) and accounted for differences in mortality incidence by race/ethnicity.

For the HDVs analysis, InMAP was used to generate gridded population-weighted average primary and secondary PM2.5 concentrations for the state of California for each year between 2020 and 2045 based on a scenario of 100% zero-emission heavy-duty vehicles (100% new and accelerated turnover of existing fleet) by 2045. This was used as the air quality input data for BenMAP to estimate the number of avoided premature deaths associated with modeled PM2.5 emission changes for each year from 2020 to 2045. The baseline health incidence rates for this analysis were closely matched to the year of modeled data. For example, rates for 2020 were used for model years 2020 through 2022 and rates for 2025 were used for 2023 through 2027.

For the analysis of emissions from large stationary sources, InMAP was used to generate gridded population-weighted average PM2.5 concentrations for the state of California for 2012 and 2017 based on the stack-level criteria emissions data from facilities covered by the Cap-and-Trade Program. The emissions for year 2012 and 2017 were chosen for the modeling and health analysis because data from these years are used for the National Emissions

Inventory and underwent more rigorous quality checking compared to the data for other years in the study period. These concentrations were the air quality inputs for BenMAP to estimate the number of avoided premature deaths associated with changes in modeled concentrations.

What are the historical and projected benefits and impacts from emissions changes from heavy-duty vehicle sources in disadvantaged communities?

Which communities benefited most from diesel PM reductions over the last 20 years?

High-Scoring CES Communities Have the Greatest Reduction in Diesel PM Concentrations Over the Last 20 Years

Diesel PM (DPM) levels dropped everywhere in California from 2000 to 2019 with the greatest air quality improvements in high-scoring CES tracts. DPM concentrations were estimated based on California's network of NOx monitors (Propper et al. 2015). Each monitor was assigned a CES score based on the census tract where it is located. In Figure 4 and Figure 5 monitors are grouped by CES quartiles. Monitors located in census tracts above the 75th percentile of CES scores had greatest reductions in DPM concentration Figure 4, though they also continue to have higher DPM concentrations than all other quartiles Figure 5.

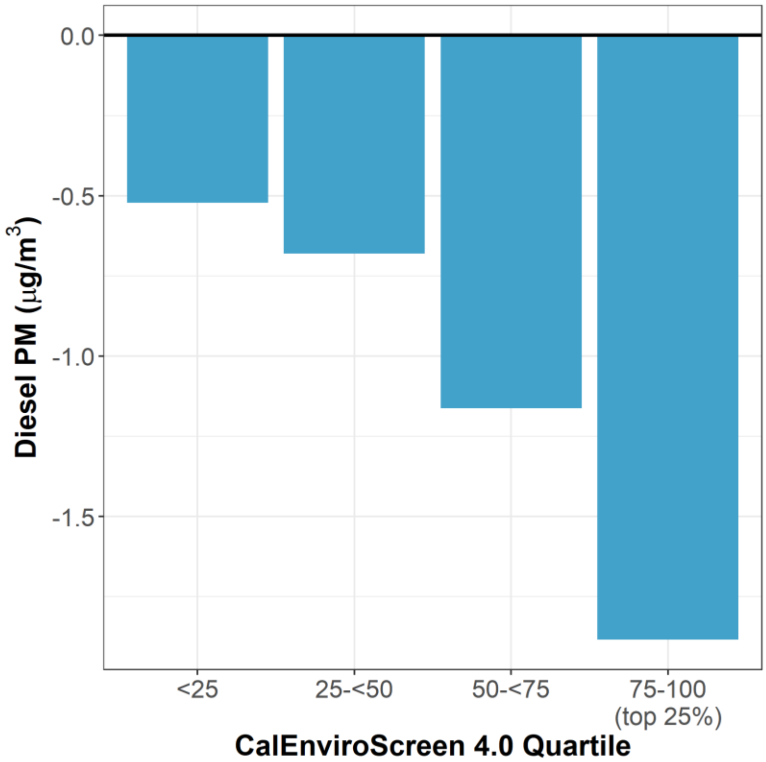


Figure 4. Reduction in Diesel Particulate Matter Concentration from 2000 to 2019 by CalEnviroScreen 4.0 Quartile

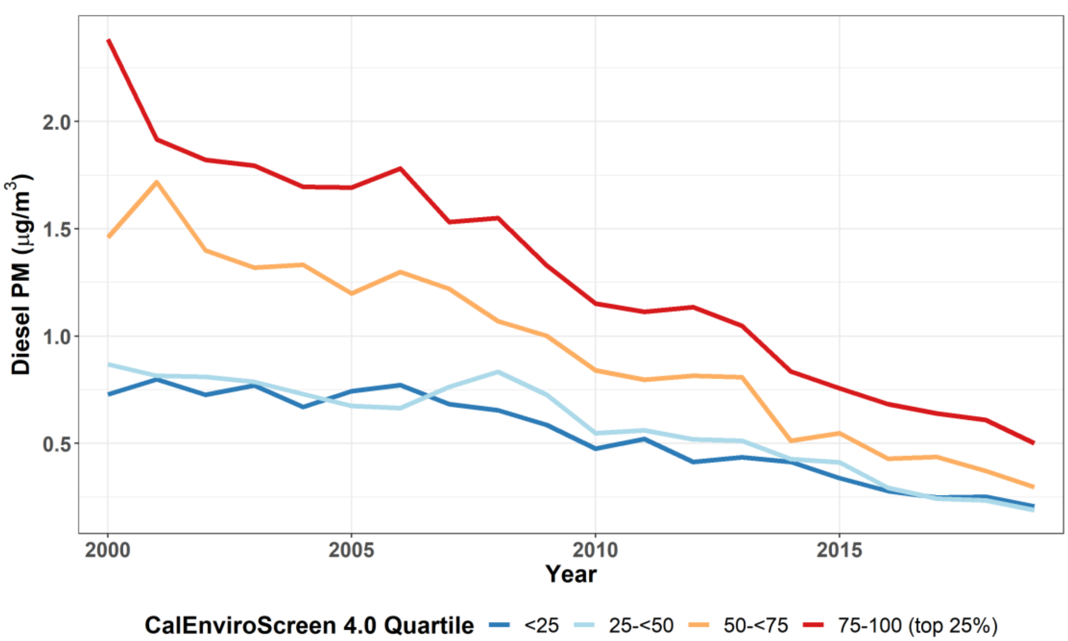


Figure 5. Diesel Particulate Matter Trend by CalEnviroScreen 4.0 Quartile from 2000 to 2019

Which communities will benefit most from deployment of zero-emission heavy-duty vehicles?

Zero-Emission Goals for Heavy-Duty Vehicles Could Reduce PM2.5 Concentrations Statewide

PM2.5 concentrations from HDVs[9] are estimated to be 58% lower[10] in a scenario of complete transition (100% new and accelerated turnover of existing fleet) to zero-emission heavy-duty vehicles by 2045 compared to the business as usual (BAU) scenario in 2045 (0.09 µg/m^3 versus 0.22 µg/m^3). Figure 6 shows the statewide annual average population-weighted exposure concentration of PM2.5 from HDV for (A) the baseline scenario for 2018 (0.27 µg/m^3), (B) the BAU scenario for 2045 (0.22 µg/m^3), and (C) 100% zero-emission heavy-duty vehicles scenario by 2045 (0.09 µg/m^3). The concentration of primary and secondary PM2.5 was modeled using InMAP based on projections of emissions under a BAU scenario and a scenario of 100% zero-emission heavy-duty vehicles by 2045.

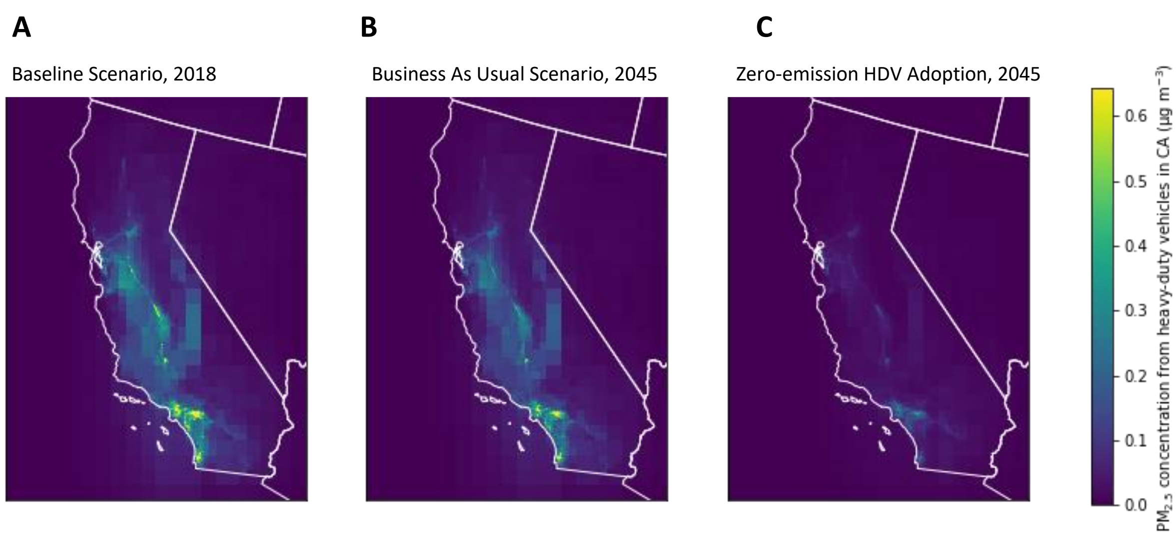


Figure 6. Population-Weighted Average PM2.5 Exposure Concentration from Heavy-Duty Vehicles Based on a Scenario of 100% Zero-Emission Heavy-Duty Vehicles by 2045

[9] The category HDVs for this analysis does not include buses.

[10] Electric vehicles can generate PM from brake and tire wear and road surfaces but emit zero PM from exhaust.

High-Scoring CES Communities and Communities of Color will Benefit the Most from PM2.5 Reductions from Deployment of Zero-Emission Heavy-Duty Vehicles

An estimated 3,800 premature deaths would be avoided with implementation of zero-emission HDVs from 2020 to 2045. While the benefit would occur statewide, a third (32%) of the avoided deaths would occur in the highest-scoring CES census tracts (Figure 7) and people of color would account for about two thirds (61%) of the avoided deaths (Figure 8). Total avoided premature deaths from 2020 to 2045 were estimated using BenMAP, using the change in population-weighted average PM2.5 concentrations estimated from InMAP that are presented in the maps in Figure 6.

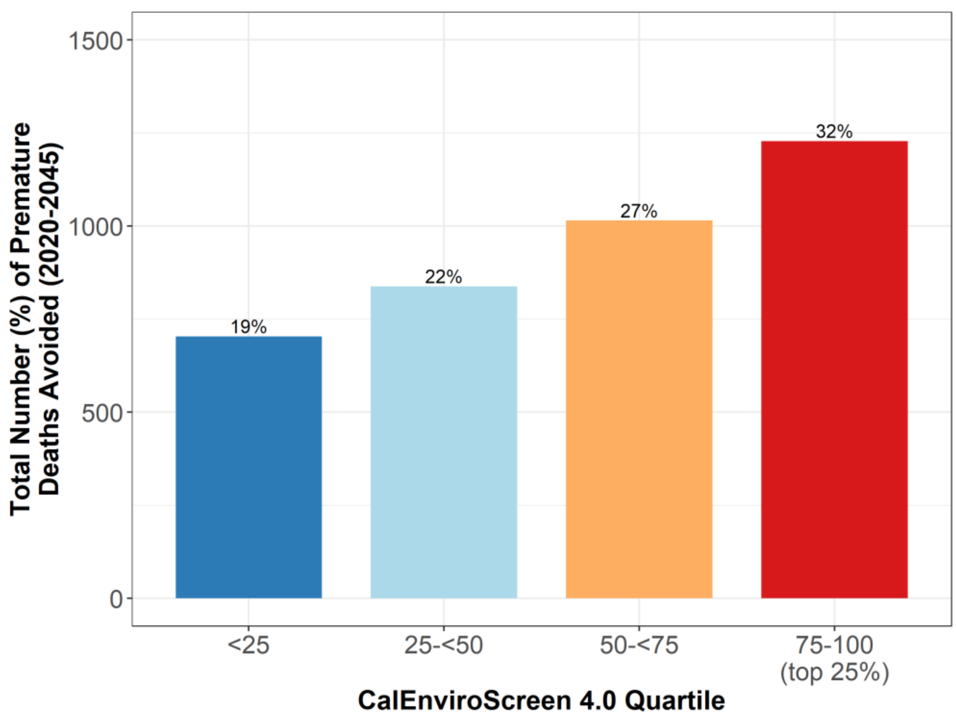
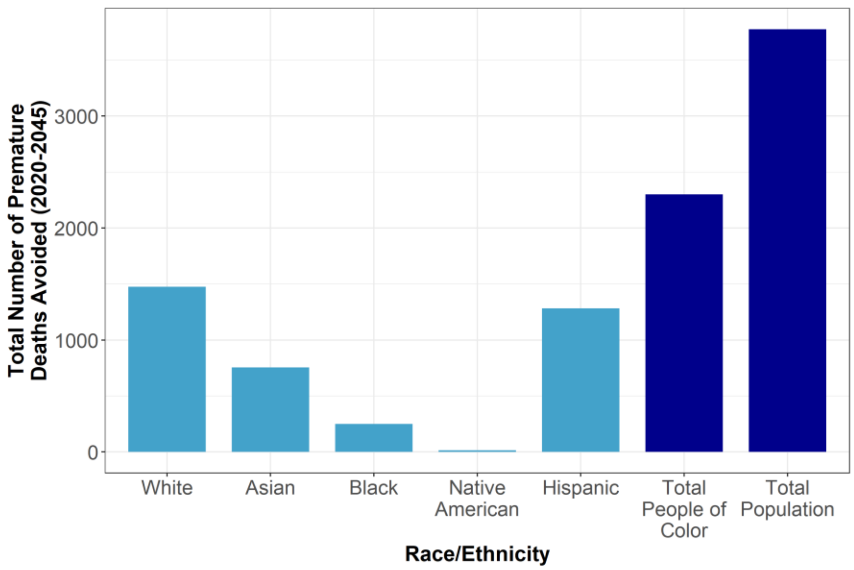


Figure 7. Total Estimated Number and Percent Premature Deaths Avoided with Change in PM2.5 Emissions Resulting from Transition to Zero-Emission Heavy-Duty Vehicles from 2020–2045 by CalEnviroScreen 4.0 Quartile

A



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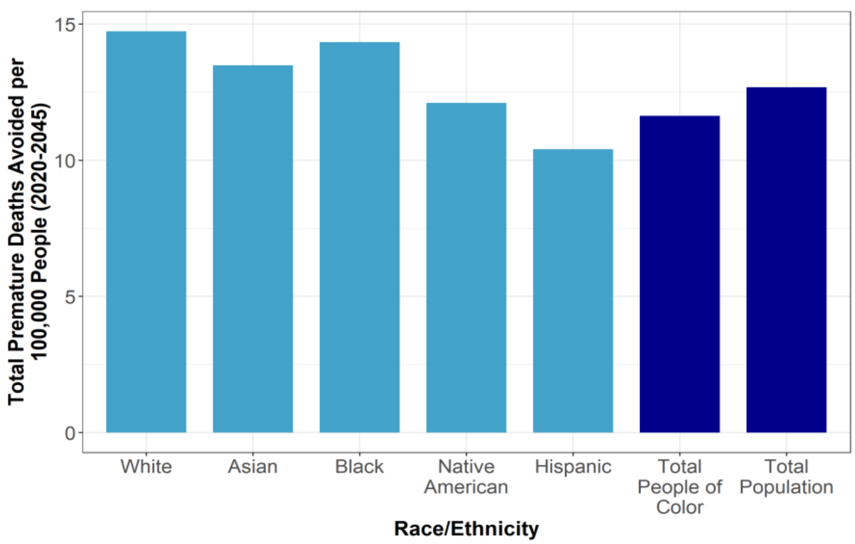

Figure 8. (A) Total Number and (B) Population-Adjusted Premature Deaths Estimated Avoided with Change in PM2.5 Emissions Resulting from Complete Transition to Zero-Emission Heavy-Duty Vehicles from 2020–2045 by Race/Ethnicity. *While the number of Native American avoided premature deaths per 100,000 is 12, the absolute number is 15 as shown on Figure 8A.

What have been the benefits and impacts from emissions changes at facilities subject to the Cap-and-Trade Program in disadvantaged communities?

Where are facilities located?

Most Covered Facilities in All Sectors are Located in or near High-Scoring CES Communities

Nearly half (280/613) of Cap-and-Trade covered facilities are located near communities with CES scores above the 75th percentile (*Figure 9*). There are fewer Cap-and-Trade covered facilities located near communities with lower CES scores. The majority of facilities in four sectors (cogeneration, electricity generation, other combustion sources and refineries) were located near disadvantaged communities (Table 1). Each facility was assigned a CES score based on the maximum non-zero CES score near the facility. This analysis included all facilities that were covered by the Cap-and-Trade Program during any year from 2011–2018 (n=613) and included individual oil and gas production facilities, rather than geological basin[11] level data.

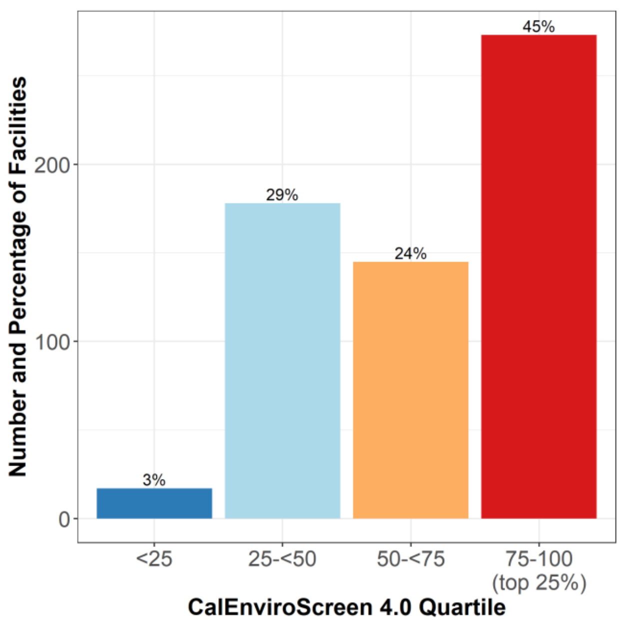

Figure 9. Number and Percentage of Facilities by CalEnviroScreen 4.0 Quartile

Table 1. Facilities Categorized in High CalEnviroScreen 4.0 Quartile by Sector

Sector (Number of Facilities)	Percentage of Facilities
Refinery (21)	71%
Other Combustion Sources (130)	61%
Electricity Generation (96)	49%
Cogeneration (42)	57%

[11] GHG emissions for oil and gas facilities are reported as an aggregate of a company's operations in a geologic basin that typically consists of a very large area covering one or more counties (CARB 2017).

Cap-and-Trade Covered Facilities are Over 3 Times More Likely to be Near Communities with High CES Scores and High Percentage People of Color

Overall, Cap-and-Trade covered facilities are three times more likely to be near communities with high CES scores and high percentage people of color. Refineries and other combustion sources are even more likely to be near communities with high CES scores and high percentage people of color (Figure 10). For this analysis, census tracts were categorized as either having a facility or not having a facility within the census tract boundary. The odds of a facility being located in a high-scoring CES census tract (75^{th}–100^{th} percentile) compared to a low-scoring CES census tract (<25^{th} percentile) was evaluated using an odds ratio approach for both CES score and percent people of color. Results are shown as odds ratios and 95% confidence intervals for CES in orange and people of color based on ACS data. An odds ratio of 1, indicated by the dashed line, signifies that a facility within a sector is not more likely to be located in a high-scoring compared to a low-scoring CES census tract. For example, refineries are nine times more likely to be located near high-scoring CES census tracts compared to low and five times for likely to be near tracts with a high percentage of people of color versus low.

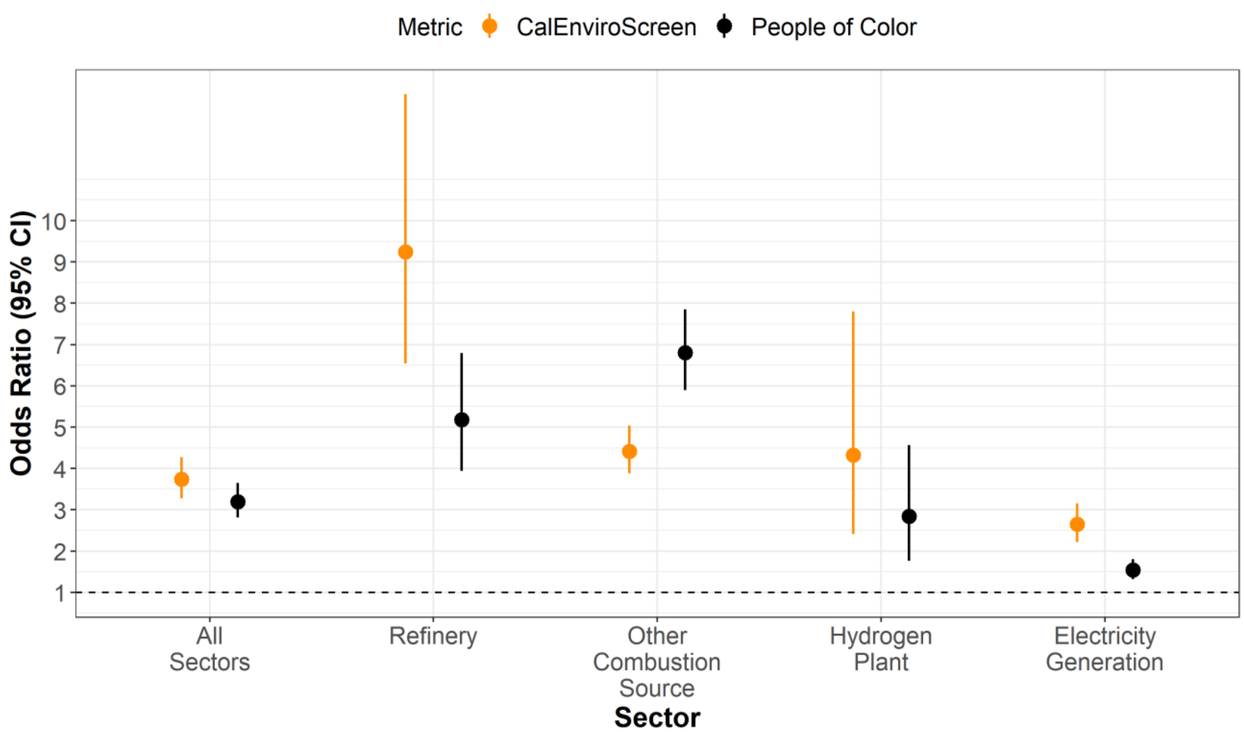

Figure 10. Odds of a Facility/Sector Being in a High-Scoring Versus Low-Scoring Community for CalEnviroScreen 4.0 Quartile and Percentage People of Color

How do facility emissions of GHGs, PM2.5, and air toxics change over time and location?

Greatest Emissions Reductions are From Facilities Covered under the Cap-and-Trade Program that are Located Near Communities with High CalEnviroScreen Scores

Between 2012 and 2018, decreases in GHG, PM2.5, and air toxics emissions were found to occur at facilities covered under the Cap-and-Trade Program that are located near the highest-scoring CES communities (Figure 11). Covered facilities with emissions data from 2011–2018 were included in this analysis to compare emissions in 2012 and in 2018 (n = 390). The number of facilities varies by pollutant because some facilities report only certain pollutants in certain years. For each facility, the absolute difference between 2012 and 2018 in GHG emissions was calculated to compare emission levels before and after the implementation of the Cap-and-Trade Program. The changes in emissions were summed for each CES quartile. Figure 11 shows the total change in emissions by CES quartile for (A) GHGs, (B) PM2.5, and (C) air toxics between 2012 and 2018. The increase in PM2.5 emissions in the low-scoring CES facilities is driven by an increase in PM2.5 emissions at one cement plant in 2018. We did not investigate the cause of the increases in PM2.5 for this facility as it was outside the scope of this report.

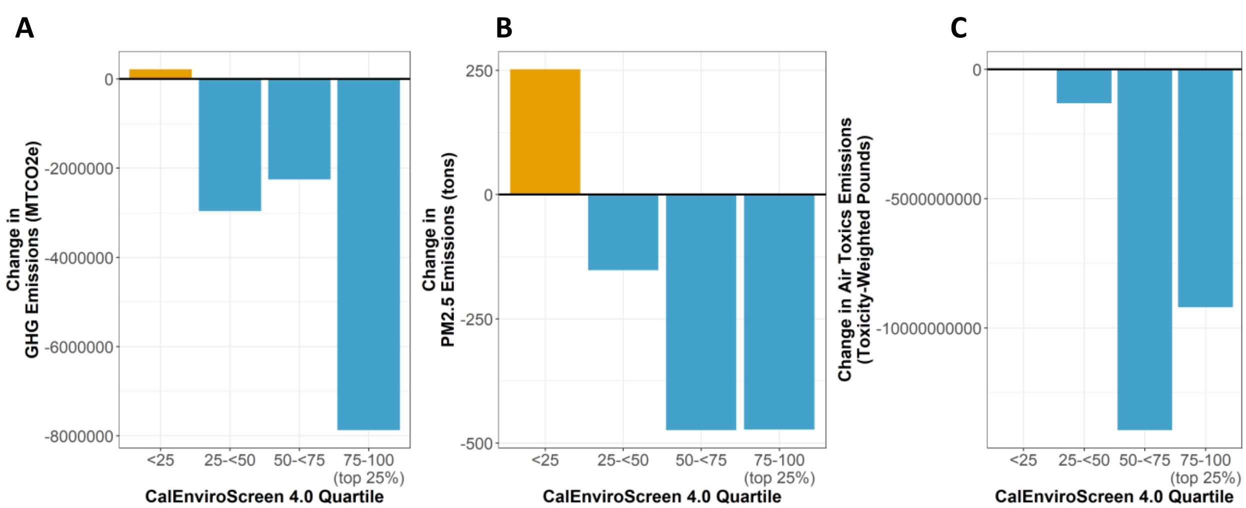

Figure 11. Change in GHG, PM2.5, and Air Toxics Emissions from 2012 to 2018 by Facility CalEnviroScreen 4.0 Quartile

What are the PM2.5-related exposure and health benefits of changing facility emissions?

High-Scoring CES Communities Experience Greatest PM2.5 Exposure Reductions and Health Benefits from Cap-and-Trade Covered Facilities

There was a 45-fold greater reduction of PM2.5 exposure concentration in high-scoring (0.18 μg/m^3) versus low-scoring (0.004 μg/m^3) CES census tracts (Figure 12) and half the avoided premature deaths occurred in high-scoring CES census tracts, 55 (37 – 73 95% CI) out of 113 total avoided premature deaths (Figure 13). InMAP was used to produce population-weighted PM2.5 concentrations from Cap-and-Trade covered facilities emissions for reporting years 2012 and 2017. The difference in modeled PM2.5 concentrations from 2012 to 2017 was calculated for each CES quartile and the reductions across each quartile are shown below. Population-weighted average PM2.5 concentrations for 2012 and 2017 were used as the air quality BenMAP inputs to estimate the number of premature deaths avoided.

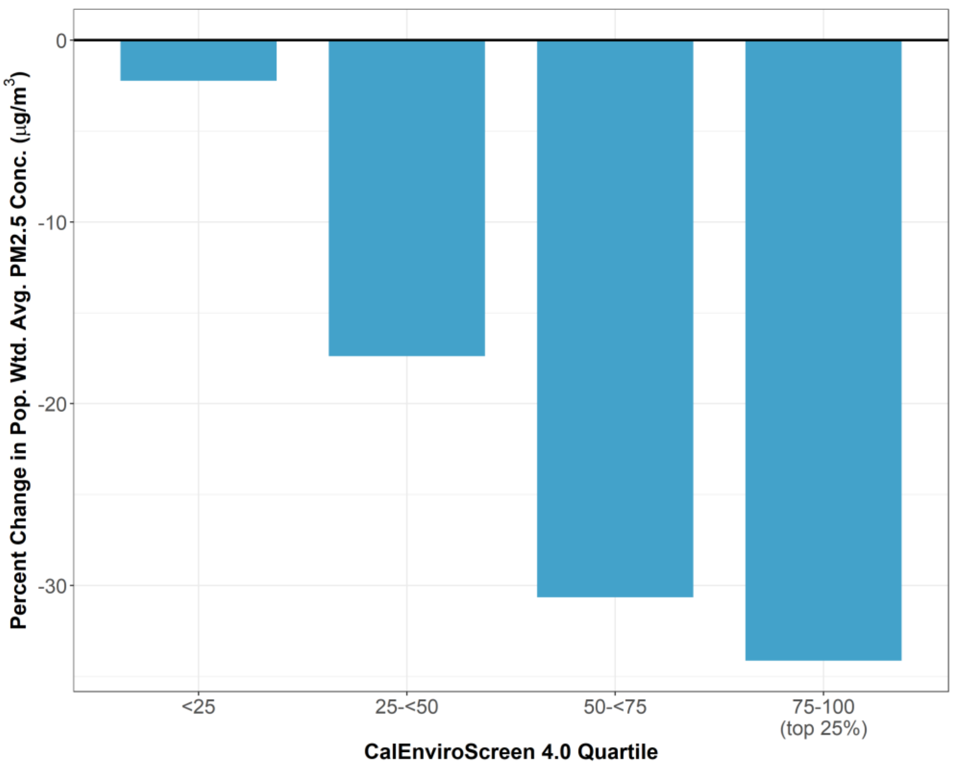

Figure 12. Change in Population-Weighted Average PM2.5 Exposure Concentration from Facilities between 2012 and 2017 by CalEnviroScreen 4.0 Quartile: InMAP Results

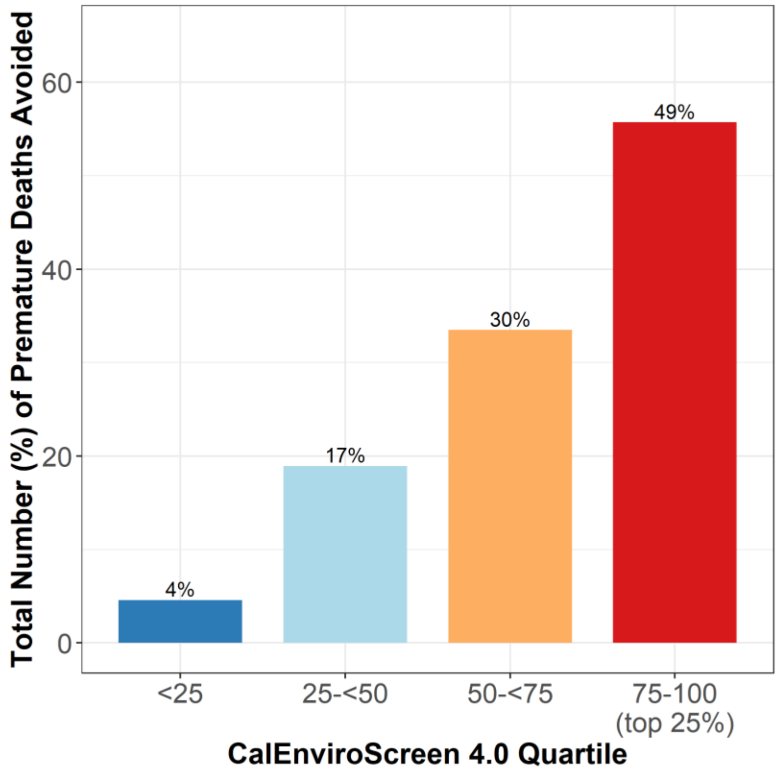

Figure 13. Total Number Premature Deaths Avoided with Change in PM2.5 Emissions from Covered Facilities between 2012 to 2017 by CalEnviroScreen 4.0 Quartile

Black Californians Experienced the Greatest PM2.5 Exposure Reductions and People of Color Experienced the Greatest Health Benefits from Cap-and-Trade Covered Facilities Emissions Reductions

Black Californians experienced a four-fold greater reduction in PM2.5 exposure concentration compared to White Californians (0.16/0.04 µg/m^3) resulting from emissions reductions at Cap-and-Trade covered facilities Figure 14). This PM2.5 reduction corresponds with approximately 13 (9 – 17 95% CI) avoided premature deaths for Blacks out of 113 total avoided premature deaths. Moreover, 68% or 75 (50 – 99 95% CI) out of 113 of premature deaths avoided were for people of color from reductions at Cap-and-Trade covered facilities (Figure 15). InMAP was used to model population-weighted PM2.5 average concentrations from stack emissions of Cap-and-Trade covered facilities for reporting years 2012 and 2017. Population-weighted average PM2.5 concentrations for 2012 and 2017 were used as the air quality BenMAP inputs to estimate the number of premature deaths avoided. Demographic classification methods in the appendix outline the differences in definitions of race/ethnicity between InMAP and BenMAP.

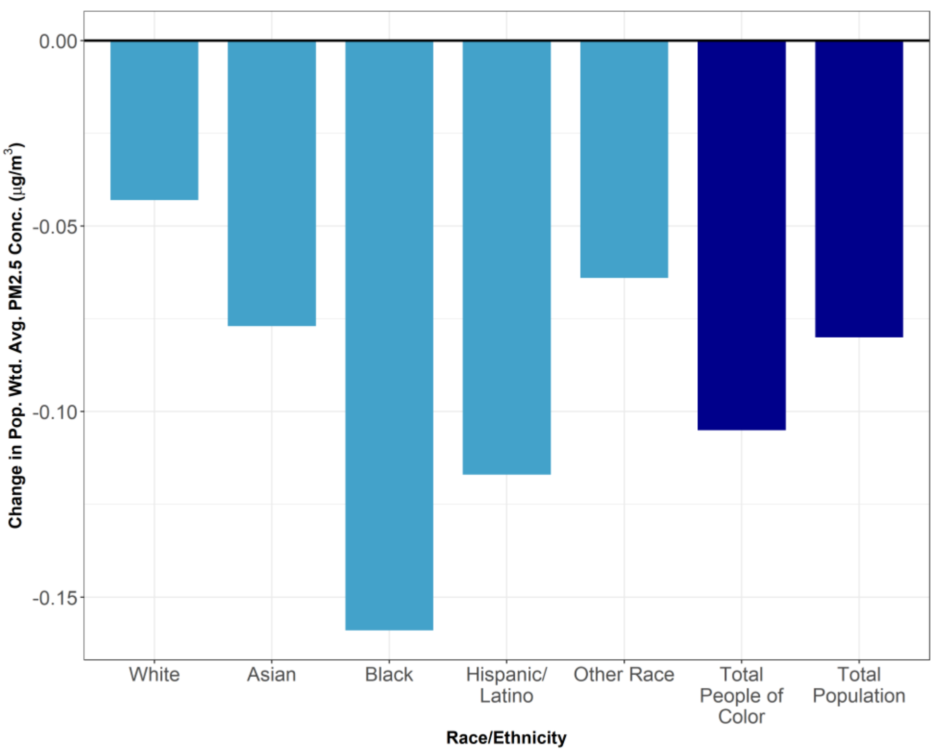

Figure 14. Change in Population-Weighted Average PM2.5 Exposure Concentration from Facilities between 2012 to 2017 by Race/Ethnicity: InMAP Results

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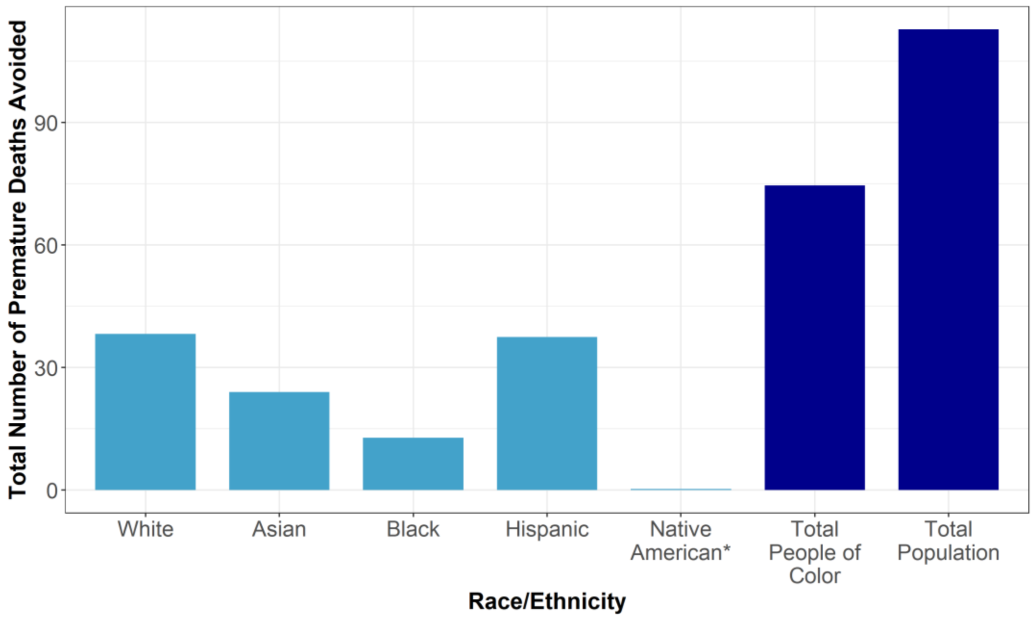

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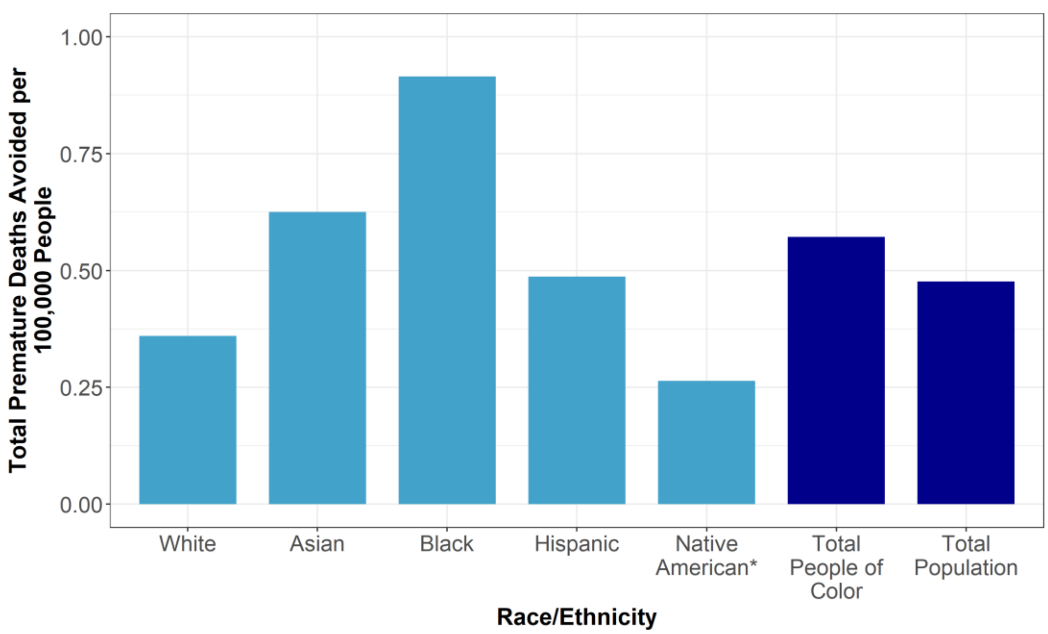

Figure 15. (A) Total Number and (B) Population-Adjusted Premature Deaths Avoided with Change in PM2.5 Emissions from Facilities between 2012 to 2017 by Race/Ethnicity: BenMAP Results. *The absolute number of Native American avoided premature deaths is less than one as shown on Figure 15A.

Inconsistent Association between GHG Reductions and Co-Pollutant Reductions

The relationship between facility emissions of GHGs and co-pollutants is highly variable by sector and pollutant. When stratified by sector, we found that the direction of change for facilities categorized as high-scoring CES facilities demonstrated was inconsistent (Table 2). The direction of the arrows in Table 2 represent the direction of emission change between 2018 and 2012 in communities with CES scores in the top 25% or high-scoring communities (change = 2018 emissions – 2012 emissions). Overall, there is a statistically significant, and moderately positive correlation between GHG and PM2.5 (R2 = 0.66) and air toxics (R2 = 0.51) (results not shown). However, these relationships vary by sector. Overall, there are 213 facilities categorized as high-scoring CES facilities, and the number of facilities varies by sector and pollutant.

Table 2. Direction of Emission Changes at Facilities Near High-Scoring CES Communities Varies by Pollutant and Sector (2018 Compared to 2012 Emissions)

Sector	Number of Facilities in High-Scoring CES Communities (Maximum)	GHG	PM2.5	Air Toxics
Cement Plants	1	↑	↓	↓
Cogeneration	19	↓	↓	↓
Electricity Generation	40	↓	↓	↓
Hydrogen Plants	6	↑	↑	↓
Oil and Gas Production	61	↓	↓	↑
Other Combustion Sources	65	↓	↑	↑
Refinery	14	↑	↑	↓

A Wide Gap in PM2.5 and Air Toxics Emissions Remains Between High and Low-Scoring CalEnviroScreen Communities

Despite the statewide emission reductions observed between the individual years 2012 and 2018, a closer look at the annual change from 2011 to 2018 by CES quartile demonstrates that a wide gap in emissions remains for facilities near high- compared to low-scoring CES communities (Figure 16).[12] For all three highlighted pollutants, (A) GHG, (B) PM2.5, and (C) air toxics, facilities near high-scoring CES communities (red) continue to experience higher total emissions than low-scoring CES communities (dark blue). The facility analysis indicates that Cap-and-Trade covered facilities are located in close proximity to vulnerable California communities. While facilities located near these vulnerable communities are reducing emissions – the facilities continue to have some of the highest overall emissions.

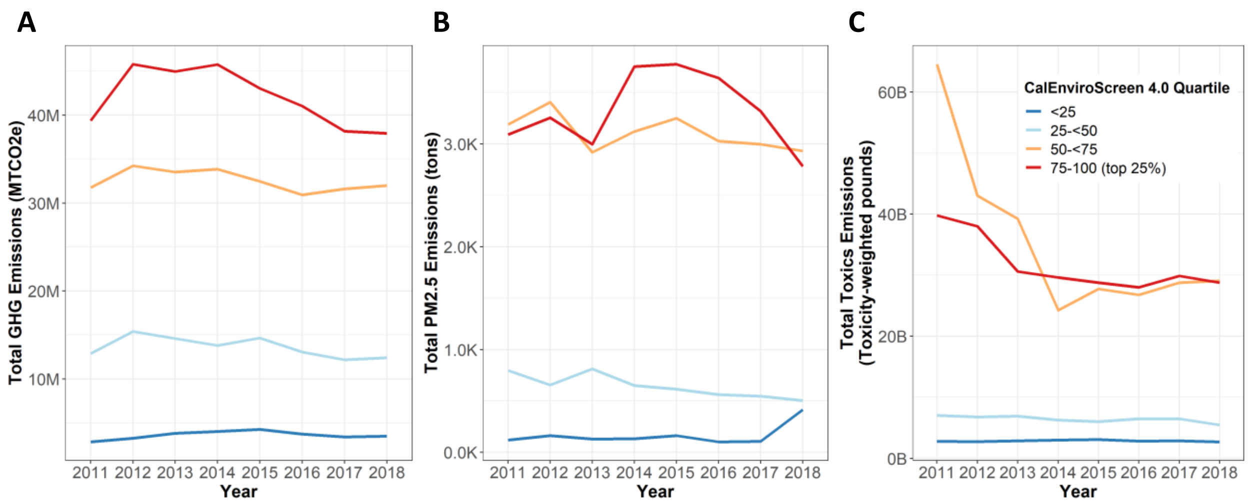

Figure 16. Trend in Total GHG, PM2.5, and Air Toxic Emissions from Facilities between 2011–2018 by CalEnviroScreen 4.0 Quartile

[12] Some changes in emissions may be due to local reporting issues.

Black Californians Continue to Experience the Highest PM2.5 Concentrations from Cap-and-Trade Covered Facilities with the Greatest Disparity Arising from Refinery Emissions

Black Californians experience twice the PM2.5 concentration compared to White Californians (0.4 versus 0.2 µg/m^3 in 2017) from emissions from covered facilities (Figure 17). Moreover, Black Californians experience PM2.5 concentrations from refineries that are 3 times greater than all other stationary source sectors combined that are covered by the Cap-and-Trade Program. (0.3 versus 0.1 µg/m^3) (Figure 18). InMAP was used to model stack emissions from Cap-and-Trade covered facilities for reporting years 2012 and 2017. InMAP produced gridded statewide estimates for population-weighted average PM2.5 concentrations.

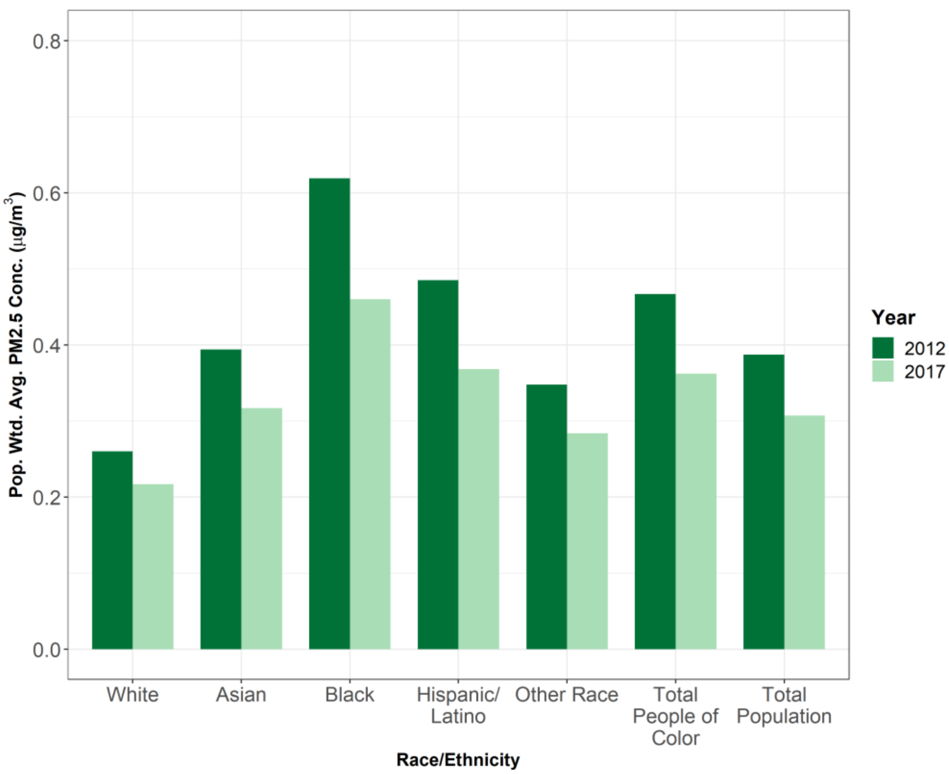

Figure 17. Population-Weighted Average PM2.5 Concentration from Facilities for 2012 and 2017 by Race/Ethnicity: InMAP Results

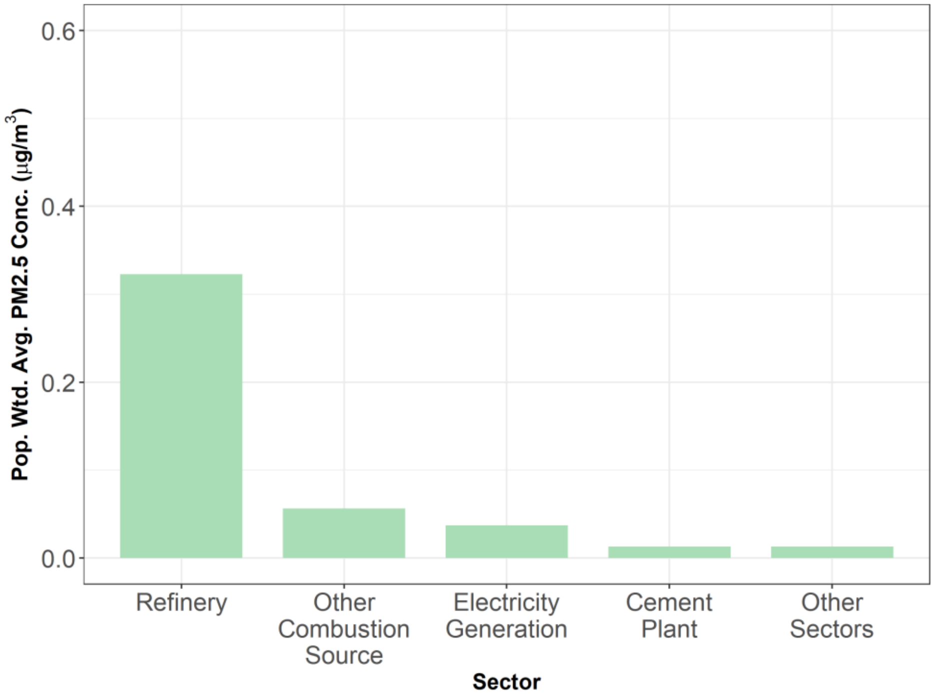

Figure 18. Population-Weighted Average PM2.5 Concentration from Facilities in 2017 for Black Californians by Sector: InMAP Results

Which entities are using offsets to comply with the Cap-and-Trade Program?

Greater Cumulative Emissions for Entities that Used Offsets

The majority of GHG and PM2.5 emissions are from entities that use offsets as a means to comply with the Cap-and-Trade Program, in lieu of other compliance mechanisms like the use of allowances and on-site greenhouse gas emissions reductions. Summed annualized emissions for facilities associated with entities that used offsets were higher than those that did not use offsets (Figure 19). Facility GHG and PM2.5 emissions were joined to their parent entity and selected for those that used offsets and those that did not.

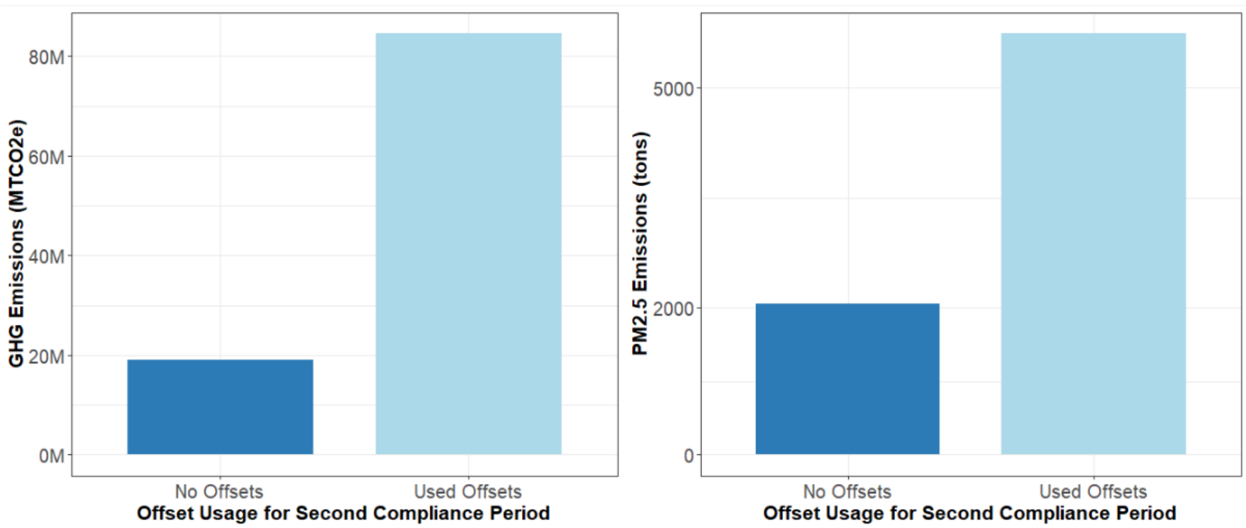

Figure 19. GHG and PM2.5 Emissions for Facilities Associated with Entities by Offset Use in the 2nd Compliance Period

Entities that Use the Most Offsets Have Facilities that Contribute the Greatest PM2.5 Exposure

Entities that used the greatest amount of offsets were associated with facilities that contributed to the highest PM2.5 concentration. Entities that used the highest amount of offset credits for the second compliance period were compared to facilities that fell within the top ten contributing PM2.5 grid cells for InMAP (Table 3). We found that the top five entities using the most offsets had a large majority of their facilities in these grid cells. Further, a majority of these entities own a refinery in a top contributing grid cell and used the maximum allowable amount of offsets (8% of total MTCO2e).

Table 3. Top Five Entities that Used the Highest Amount of Offset Credits and if an Associated Facility is in Top Ten Source Grid Cells for the 2nd Compliance Period

Rank of Entity Offset Use	Entity Name	Entity Offset Percentage	Entity Owns a Facility in Top Ten Source Grid Cells for PM2.5 Concentration	Entity Owns a Refinery
1	Tesoro Refining & Marketing Company LLC	8.0%	Yes	Yes
2	Chevron U.S.A. Inc.	8.0%	Yes	Yes
3	Phillips 66 Company	7.7%	Yes	Yes
4	Southern California Gas Company	7.4%	No	No
5	Shell Energy North America (US), L.P.	8.0%	Yes	Yes

Discussion

Federal, state and local air quality programs have led to significant improvements in air quality in California. The air quality impacts of the state's climate change programs would be in addition to the benefits from these ongoing programs that have reduced emission from mobile and stationary sources.

In 2017, OEHHA published a preliminary evaluation of the benefits and impacts of GHG limits in disadvantaged communities, with a focus on emissions from facilities subject to the Cap-and-Trade Program (OEHHA 2017). That initial report and others found a disproportionate number of Cap-and-Trade covered facilities located in disadvantaged communities, as did other researchers (Anderson et al. 2018; Cushing et al. 2018). The OEHHA report concluded that future GHG emission reductions were likely to result in reduced emissions of criteria air pollutants and air toxics in disadvantaged communities.

This report extends that initial analysis in several ways. We added an analysis of emissions from heavy-duty vehicles. Understanding the impacts of past and future mobile-source emissions policies is especially important to disadvantaged communities. We calculate diesel PM concentration trends over the last 20 years and prospectively project concentration trends associated with implementation of zero-emission HDV regulations and policies from 2020-2045. This report approaches this analysis through an environmental and health equity lens. The analyses are stratified by race/ethnicity and CES 4.0 scores grouped by quartiles.

We expand the analysis on facilities subject to the Cap-and-Trade Program to include both an evaluation of emission trends and modeling to estimate statewide PM2.5 concentrations and PM2.5 -related health benefits from changes in PM2.5 concentrations. The report continues our analysis of the trends at stationary sources covered by the Cap-and-Trade Program and uses significantly more years of data than any previous studies.

This report is organized around two research questions:

1. What are the historical and projected benefits and impacts from emissions changes from heavy-duty vehicle sources in disadvantaged communities?
2. What have been the benefits and impacts from emissions changes at facilities subject to the Cap-and-Trade Program in disadvantaged communities?

Findings

Heavy-Duty Vehicles

We conducted a retrospective and prospective analysis of concentration trends from HDVs. For the retrospective analysis, we found that that over the last 20 years, DPM concentrations have broadly decreased for all Californians, with DPM concentrations continuing to narrow between 2011 and 2019 with the greatest benefits for the highest-scoring CES census tracts. However, although overall DPM concentrations have fallen from 2000 to 2019, there is still an equity gap in DPM concentrations, as higher-scoring CES communities have higher concentrations than are found in lower-scoring communities. The challenge in closing this gap remains. This finding is consistent with other researchers who have documented that areas that have been historically the most burdened by pollution are still the most burdened today (Colmer et al. 2020).

For the prospective analysis, we find that a transition to zero-emission HDVs would prevent about 3,800 (2,500 – 5,000 95% CI) premature deaths from 2020 to 2045. One-third of this benefit would occur in the highest-scoring quartile of CES census tracts, and two-thirds would benefit people of color. This suggests that implementation of zero-emission HDVs has the potential to significantly reduce the disparity in DPM exposure by CES score and by race/ethnicity.

The benefit of electrifying HDVs is an important step in addressing equity and pollution burden (Brown et al. 2021). Other researchers have found that low-income communities of color disproportionately bear the burden of on-road emissions due to their proximity to roadways, distribution centers, and warehouses (Jaller et al. 2020; Reichmuth 2019). Because of this, these communities would benefit the most from electrifying large on-road sources such as HDVs (Reichmuth 2019). Apte et al. (2019) demonstrated that HDVs contribute the largest exposure to Black and Hispanic populations, and people who live in disadvantaged communities experience the highest PM2.5 exposure from HDVs.

Stationary Sources Subject to the Cap-and-Trade Program

We conducted a retrospective analysis of facility emissions covered by the Cap--and-Trade Program. Our results indicate that covered facilities in the Cap-and-Trade Program have a disproportionate impact on vulnerable communities based on facility proximity and emissions from 2011 through 2018. Communities with high CES scores and high percentages of people of color are three times more likely to be located near a covered facility. This means there is a potential for stationary sources subject to the Cap-and-Trade Program to benefit or impact the health of residents in these communities based in part on the way entities comply with the

Program. Other factors also impact emissions, such as local air district air pollution and federal Title V permits.[13]

Facilities near high-scoring CES communities emit more GHGs, PM2.5, and air toxics compared to those near lower-scoring CES communities. In our analysis, we find that since the implementation of the Cap-and-Trade Program in 2013, the greatest reduction of GHG, PM2.5, and air toxics emissions have occurred at facilities subject to the Cap-and-Trade Program located near vulnerable communities. These communities also experience the largest share of health benefits due to reductions of PM2.5 emissions from these facilities. It is important to note that our analysis compared the change in emissions between two years (2012 and 2017); if different years were selected, the results would vary since total emissions from a facility vary annually (see Figure 16).

Despite GHG, PM2.5, and air toxics emissions reductions from Cap-and-Trade-covered facilities near vulnerable communities, several challenges remain in achieving environmental and health equity. The pace of improvement is from stationary source is nearly flat compared to the improvement in DPM. Moreover, a wide disparity remains in emissions of GHG, PM2.5, and air toxics between high and low-scoring CES communities. The highest PM2.5 concentrations arising from Cap-and-Trade covered facilities are in communities with high CES scores and high percentages of people of color. It is of importance to note the role air districts play in regulating PM and air toxic emissions from stationary sources. Although decreasing GHG emissions has the potential to reduce co-pollutants, we found an inconsistent association between GHG reductions and co-pollutant reductions.

Our work also finds that refineries are the top contributor to the inequitable burden of PM2.5 exposure, especially for Black Californians. Moreover, we find that refineries are also owned by parent companies that are among the highest users of offset credits to comply with the Cap-and-Trade Program. This is consistent with the findings in work by Anderson et al. (2018). Apte et al. (2019) also demonstrated that refineries contribute to high exposure burden of PM2.5 for people of color, particularly Blacks and Hispanics. However, despite the use of offsets by entities that own refineries, we find that Black Californians still experienced a four-fold greater reduction in PM2.5 exposure compared to White Californians.

Previous research on Cap-and-Trade covered facilities and equity implications has been focused on the first few years of Cap-and-Trade (Cushing et al. 2018; OEHHA 2017), while our analysis includes data from 2011–2018. Findings from previous researchers are consistent with the additional years of data, including that Cap-and-Trade covered facilities are more likely to be near disadvantaged communities and communities of color and that these facilities emit more GHGs, PM2.5, and air toxics than facilities not near disadvantaged communities (Cushing et al.

[13] Title V permits under the Clean Air Act are legally-enforceable pollution control requirements from federal or state regulations that apply to a source.

2016; Cushing et al. 2018). However, our work highlighted that the largest share of emission reductions after Cap-and-Trade implementation are in high-scoring CES communities.

Limitations

Heavy Duty Vehicles

For the HDV retrospective analysis, we used air quality data on nitrogen oxide (NOx) levels as a surrogate to estimate DPM. Air monitors are not uniformly distributed throughout California. Ambient air quality monitors must be placed according to siting criteria, which often require monitors to be placed in areas of high pollution burden. According to Propper et al.(2015), large stationary sources of pollution can make a significant contribution to NOx emission inventories. Additionally, there are different numbers of monitors in the census tracts covered in each CES 4.0 quartile; the majority are in higher-scoring CES census tracts. Also, CES includes a DPM emissions layer. Because the DPM layer is one of many CES layers, it is unlikely to affect the categorization of monitors. Lastly, it is difficult to attribute reductions to specific measures. Both fuel and technology measures were adopted during our study period with overlapping implementation schedules. These measures include the increased use of alternative diesel, which leads to lower PM emissions compared to conventional diesel fuel.

Our prospective HDV analysis relies on modeled emission data, including both historical and future projections, and therefore has an inherent level of uncertainty. EMFAC2017 was used to estimate emissions. To project emissions to 2045, the Emissions Spatial and Temporal Allocator (ESTA) tool was used, which can model different rates of ZEV adoption. Because projected emissions are hypothetical, the anticipated emission reductions and benefits in this report could be overestimated or underestimated.

Stationary Sources Subject to the Cap-and-Trade Program

It is challenging to discern the influence of the Cap-and-Trade Program on emission trends from large stationary sources. These trends are affected by factors such as normal year-to-year variation in activities, economic and market shifts, and facility shutdowns over time. In addition, methodologies for emission estimates, processes subject to reporting, and reporting requirements vary by air district and over time (CARB 2020c). Further, many policies influence facility emissions. These include federal and regional emissions regulations such as local air district permits for criteria pollutants and air toxics. Other climate programs that influence emissions include the Low Carbon Fuel Standard and energy efficiency. This makes it difficult to attribute changes in emission patterns to specific policies.

There are some methodological limitations for interpreting the results presented in this report. Our analysis groups facilities by CES quartile, which does not identify or differentiate between specific facilities that may be increasing or decreasing their emissions. Within some groups, such as CES quartiles or sectors, there is variability in the emission levels and changes that occur. In addition, because emission levels vary annually, comparing different years would yield different results.

Since the release of the initial OEHHA (2017) report, additional years of data have become available for analysis. However, at the time our analysis was finalized in 2021, the most recent GHG, criteria air pollutant and air toxics data was from 2018[14]. The criteria and air toxics emissions used in this analysis are self-reported by facilities that may be using a variety of methodologies to estimate routine emissions, so these emissions are not directly or uniformly measured. This could lead to variability when comparing these emissions statewide.

Several assumptions were made in compiling a dataset for this work. For example, missing co-pollutant emissions data in the California Emission Inventory Development and Reporting System (CEIDARS) data from CARB were filled in using previous or subsequent years of data, following the approach used in the CARB's Pollution Mapping Tool. Missing data can arise from facility-specific reporting requirements based on district-approved emission inventory plans or exemptions based on risk assessments. They probably do not represent the true absence of emissions (CARB 2020c). To analyze the change over time, we compared the change in emissions between 2012 and 2017. In some cases, facilities may have missing emissions data that were rolled over and may represent data from a previous or subsequent year. For all of the trend analyses, a comparison of different years of data may suggest different results, which makes it difficult to reliably estimate longer-term impacts of multi-year programs.

A number of data gaps for individual facilities in the oil and gas production sector were identified, including incomplete facility-level data for GHG emissions and duplicate geographic coordinates for certain oil and gas facilities owned by a single company within a basin. For many oil and gas facilities, GHG data was only available at the basin level. These data gaps limit the number of facilities in the oil and gas sector in our trend analysis, because only facilities with reported emissions of both GHGs and co-pollutants at the facility level are included.

Air districts report location data to CEIDARS with criteria air pollutant and air toxics emissions data. We used visual inspection to identify locations that did not appear to represent actual emission points and in some cases were office buildings, which are unlikely to be sources of emissions. This provides some uncertainty that the location reported represents an emission release point and limits our ability to estimate the scope of impacts on nearby communities. The stack emissions data provide some improvement to the spatial resolution, but these locations were not used in the facility-level proximity analysis. It is likely that using different point locations or representing facilities using a polygon or the fence-line boundary would influence the results, specifically with regard to the categorization of facilities by CES quartile.

[14] GHG data for 2019 was released too late to be incorporated in this report.

This analysis uses a GHG metric based on reported emissions in the MRR database. The metric includes covered GHG emissions and those from biogenic fuel combustion. This report includes only facilities covered by the Cap-and-Trade Program during at least one year. Therefore, facilities that attribute all of their GHG carbon dioxide (CO2) emissions to biogenic-derived fuels are not included here because they are never covered by the Cap-and-Trade Program. The emissions categorized in the MRR data as "emitter covered emissions" are used by CARB to determine if a facility is covered by the Cap-and-Trade Program. However, we assume that any fuel combustion at covered facilities, regardless of fuel source, contributes to local emissions of criteria air pollutants and air toxics. Therefore, using this metric provides a more representative picture of local impacts.

Exposure and Health Modeling

We used InMAP to model PM2.5 concentrations and BenMAP to model health impacts. Both models have limitations. InMAP is a reduced complexity model that results in less-accurate estimates compared to more-complex air quality models, as documented by previous research (Apte et al. 2019; Tessum et al. 2015; Tessum et al. 2017).

When using BenMAP to estimate health benefits, in the absence of established California specific health impact functions, we used national estimates provided in Krewski et al. (2009) which may influence the estimates of health benefits. The model is limited to producing annual average PM2.5 concentrations which restricted the types of health endpoints that could be assessed. Additional limitations of these models are discussed in the appendix.

It is important to note that the two models used in this report, InMAP and BenMAP, use slightly different methods for categorizing race/ethnicity. These categorizations of population demographics are built into each model and contribute some variability to the results. Specifically, InMAP categorizes Native Americans as "other races", while BenMAP has Native Americans as their own demographic group. The demographic category for Asians is complex; it might or might not include people of Pacific Islander origin. The most similar category between the two models is the grouping of total people of color.

Offsets

The Cap-and-Trade Program issues offset credits to qualifying projects that reduce or avoid greenhouse gases. It is not possible to discern with certainty if offsets have direct impacts or benefits to disadvantaged communities because offset usage is tracked at the entity level, not the individual facility, and an offset is interchangeable with an allowance for compliance purposes. Each entity can have multiple facilities that operate throughout the state. Further, individual facilities can change ownership and/or can change their reporting status under the Cap-and-Trade Program during our study period. Finally, compliance obligation data is reported by period, so if a facility changes ownership mid-period, it would not be reflected in the data.

Therefore, some facilities may not be captured in our analysis or associated with the correct entity.

In several instances, entities that used offset credits to satisfy their compliance obligation were associated with transportation fuel suppliers whose emissions are not localized and may not occur at the reporting location. Therefore, it is not possible to tease out if entities are using offsets to account for localized, stationary GHG emissions or emissions associated with the fuel suppliers. Because of these limitations and constraints with understanding the spatial use of offsets, the analysis in this report is restricted in scope.

Future Work

The purpose of this report is to understand community-scale impacts of emissions from HDVs and facilities subject to the Cap-and-Trade Program. Below, we describe several improvements that would facilitate future evaluations by OEHHA, CARB, and other researchers.

Collecting Granular, Community-level Data for Mobile Sources

With zero-emission HDVs being phased in, we sought to understand emission patterns and their impacts. Finer resolution data is needed to better understand the impacts of mobile source emissions at the community level. Due to data and capacity limitations, we relied on modeled emissions from CARB. Although the modeled emission data is provided at the 1-km grid scale, it relies on data collected at a regional scale. For example, some data is reported at the county level, and other data is inferred from Department of Motor Vehicles (DMV) odometer readings and registration information. An improved understanding could be developed from an evaluation of data that captures more detailed information on travel routes, the distribution of vehicle fleets, and mobility patterns, especially for trucks frequenting distribution centers, cold storage facilities, and warehouses. Data harnessed from smartphones and road sensors could provide a more comprehensive assessment of community-specific benefits and impacts from statewide policies and programs.

Improving Data Accessibility for Criteria Pollutant and Air Toxics Emissions Data

Several improvements to data availability, accessibility, quality, and transparency would better support an equity analysis of the facilities covered by the Cap-and-Trade Program. Regulations have been implemented that aim to address many of these critical data gaps. These include the adoption of the Regulation for the Reporting of Criteria and Toxic Air Contaminants (CTR), which; Cal. Code of Regs. tit. 17, § 93400 et seq. (2020) implements statewide annual reporting of emissions starting January 1, 2020 (CARB 2022). This regulation should improve the emission inventory and support mandates of AB 617 and AB 197, as full implementation is phased in throughout the decade. Improving the timeliness of data releases could provide more up-to-date information on current estimated emissions and continuing trends from facilities. In addition, more historical data could be made publicly available. Emissions data from the years before a facility was covered by Cap-and-Trade could be added to CARB's Pollution Mapping Tool. This would allow users to determine if facility emissions of criteria air pollutants and toxics increased as they passed the GHG emission threshold for being covered by the Cap-and-Trade Program. Finally, some datasets related to California's climate change policies are currently spread out in different sections of CARB's website, or are only available on request. These datasets could be made available through an organized data portal. They could also be added to the Pollution Mapping Tool, which lists all available data for a facility, and shows how to access that data. These measures to increase data availability would be valuable improvements for public access and research.

Adding Finer Scale Criteria Pollutant and Air Toxics Emissions Reporting for the Oil and Gas Sector

The Pollution Mapping Tool continues to improve as a data portal, but could be enhanced to provide more information about the oil and gas production sector. Data on facility-level GHG emissions and complete lists of co-pollutants for the oil and gas production sector would be particularly useful, including air toxics emission estimates. More informative data could result from a modification of emission reporting requirements for oil and gas facilities within a geologic basin, in order to report individual facility GHG emissions. This would go beyond the current reporting structure that is aligned with federal GHG emission reporting requirements. This could include some harmonization of the definition of a 'facility' across the GHG and CEIDARS reporting systems. Facility locations, as reported to CEIDARS, could also be audited to ensure location accuracy.

Implementing Statewide Data Standards for all Emission Sources

Spatial and emission datasets collected by the air districts could be expanded, improved, and updated more frequently, and improved by adopting statewide quality-control methods for reporting facility and stack locations. Specifically, improvements to the CEIDARS stack-level emission data could be made, including reporting locations of stacks in a consistent coordinate system across all facilities, and insuring there are no missing values across fields. In addition, the emission factors and methods used to calculate facility emissions across air districts could be standardized and made more easily available in order to support the comparability of estimated emissions across the state. The CTR addresses some of these concerns, such as concerns about stack locations and facility coordinates. However, the consistent use of emission factors and methods are not yet included in CTR. Working with the air districts, as outlined in the AB 617 statute, to add statewide, consistent reporting methods into CTR would improve data transparency and emissions tracking. Finally, specific datasets are only available by request at each district, making a statewide analysis difficult. For example, shapefiles for facility boundaries, information on deployed control technology, and facility-specific health impact assessments could be made available statewide. Providing this information with detailed methods would increase transparency and uniformity across the air districts.

Increasing Transparency in Offset Entity Information

Because offset usage is reported by the entity, or parent company, we were unable to assess the benefits and impacts of offset usage by individual facilities. Since there may be several facilities in different locations that are associated with a specific entity, providing offset usage data at the facility level could support a deeper understanding of the impact of the use of offsets at facilities covered by the Cap-and-Trade Program in communities, especially because facility-level GHG and co-pollutant data is already publicly available. This could be beneficial because there has been only minimal research on offset usage, which could be due to the limited availability of data.

Creating Environmental and Health Equity Benchmarks

Equity benchmarks help measure progress toward achieving environmental justice, and enable us to better evaluate health and environmental inequities. For future analyses, equity benchmarks could be developed, in collaboration with communities, to track exposure and health impacts from changes in emissions from facilities subject to the Cap-and-Trade Program in low scoring CES communities and in communities of color.

Over the last twenty years, CARB's diesel combustion regulations have successfully reduced diesel PM concentrations statewide, especially in high-scoring CES tracts and in communities of color. However, these communities continue to experience disproportionate levels of exposure to diesel PM. In this analysis, we find that a scenario of 100% zero-emission HDVs by 2045 would have outsized benefits for these same communities, potentially narrowing the gap between high and low-scoring CES tracts, and clarify that progress on this front could be tracked by CES score and by race/ethnicity.

The same method could be applied to the facilities subject to the Cap-and-Trade Program. We found emissions reductions of GHGs, PM2.5, and air toxics in high-scoring CES tracts and in communities of color between 2012 and 2017. Still, wide disparities remain. Black Californians, in particular, experience the highest PM2.5 exposure levels from emissions from facilities subject to the Cap-and-Trade Program. We assign a CES score to each facility subject to the Cap-and-Trade Program. This provides a method to track progress on of emissions. Modeling emissions from these facilities adds exposure and health to the analysis. With this method, equity benchmarks could be developed to ensure that high-scoring CES tracts and communities of color continue to benefit from emissions reductions at stationary sources.

This report uses an environmental and health equity lens to evaluate the benefits and impacts of GHG and co-pollutant emissions associated with HDVs and facilities subject to the Cap-and-Trade Program. Monitoring outcomes within disadvantaged communities and communities of color is essential to ensure that California achieves climate goals that benefit everyone. This report presents a systematic framework to support the ongoing evaluation of HDVs and facilities subject to the Cap-and-Trade Program.

OEHHA's 2017 report covered emissions trends for stationary sources under the first Cap-and-Trade reporting period. It concluded that reductions in GHGs would likely result in PM2.5 reductions. This report covers the first and second Cap-and-Trade Program reporting periods and HDVs emissions. In both the HDVs and stationary source sectors, we found notable progress in reducing PM2.5 emissions, exposure to PM2.5, and PM-related health impacts in the highest-scoring CES tracts, and in communities of color. For diesel PM, we also found that the gap between the highest and lowest-scoring CES tracts has been narrowing over the last 20 years. Moreover, we found that a transition to 100% zero-emission heavy-duty vehicles by 2045 would have an outsized benefit to the highest-scoring CES tracts, and has the potential to close the gap between high and low-scoring CES tracts.

For Cap-and-Trade covered facilities, we found the greatest reduction of GHG, PM2.5, and air toxic emissions near high-scoring CES communities, along with the largest share of health benefits. Although we observed reductions in GHGs and PM2.5 in these communities, the relationship between GHGs and co--pollutants was highly variable by year and sector. This suggests that if we had chosen different years for our analysis, our results could have been different. It also suggests that strategies to reduce GHGs from Cap-and-Trade covered facilities will not necessarily reduce PM2.5 and air toxic emissions from all facilities. This highlights the need for greater state partnerships with air districts in order to reduce these emissions.

Furthermore, we found a wide gap between high and low-scoring CES tracts and that the greatest disparity for Black Californians comes from refinery emissions. Lastly, while entities that are associated with refineries are among the highest users of offsets, we find that Black Californians experienced a four-fold greater reduction in PM2.5 exposure than White Californians did, from 2012 to 2017. These findings suggest a continued need to assess co-pollutant emissions from HDVs and facilities subject to the Cap-and-Trade Program.

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Appendix

Detailed Data Sources and Methods

Mobile Source

The methodology used in our prospective analysis had three distinct steps. First, we regridded the emissions data we received from CARB to the InMAP grid. Second, we combined the regridded emission data with the InMAP Source-Receptor Matrix (ISRM) to generate PM2.5 concentrations for 2018. Finally, we used the modeled 2018 data as baseline to project future PM2.5 concentrations from 2020 to 2045 under two scenarios. The first scenarios assumed the HDV would be electrified over the next 25 years while the alternative scenario did not. We then took the modeled concentrations from the two scenarios to compare PM2.5 concentrations and potential health impacts.

Table 4. Assumptions for Zero Emission HDV Scenario

Pollutant	**Regulations/Concepts**	
	Currently Adopted	**Scenario for Report**
NOx	Advanced Clean Trucks (ACT), HD Omnibus*	Zero Emissions Vehicle (ZEV) requirements that go above and beyond ACT, Heavy Duty Inspection and Maintenance (HD I/M), HD Omnibus plus Federal NOx standard*
Diesel PM Exhaust	ACT	ZEV requirements that go above and beyond ACT
PM Tire Wear	None	None
SOx	ACT	ZEV requirements that go above and beyond ACT
ROG	ACT	ZEV requirements that go above and beyond ACT, HD I/M
TOG	ACT	ZEV requirements that go above and beyond ACT, HD I/M

*Only affects heavy-duty vehicles not medium-duty vehicles

CARB provided annual total projected emissions for NOx, SOx, primary PM2.5, and VOC for 2020 to 2045. The projected emissions assumed an accelerated turnover scenario (Table 4) which means that vehicles are retired or scrapped earlier than they would have naturally and then replaced with some cleaner technology. However, NH3 was not provided so we made the conservative assumption that NH3 emissions from HDV did not decrease over the time period (2020-2045). Additionally, we did not incorporate plumb height for our analysis and assigned all emissions to ground level. Finally, the projections do not account for change in traffic or emission patterns over time; they only account for the transition to zero-emission HDV. Changing in the spatial allocation of trucking in California would also have an impact on the resulting PM2.5 concentrations.

GHG Emissions Data

GHG emissions data are collected according to the Mandatory Reporting Regulation (MRR) for GHG emissions, which was developed pursuant to the AB 32 requirement for GHG emissions reporting and verification. Entities must report GHG emission data if emissions exceed 10,000 MTCO_2e per year and are subject to the Cap-and-Trade Program if annual covered emissions exceed 25,000 MTCO2e (also referred to as “covered by”). For these programs, an entity is defined as a person, firm, association, organization, partnership, business trust, corporation, limited liability company, company, or government agency (CARB 2019b). Covered emissions are defined based on the source or process producing the emissions and not all GHG emissions are covered. Specifically, emissions are categorized as “covered” if they result from the combustion of fossil fuels, chemical and physical processes, vented emissions, emissions from certain biogenic fuel combustion, and emissions from suppliers of CO_2. However, the metric for covered emissions does not take into account data for all localized emissions. Specifically, covered emissions do not include all GHG emissions resulting from biomass combustion, even though these contribute to localized co-pollutant emissions.

The GHG emissions metric used for this analysis was calculated by OEHHA as the sum of two variables provided in the MRR datasets: (1) Emitter CO2e from Non-Biogenic Sources and CH_4 and N_2O from Biogenic Fuels and (2) Emitter CO_2 from Biogenic Fuels. This new emissions metric is different than emitter covered emissions metric used in the first OEHHA report and by others. The new metric accounts for biogenic emissions, which arise from biomass combustion, are excluded from emitter covered emissions, but still contribute to localized emissions. Further, the new metric can be calculated for reporting years 2008–2018, which extends the years of GHG emissions data available for analysis. However, we are using 2011–2018 data for this work.

To match facilities with their emissions data, we used crosswalks obtained from CARB, to link GHG facilities and CEIDARS facilities as these emissions are reported under separate regulatory programs using different identification numbers (i.e., facilities use one id number for GHG emissions reporting and a different id number for criteria and air toxics reporting). In some cases, one GHG id number (arbid) corresponds to more than one CEIDARS id number (facid), particularly for facilities in the oil and gas sector. For this sector, we used CARB's Onshore Oil and Gas Facility Crosswalk to link the arbid number to the facid number (CARB 2017a). See below for more information about this sector.

All sectors, with the exception of oil and gas production, report facility-level GHG and co-pollutant data. The scale of data reporting for the oil and gas production sector depends on the pollutant being reported and the number of facilities a company operates within a geologic basin. GHG emissions for oil and gas production facilities are reported as the total GHG emissions for all of a company's operating facilities in a geologic basin. If a company only has one facility in a geologic basin, the co-pollutant emissions at the geologic basin scale represent the total emissions from all facilities for a given company within a geologic basin.

The number of facilities covered by the Cap-and-Trade Program varies by year and ranges from 320 to 350 between 2011 and 2018 (Table 4). This corresponds to a larger number of CEIDARS facilities due to the one-to-many relationship that exists for some facilities in the oil and gas production sector. The number of CEIDARS facilities ranges from 467 to 591 facilities between 2011 and 2018. This report uses subsets of these facilities for the analyses presented.

Table 4. Number of Cap-and-Trade Covered Facilities by Year (2011–2018)

Year	# MRR Facilities (id = arbid)	# CEIDARS Facilities (id = facid)
2011	320	543
2012	342	576
2013	350	584
2014	349	591
2015	346	585
2016	341	504
2017	335	484
2018	331	467
Number of Distinct Facilities	**358**	**613**

Emissions Data for Criteria Air Pollutants and Air Toxics

Annual emissions of criteria air pollutants, their precursor emissions, and air toxics are reported by facilities to county or regional air districts, which compile and submit this information to CARB for inclusion in the CEIDARS database. Facility-level air toxics data was used to calculate total and toxicity-weighted pounds of air toxics. Annual toxicity-weighted emissions were calculated for each facility by multiplying the emissions by the respective inhalation toxicity weights established under the US EPA Risk-Screening and Environmental Indicators (RSEI)

Model (US EPA 2018b). Inhalation toxicity weights were assigned using CAS Registry Number (CAS RN), when available. When a chemical could not be matched directly by CAS RN, toxicity weights were assigned based on the chemical class of the compound. The toxicity weights used for this analysis are available upon request. Toxicity equivalency factors were applied to PAHs and to dioxins and dioxin-related compounds based on US EPA RSEI methodology (US EPA 2019). Remaining compounds that did not have a RSEI toxicity weight were assigned toxicity weights using health guidance values from OEHHA/CARB Approved Risk Assessment Health Values as input for RSEI methodology (CARB 2020e).

Construction of Facility Dataset

We joined the facility GHG data to the criteria air pollutant and air toxics data for all facilities using a crosswalk (or tool for evaluating data across differently configured datasets) provided by CARB that links facilities by their Air Resources Board IDs (arbid for GHG emissions) and Facility IDs (facid for criteria air pollutant and air toxics emissions reported in CEIDARS). Following the approach in CARB's Pollution Mapping Tool, emissions from oil and gas facilities were represented at both the basin and facility-level, when applicable.

Additional assumptions and data cleaning steps are listed below.

- Some sector categories in the MRR dataset differed from one year to another, and select categories were combined as shown in Table 5.
- There are gaps in the co-pollutant data due to requirements for reporting frequency. In many cases, the missing data for certain facilities was not due to a change in facility operations (i.e., the facilities continued to operate, but no data was provided). In these cases, data gaps were filled in using the subsequent or previous year of data available for a given facility, following the method used for the US EPA air trends analysis (US EPA 2018a).
    - One exception to this was for Mt. Poso Cogeneration Company (arbid 101228, EIA plant id 54626) in Bakersfield. This facility reported emissions of a number of metals in 2010. However, in 2010, the parent company announced this facility would switch from using a blend of coal, petroleum coke and tire-derived fuel to mainly biofuels[15] (DTE Energy). Data provided on the US EPA Energy Information Administration website indicated that the fuel blend was last used in 2011 US EPA Energy Information Adminstration (2021). Therefore, the 2010 metals data was only rolled over to 2011 and was not rolled over to subsequent years.
- The co-pollutant data contained both Not Applicable (NA) and zeros, which cannot be easily differentiated due to data processing steps (personal communication, CARB);

[15] DTE Energy Services: https://dtepowerandindustrial.com/wp-content/uploads/2015/03/09-DTE-Energy-Services-expands-its-nationwide-renewable-portfolio-with-plans-to-convert-California-coal-plant-to-biomass-Nov-8-2010_Mt-Poso.pdf

therefore, all missing data (NA or zeros) were filled in using the US EPA air trends analysis approach described above. This approach is warranted as many facilities are only required to update their air toxics emission data if there has been a change in facility operations (CARB 2015).

- Three refineries in Southern California report GHG and co-pollutant emissions at different scales during different years. In 2014, these three refineries began to report their combined GHG emissions for all three facilities under a single arbid (i.e., arbid 100335 and arbid 101492 merged into arbid 101246). However, each facility continues to report emissions of criteria air pollutants and air toxics at the individual facility level. To support our analysis of the relationships between GHG and co-pollutant emissions, and to improve our understanding of local scale changes in co-pollutant emissions, we used a ratio approach to assign GHG facility emissions to the individual facility emissions from 2014 onwards. This is a different approach than the one used in OEHHA's previous report (OEHHA 2017).
- We were unable to obtain the 2018 data for facility operating status from CARB. Therefore, we assumed the facility status in 2018 was the same as 2017.

Table 5: Stationary Source Sectors Included in OEHHA Analysis

Sector in OEHHA Report	**Sector(s) in MRR Dataset (2008–2018)**
Cement Plant	• Cement Plant
Cogeneration	• Other Combustion Source / CO2 Supplier • Cogeneration Facility
Electricity Generation	• In-State Electricity Generation
Oil and Gas Production	• Oil and Gas Production / Supplier of Natural Gas, NGL, or LPG • GSC (Oil and Gas Production)
Hydrogen Plant	• Hydrogen Plant
Other Combustion Source	• General Stationary Combustion • Other
Refinery	• Refinery / Transportation Fuel Supplier • Refinery and Hydrogen Plant / CO2 Supplier • Refinery and Hydrogen Plant / Transportation Fuel Supplier • Refinery and Hydrogen Plant • Refinery and Hydrogen Plant / Transportation Fuel Supplier / CO2 Supplier • Petroleum Refinery

Emissions from Facilities in the Oil and Gas Production Sector

Oil and gas production emissions are reported at different scales for different pollutant types. This difference in reporting scale limits the analysis that can be performed for the oil and gas production sector. CARB (2020c) notes that oil and gas production facilities report GHG emissions as the aggregate of a company's operations in a geologic basin, which often cover large geographical areas. This approach and definition for oil and gas facilities and GHG reporting matches US EPA's GHG reporting requirement. Criteria air pollutants and air toxics are reported at the 'sub-facility'-level which can be a point-source facility to a collection of smaller sources within a contiguous oil or natural gas lease.

The emission locations are best represented using the coordinates associated with the CEIDARS id (facid), particularly for the oil and gas sector, as the locations provided in the Pollution Mapping Tool are representative location for the oil and gas basin rather than a location associated with emissions for companies with more than one facility within a geologic basin. Several oil and gas companies report the same coordinates for a number of their facilities within a basin, which limits the understanding of where co-pollutant emissions actually occur. These include facilities grouped under arbid 104029 (39 facilities), arbid 101674 (11 facilities), and arbid 104458 (6 facilities).

Facilities in the oil and gas production sectors can be grouped into three categories to indicate if the point location is associated with known localized emissions of GHGs, co-pollutants, or both. The spatial analysis in this report utilizes only facility locations where known co-pollutant emissions occur, despite the absence of GHG emissions data for these locations. For the analysis of the relationship between GHG and co-pollutants, co-pollutant emissions for all of a company's facilities within the geologic basin were aggregated to match the scale of GHG emissions reporting following the approach used by CARB in the Pollution Mapping Tool.

A map of California's geologic basins and the locations of oil and gas production 'facilities' statewide that was adapted from the CARB Pollution Mapping tool is shown in Figure 20. The inset shows an example of a representative region in Central California and shows the three categories of locations. Locations in the first category represent the company's only facility within the geologic basin (indicated by the solid purple pin). The coordinates for these facilities (n = 12) represent locations where GHGs and co-pollutants are assumed to be emitted. The next category of locations, indicated by the purple pin with the dot inside, are used to represent a company's aggregate emissions from all facilities within a geologic basin and do not represent actual point emissions. The last category of locations are the individual facilities. The purple squares with stars represent facilities that are one of many facilities within a geologic basin.

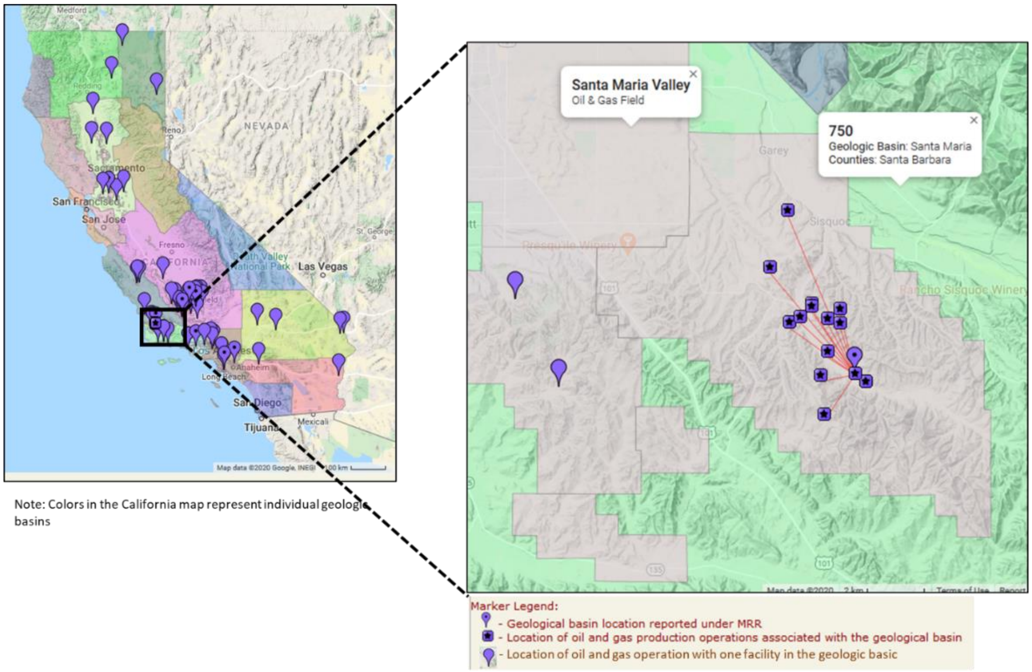

Figure 20. California Map of Statewide Geologic Basins and Example of the Different Categories of Cap-and-Trade covered facilities in the Oil and Gas Production Sector

Analytical Methods

Offsets Analysis

Offset credit issuance tables and compliance reports were downloaded from CARB's website for the second compliance period (2015–2017) in February 2021 (CARB 2019b). Offset credit issuance tables detail available offset projects, and compliance reports provide entity-level data on how covered entities meet their compliance obligations through the use of allowances and/or offset credits. We calculated the percent of offsets used by entities to meet their obligation by dividing the total offsets surrendered by their surrender obligation. Entities were categorized as either using or not using offsets to meet the compliance obligation. The compliance obligation data was then joined to the master emission data by ARB ID. Entities were only included if they were covered during the entire compliance period.

The facility GHG and PM2.5 emissions associated with entities that used offsets were summed and compared to those that did not use offsets. Due to the nature of the way offsets are reported, and facilities used in our master emission spreadsheet, not all emissions could be accounted for.

We then selected the top five entities that surrendered the highest amount of offset credits for the compliance period. The facilities associated with these entities were selected and examined against the top ten source grid cells for PM2.5 from InMAP modeling results. If one of the entities' facilities was a refinery, and in the top ten source grid cell, we noted so. In some instances there was more than one facility in a grid cell. The list of entities and associated facilities used in our analysis is available.

Facility Stack Emissions Data

Facility PM2.5 emissions are reported at individual stacks in CEIDARS; including annual emissions, release height, and coordinates. The total emissions for a facility are also reported. For facilities who's summed stack emissions were less than the total emissions reported from a facility, the difference between the summed stack emissions and facility emissions were assigned as a ground-level emission and given the latitude and longitude that corresponded to the facilities location in the Pollution Mapping Tool.

Individual stack information is not reported in one consistent geographic coordinate system in CEIDARS. Therefore we had to convert all spatial stack information into one geographic coordinate system. We assigned all stacks a latitude and longitude in the World Geodetic System 1984 (WGS84) projection.

For facilities and/or stacks with missing spatial information, coordinates were imputed based on data provided by CARB. Using a unique identifier (arbid_facid), we pulled location information from the MRR data, oil and gas crosswalks, arbid to facid crosswalk, and other data provided by CARB.

Data Cleaning for Exposure and Health Modeling

To clean the stack height data, we followed protocols similar to those used by CARB's Atmospheric Modeling and Support Section. For missing stack height values, we used the fallback value developed by CARB, 121.4 feet. A zero value for stack height was interpreted as missing and was replaced with the aforementioned fallback value. Stack height was converted from feet to meters by dividing by 3.2808. Since CARB uses the Sparse Matrix Operator Kerner Emissions (SMOKE) Modeling System to process and clean emissions data in preparation for modeling, we also checked whether the stack height fell within SMOKE's acceptable range for this parameter, 0.5 to 2,100 meters shown in section 2.9.9 of the SMOKE Manual (The Institute for the Environment - The University of North Carolina at Chapel Hill 2017). If stack height fell outside this range, we set the value to the top or the bottom of the range, depending on whether stack height was higher than the upper value of the range or lower than the lower value of the range.

For annual emissions of the five precursor pollutants (PM2.5, NOx, SOx, ammonia (NH3), or volatile organic compounds (VOCs), we replaced missing values with zeros. For some facilities, the total emissions for the facility were greater than the sum of emissions from all of the facility's stacks. To capture emissions that were not associated with a stack, we took the difference in emissions between the facility total and the total from all stacks and assigned these emissions to ground-level. If the value of these computed ground-level emissions was negative, we changed the value to zero, since there were no negative emissions in the raw data. The stack height for these computed ground-level emissions was set to zero.

Intervention Model for Air Pollution (InMAP)

The Intervention Model for Air Pollution (InMAP) is a reduced complexity air quality model that estimates annual-average concentrations of primary and secondary PM2.5 based on annual precursor emissions. The precursor species included in this model are primary PM2.5, NH3, NOx, SOx, and VOCs. InMAP uses pre-processed physical and chemical information from a chemical transport model and allows for a variable spatial resolution grid to reduce computational time. Although InMAP is best used for estimating marginal changes in concentrations, InMAP can estimate total concentrations of PM2.5 within published air quality model performance criteria (Tessum et al. 2017). For this analysis, we use only marginal changes in concentrations.

The InMAP model domain for the state of California consists of 21,705 variably sized grid cells and includes portions of neighboring states (Oregon, Idaho, Nevada, and Arizona) (Apte et al. 2019). Grid cell sizes range from 1 km^2 to 2,304 km^2 (48 km on each side), with smaller grid cells used for more populated areas. The grid cell size was determined based on the number of people in a grid cell, using census block group population data from the 2012–2016 5-year American Community Survey. Population counts were assigned to each InMAP grid cell using an area-weighting approach. The proportion of each block group in a grid cell was used to assign the proportion of the block group's population to that grid cell. No block group was double counted, and all population in a block group was assigned to a grid cell. Grid cells covering more populated regions were split into smaller grid cells until no grid cell larger than 1 km^2 has a population of more than 20,000 people, and no grid cell larger than 1 km^2 contains a census block group with a population density greater than 2,500 people/km. It is of importance to note some grid cells do contain areas that are not inhabited, such as the ocean. In these instances,

InMAP was used to create a Source-Receptor Matrix (ISRM) for the aforementioned model domain, which was used to estimate concentrations of primary and secondary PM2.5 in this study. The ISRM describes the change in concentration at each receptor grid cell for a unit increase in emissions at a specified source grid cell for each of the 21,705 grid cells for each of the five pollutants at three heights (0–57 meters, 57–140 meters, and above 760 meters). For emissions at heights between 140 and 760 meters, linear interpolation was used to obtain model values. For each of the five precursor pollutants, total emissions in a given source grid cell were multiplied by the corresponding model values to scale the concentrations in each receptor grid cell. The total PM2.5 concentration in a given receptor grid cell was then determined by summing the concentration contributed by each source grid cell from each of the five precursor species.

Population exposure was estimated by calculating population-weighted average concentrations of PM2.5. Population counts in each grid cell were based on census block group data from the 2014–2018 5-year American Community Survey for the state of California, using an area-weighting approach as described above. An area-weighting approach was also used to assign the population in CES 4.0 quartiles to each grid cell that overlaps with the state of California. Population-weighted average concentrations were calculated for various demographic groups based on the following formula:

$$\frac{\sum_i^N C_i * Pop_i}{\sum_i^N Pop_i}$$

where N is the total number of grid cells, C_i is the concentration in grid cell I, and Pop_i is the population in grid cell i.

ISRM Conditions and Limitations

There are several factors that contribute to uncertainty in modeled concentrations using the ISRM. InMAP uses simplified meteorology and annual-average parameters from a chemical transport model, which results in less accurate estimates compared to more complex air quality models. Furthermore, the ISRM was created using atmospheric chemical conditions based on the 2005 US EPA National Emissions Inventory. The baseline concentrations were used to calculate secondary PM2.5 formation rates, so changes in emissions of precursor pollutants since 2005 would contribute to model uncertainty, especially for the formation of secondary PM2.5 (Apte et al. 2019).

The effective plume height is the sum of stack height and plume rise, which is based on stack diameter, gas temperature, and gas velocity. Since our study used stack height to determine the corresponding ISRM height layer, this may result in an overestimation of the impacts of stack emissions if plume rise would result in using a higher ISRM height layer.

The mobile source analysis in this report did not include emission sources that are located outside the state of California. Since out-of-state emissions from HDV may contribute to PM2.5 concentrations within the state, the total PM2.5 concentrations presented in this report may be slightly lower than if these out-of-state emissions were included.

Benefits Mapping and Analysis Program (BenMAP)

The Benefits Mapping and Analysis Program: Community Edition (BenMAP:CE) is an open-source environmental benefits mapping and analysis program that was created by the US EPA (US EPA 2021). BenMAP is widely used as a tool to assess the human health impacts of air pollution and results have published extensively in the peer-reviewed literature (Sacks et al. 2018; Sacks et al. 2020). We used BenMAP version 1.5.8 to calculate change in PM2.5 emissions and the resulting impact on avoided premature mortality by CES 4.0 quartile and by race/ethnicity.

Avoided premature mortality attributed to PM2.5 was the single health endpoint assessed in this analysis. This is because the available input air quality data is annual population-weighted average PM2.5 concentrations. Daily PM2.5 concentration data is required to estimate the effects on short-term health endpoints, such as asthma exacerbation and emergency room visits. The health calculation estimates presented in this study reflect changes associated with two individual years of data to provide some indication of what a change in exposure concentrations means for adverse health outcomes.

The United States setup was modified to add the Grid Definition for InMAP shapefile and the Population Dataset generated using PopGrid, which allocates the 2010 block-level U.S. Census population to a user-defined grid, creating a population file ready for importation to BenMAP-CE. We used the population counts and weights according to the BenMAP manual. The source of air quality data was population-weighted average PM2.5 concentrations generated using InMAP based on stack level emissions data. We used 2012 concentrations for the baseline and 2017 concentrations for the control which BenMAP uses to calculate the delta or change in emissions. We used the health impact functions available in BenMAP based on Krewski et al. (2009).

A health impact function (HIF) incorporates four key sources of data: (1) modeled or monitored air quality changes, (2) population dataset (we used ACS, and PopGrid), (3) baseline incidence rates, and (4) an effect estimate. As shown in Figure 21 and Figure 22 from the BenMAP manual, these HIFs are derived from epidemiology studies that relate pollutant concentrations with health outcomes (US EPA 2017b). The relationship of these variables is expressed as:

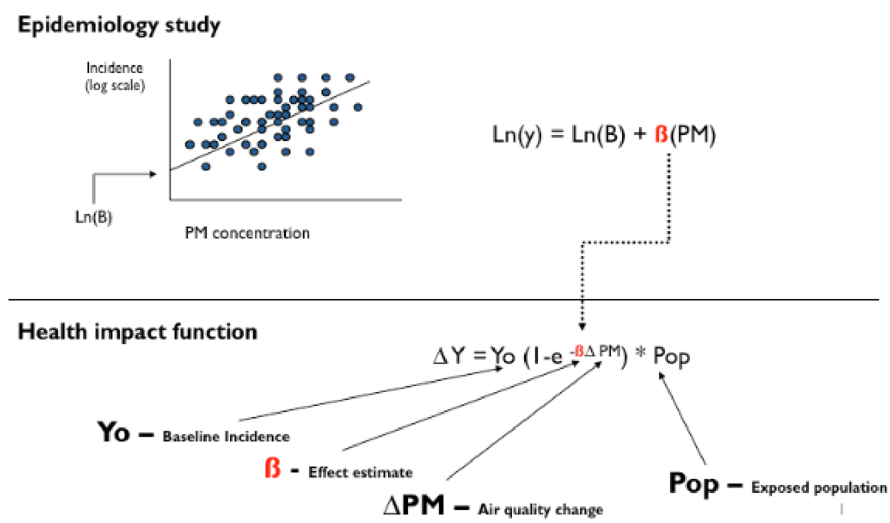

Figure 21. Health Impact Function Variables and Equation

Figure 22. Data Used by US EPA BenMAP: Community Edition Tool to Estimate Health Impacts

BenMAP Limitations

Sacks et al. (2018) highlighted limitations including the expertise required to develop air quality inputs for the tool and that only overall ambient concentrations of PM2.5 and ozone, and not source-specific contributions, can be estimated. The health impact function used in this study, Krewski et al. (2009), is based on national data and is not specific for California. California-specific health impact functions would greatly improve the estimates produced using BenMAP for future analyses.