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Enhancing equity while eliminating emissions in California's supply of transportation fuels

California Carbon Neutrality Study 2

Research Report | April 2021

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DISCLAIMER

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GLOSSARY

Ambient $PM_{2.5}$: Concentration of solid particles and liquid droplets in the air with a mass per cubic meter that is less than 2.5 micrograms. $PM_{2.5}$ is directly emitted through multiple sources, in particular, the combustion of solid and liquid fuels.

American Petroleum Institute (API) gravity: A standardized measure of crude oil density, which is one of the characteristics that affects crude oil price.

Business as usual scenarios: Trajectories given no additional transportation sector-specific decarbonization policies are implemented in California from 2020 to 2045. See Table IV.1. for specifications of the extraction business-as-usual scenario (E-BAU) and refining business-as-usual scenario (R-BAU) used in our study. Study 1 BAU reflects fuel demand quantities in California from 2030 to 2045 projected by Study 1 (i.e., fuel demand trajectory given no new decarbonization policies to decarbonize California's transportation sector are implemented from 2020 to 2045).

CalEPA: California Environmental Protection Agency

Capacity Utilization Factor (CUF): The operating level of a refinery compared to its rated processing capacity.

Cap-and-trade (C&T) program: California economy-wide program introduces a carbon price, which alters the cost of production for regulated entities, including extracting and refining facilities.

CARB: California Air Resources Board

Carbon capture and storage (CCS): Greenhouse gas mitigation technology that combines the capture of carbon dioxide from concentrated industrial (flue) sources with transport of carbon dioxide to suitable sites for permanent geological sequestration, either in deep saline formations or depleted oil and gas fields.

CEC: California Energy Commission

CEIDARS: California Emissions Inventory Development and Reporting System

Central low carbon scenario (LC1): The central low carbon fuel demand scenario provided by Study 1.

Direct labor impacts: The impact employment and compensation in industries directly affected by a change in economic conditions. In this study, direct impacts arise in the extraction and refining segments.

Disadvantaged Community (DAC): As defined by the Office of Environmental Health Hazard Assessment through CalEnviroScreen 3.0, disadvantaged communities are census tracts in California that include populations with high exposure to cumulative pollution and who are particularly vulnerable to adverse health impacts due to socioeconomic and environmental factors.

DOC: Department of Conservation

EIA: Energy Information Administration

Emission factors: The amount of pollutants or greenhouse gas emissions produced per barrel of crude oil extracted or refined.

Employment: The number of part- or full-time workers formally tied to a firm at a given point in time.

Excise tax: A tax on crude oil production imposed at the state-level (also known as a severance tax). If set at the appropriate level, an excise tax can function similarly as a production quota and can result in similar oil production.

Full-time equivalent (FTE) job-years: The number of full-time jobs supported by an industry for one year.

IEA: International Energy Agency

Indirect labor impacts: The impact of a change in economic conditions on industries connected to the primary industries through a supply chain.

Induced labor impacts: The impact of a change in economic conditions on industries where income generated by directly and indirectly impacted industries is spent.

InMAP: Intervention Model for Air Pollution

Low Carbon Fuel Standard (LCFS): A statewide program intends to reduce the carbon intensity of transportation fuels by setting annual declining carbon intensity standards. In 2018, CARB added alternative jet fuel and carbon capture and sequestration as LCFS crediting opportunities, along with several other refinements, which went into effect in January 2019. The most recent amendments in 2018 set a target of a 20% reduction in carbon intensity compared to 2010 levels in 2030. These amendments also extended these standards to all subsequent years after 2030.

Macroeconomic condition: Factors that could affect future quantities and revenues of California's extraction and refining. Macroeconomic conditions included in this study are global crude oil prices, California carbon prices, efficiency improvements (i.e., innovation), and the cost of carbon capture and storage.

Morbidity: Non-fatal adverse health effects, such as asthma and other illnesses. Metrics to measure morbidity in this study include hospital visits, emergency room visits and the number of asthma conditions.

MRIO: Multi-Regional Input-Output

$MtCO_2e$: million metric tons of carbon dioxide equivalent

NGO: non-governmental organization

North American Industry Classification System (NAICS): Standardized system that classifies economic activity by industry. Each NAICS code corresponds with an industry. NAICS codes vary from one to six digits and are nested within each other (i.e., codes with fewer digits reflect activity in a broad industry; industry activity becomes more specific with more digits).

North/South refinery clusters: Because of the limitation in the resolution of available data, projected refinery production is presented at the level of two clusters. The North cluster includes refineries in Contra Costa County and Bakersfield; the South cluster includes refineries in Los Angeles and Santa Barbara County.

OPGEE: The Oil Production Greenhouse gas Emissions Estimator

$PM_{2.5}$ precursors: In addition to the direct (primary) emissions of particles, $PM_{2.5}$ can also be formed through the chemical reactions of gases such as sulfur oxides (SO_x) and nitrogen oxides (NO_x), volatile organic compounds (VOCs), and ammonia (NH_3).

Population weighted emissions exposure (PWEE): Defined as the product of the toxicity-weighted quantity of toxic air contaminants emitted at a site in a given census tract and year and the population at risk of being exposed. In practice, we assume that the entire population living within 2 miles from a TAC-emitting extraction or refining site is at risk of being exposed.

Premature mortality: Deaths of infants less than 1 year old, and of individuals aged 29 years old or more.

Production quota: A statewide oil production limit on new and existing wells that reduces extraction first from fields with more costly extraction followed by fields with less costly extraction.

QCEW: Quarterly Census of Employment and Wages

Setback/setback policy: A policy that requires a minimum distance between wells and sensitive areas (e.g., residences, hospitals, schools).

Toxic air contaminant (TAC): An air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health (California Health and Safety Code Section 39655). This analysis considers nine TACs with the highest toxicity-weighted releases in the TFFSS.

Transportation fossil fuel supply sector (TFFSS): Industries whose activities are primarily and directly related to the extraction and refining of oil for the purpose of supplying transportation fuels in California.

Value of statistical life (VSL): Amount people are willing to pay for small reductions in the risk of dying. The VSL does not correspond with the value of an individual life.

Well entry: The number of wells that begin to produce crude oil in a field. Well entries occur when oil extraction firms find it profitable to drill new wells in a particular field (i.e., when its capital and operating expenditures are lower than the price of crude oil).

Well exits: The number of wells that end crude oil production permanently. Well exits occur when forecasted well-level production is lower than a field-level production threshold, which is based on the average production of the field's plugged wells in each well's final production year (see Section 2.3 of the Technical Appendix). When a well exits, it does not produce crude oil for the remaining years in the forecast period.

EXECUTIVE SUMMARY

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Photo by the Bureau of Land Management, California

EXECUTIVE SUMMARY

ENHANCING EQUITY WHILE ELIMINATING EMISSIONS IN CALIFORNIA'S SUPPLY OF TRANSPORTATION FUELS

California is implementing some of the world's most ambitious decarbonization policies, with the goal of reaching statewide carbon neutrality by 2045. The transportation sector is central to these efforts as it currently accounts, in total, for about one-half of statewide greenhouse gas (GHG) emissions. This study analyzes the pathways and implications of decarbonizing (i.e., reducing GHG emissions) California's transportation fossil fuel supply sector (TFFSS) with a focus on oil extraction and refining. The pathways we analyze align with future projections of California's transportation fossil fuels demand, as modeled by the companion study conducted by the UC Institute of Transportation Studies (henceforth referred to as Study 1).

There are many possible pathways for decarbonizing the TFFSS. Each decarbonization trajectory available to the State between now and 2045 offers a unique mix of statewide labor and health impacts as well as distributional consequences in terms of where these benefits are distributed and where impacts occur. For example, for the same GHG emissions target in 2045, some pathways may lead to more statewide health benefits, whereas others may result in different statewide job and compensation impacts. Likewise, for some pathways, communities experiencing disproportionate pollution and health burdens may receive a greater share of health benefits associated with decarbonization, helping to narrow existing inequities in health impacts from pollution exposure across the state.

This study conducts original research to help the State navigate these considerations. To do so, we combine a comprehensive synthesis of existing knowledge with state-of-the-art statistical and numerical methods to generate empirically-grounded projections of decarbonization scenarios to 2045. Our data-driven approach enables policymakers and stakeholders to examine the equity, health and labor market impacts of TFFSS decarbonization in a spatially-explicit manner. We apply this approach across a large landscape of possible future pathways, covering 1,440 and 432 different scenarios for the extraction and refining segments of the TFFSS, respectively. Each scenario is a unique combination of future policy and macroeconomic conditions.

Our analytical approach pairs models of oil extraction and refining with an atmospheric transport model to determine which parts of California are exposed to local TFFSS air pollution, and a detailed input-output employment model to quantify direct TFFSS employment impacts and indirect employment impacts in other sectors. Within this modeling structure, we develop a conceptual framework for analyzing certain equity, health and labor market impacts of decarbonization (Figure ES.1.). Furthermore, this study highlights where critical knowledge gaps remain

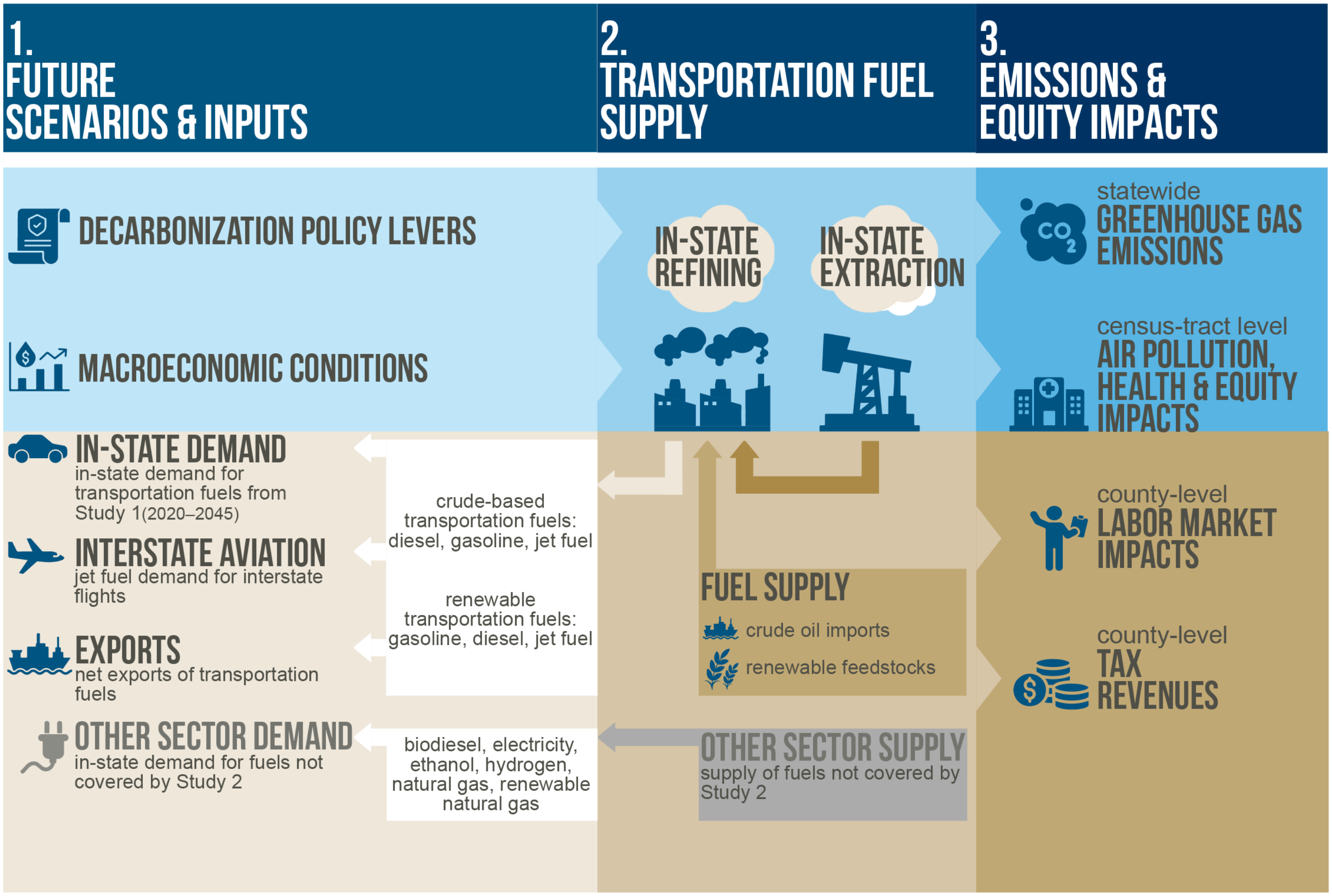

FIGURE ES.1. Schematic showing modeling and analytical approach used in this study.

in understanding TFFSS decarbonization options and their equity, health and labor consequences.

We analyze the oil extraction and refining segments within California's TFFSS. For both segments, our analysis proceeds along two steps. First, we employ a simplified version of our model to examine a large suite of TFFSS decarbonization scenarios. This scenario selection step enables us to apply an internally-consistent framework for comparing scenarios in order to reveal broad patterns that emerge across scenarios. However, the simplifications that allow comparison across a large set of scenarios also produce approximated equity, health and labor impacts. In the second step, we apply our full model to a handful of scenarios in order to better quantify outcomes and to improve spatial disaggregation.

Despite these methodological steps, we stress that projections over such a long time horizon remain highly uncertain. In this case, uncertainties are even greater given the unprecedented nature of California's decarbonization goals. These scenarios, in particular, are comparative and are designed to contrast modeled outcomes based on the application of potential policy levers (low carbon scenarios) or the absence of new policies (no-policy or business-as-usual, BAU, scenarios). As such, this study provides a broad comparison of different pathways the State could pursue rather than literal forecasts of each future decarbonization pathway. We also emphasize that this study analyzes a limited set of potential costs and benefits due to data limitations and existing knowledge gaps.

EXTRACTION SEGMENT RESULTS

Crude oil extraction has been declining in California since 1985. This trend, if continued, suggests that in-state crude oil production and GHG emissions associated with extraction will decline by 38% and 44%, respectively, between 2019 and 2045 without new policy measures. Additional policies are needed if the State aims for decarbonization in the realm of 80%

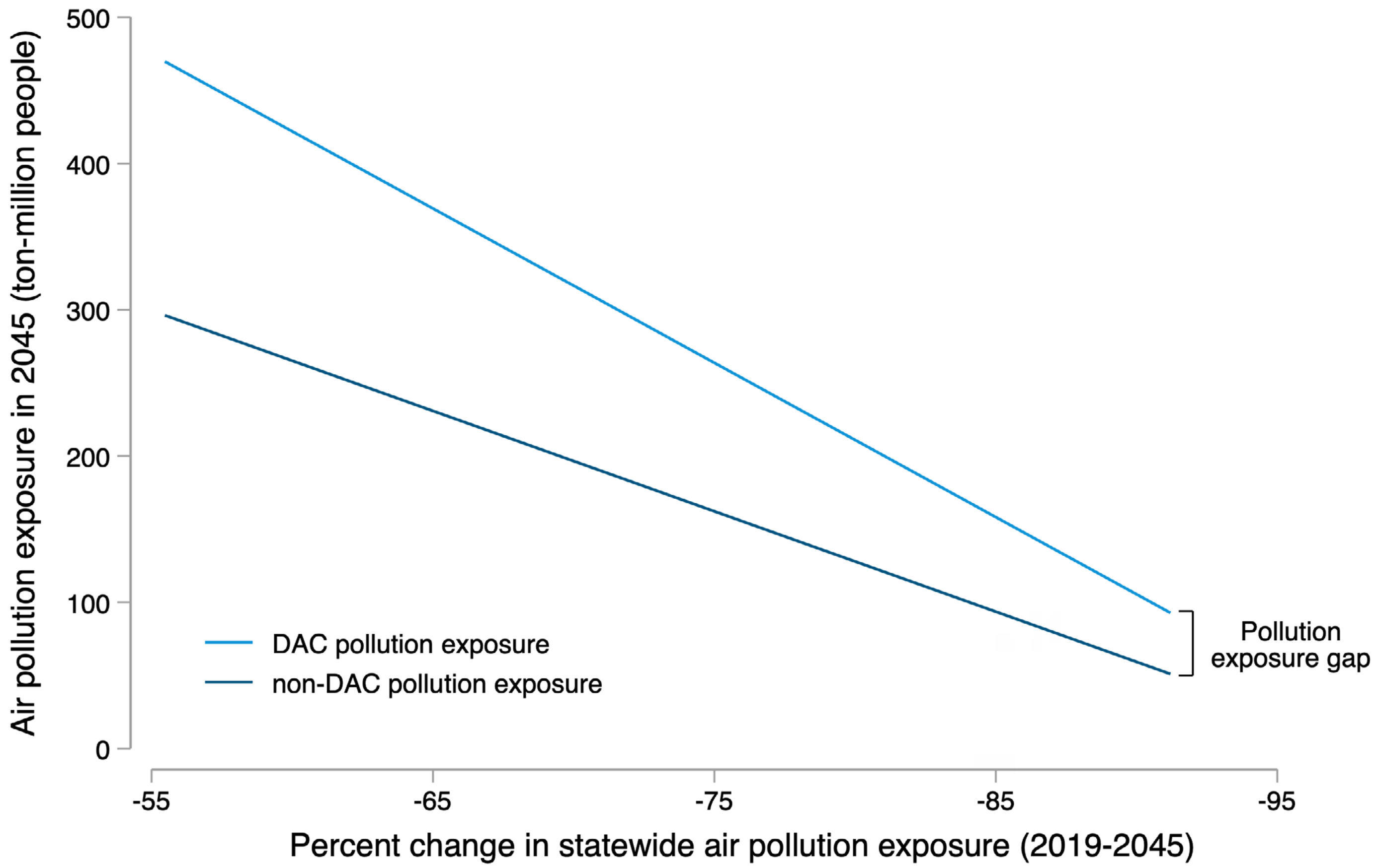

FIGURE ES.2. The air pollution exposure gap between disadvantaged and other communities narrows as statewide air pollution exposure from oil extraction falls following a production quota with auctioned permits. This figure reproduces Figure III.10. in the main text.

– 90% by 2045 in the extraction segment. We evaluate two potential policy levers: (i) a statewide oil production quota—or an equivalent excise or severance tax on extraction—on new and existing wells that reduces extraction first from fields with more costly extraction and then from fields with less costly extraction, and (ii) setbacks that prohibit extraction from new and existing oil wells within a certain distance of "sensitive" sites designed primarily for public health benefits and not GHG reductions, per se. Both policies generate statewide health benefits in terms of reductions in exposure to ambient $PM_{2.5}$ and toxic air contaminants (TACs), as well as labor market impacts in terms of reduced employment and worker compensation driven by changes in oil extraction.

Analyzing across a large set of scenarios, we find that a tighter statewide crude oil production quota not only lowers local air pollution exposure across the state, but also narrows the gap in pollution exposure between disadvantaged and other communities across the state (Figure ES.2.). That is, there is a built-in "equity benefit": as total air pollution exposure falls with declining statewide oil production under the quota, a greater share of that reduced air pollution exposure flows to disadvantaged communities. This enables the existing gap in air pollution exposure between disadvantaged and other communities to fall across the state. This equity co-benefit may arise because a production quota reduces oil extraction first from fields with higher extraction costs, which in California tend to be in locations near relatively more disadvantaged communities. A production quota, if implemented with auctioned extraction permits (or, equivalently, an excise or severance tax), also provides the State with additional state revenue that may be directed toward offsetting the various costs of TFFSS decarbonization.

Setbacks are considered primarily for public health benefits and not for GHG reductions, per se. Indeed, we find that setbacks with currently considered distances are not sufficient by themselves to achieve 80%–90%

TABLE ES.1. Scenarios selected for the full analysis

SEGMENT	SCENARIO	DESCRIPTION
Extraction	E-BAU	A. No decarbonization policy. B. Benchmark macroeconomic conditions include: IEA crude oil price pathway, low innovation, price floor carbon price and medium CCS cost.
Extraction	LCE1	A. Annual production quota that decreases linearly and results in an 80% reduction from 2019 historical production in 2045 (2045 quota = 31 million barrels). B. Benchmark macroeconomic conditions.
Extraction	LCE2	A. Annual production quota that decreases linearly and results in an 80% reduction from 2019 historical production in 2045 (2045 quota = 31 million barrels). B. 2,500-foot setback. C. Benchmark macroeconomic conditions.
Refining	R-BAU	A. Business-as-usual (BAU) fuel demand trajectory from Study 1. B. Historic exports. C. Benchmark macroeconomic conditions include: IEA crude oil price pathway, low innovation, price floor carbon price and medium CCS cost.
Refining	LCR1	A. Central low-carbon (LC1) fuel demand trajectory from Study 1. B. Historic exports. C. Benchmark macroeconomic conditions.
Refining	LCR2	A. Central low-carbon (LC1) fuel demand trajectory from Study 1. B. Low exports constrained to linearly drop to zero by 2045. C. Benchmark macroeconomic conditions.

"BAU" refers to business-as-usual; "LC" refers to low carbon; "E" is for extraction and "R" is for refining.This table appears in the body of the report as Table IV.1.

decarbonization by 2045. In particular, a setback distance of 2,500 feet between wells and residences, schools, playgrounds, daycare centers, elderly care facilities and hospitals leads to a 49% GHG reduction between 2019 and 2045. Increasing the setback distance to 5,280 feet (1 mile) results in a 2019–2045 GHG reduction of 58%.

The introduction of setbacks with a production quota allows the same improvement in aggregate, statewide local air pollution exposure to be achieved with slightly fewer job losses. Suggestive statistical analysis indicates that this may be because setbacks reduce oil production from fields that employ fewer TFFSS workers. For the same improvement in aggregate statewide local air pollution exposure, the addition of setbacks to a production quota results in a lower share of air pollution benefits borne by disadvantaged communities. This may be because oil fields that are more affected by setbacks tend also to be located in more densely populated areas where there is, in general, a more balanced share of communities identified as disadvantaged and non-disadvantaged. Alternative setback designs could alter this finding. For example, a setback policy that defines sensitive sites specifically according to criteria influencing disadvantaged community (DAC) status—such as socioeconomic or health criteria—could increase the share of health benefits borne by communities in existing disadvantaged census tracts.

We also examine how outcomes may differ under varying future macroeconomic conditions: i.e., crude oil price, level of innovation, carbon price, and carbon capture and storage (CCS) cost. One example comes from the extraction segment; under each of the following macroeconomic conditions—1) higher global crude oil prices, 2) higher California carbon prices (e.g., from the State's GHG cap-and-trade program), 3) lower costs of implementing CCS, and 4) lower local pollution intensity from crude oil extraction—decarbonization would involve fewer job impacts (but also smaller local air quality improvements) compared to no policy, BAU scenarios.

To quantify the GHG emissions, production, equity, health and labor consequences of decarbonizing the extraction segment of California's TFFSS, we analyze two future low carbon policy scenarios in detail using our full model (Table ES.1.): LCE1 includes a 20% production quota, whereas LCE2 includes a 20% production quota and a 2,500-foot setback. The 80% reduction in crude oil production that results from the 20% production quota in these two scenarios matches the 80% reduction in gallons of gasoline equivalent fuel demand from Study 1's central low carbon scenario (LC1). Both scenarios reduce GHG emissions from extraction by approximately 90% in 2045 relative to 2019 (Figure ES.3.). But compared to LCE1, LCE2 is more stringent because of its greater cumulative GHG reductions between 2019 and 2045, relative to a no-policy business-as-usual scenario in the extraction segment (E-BAU).

Compared to E-BAU conditions, we estimate that these scenarios will reduce premature mortality and other adverse health outcomes cumulatively by 17% to 37% between 2019 and 2045, with the LCE2 scenario generating larger health benefits. Up to 30% of the projected health benefits and up to 59% of the reductions in exposure to toxic air contaminants (TACs) accrue to DACs, many of which are located in Kern County. Modeling of the total labor market impacts of the two low carbon scenarios indicates that cumulative employment and worker compensation will decline by 18% under LCE1 and by 24% to 29% under LCE2 over 2019–2045, relative to the E-BAU scenario. Kern and Los Angeles Counties are the most impacted by the low carbon scenarios for extraction.

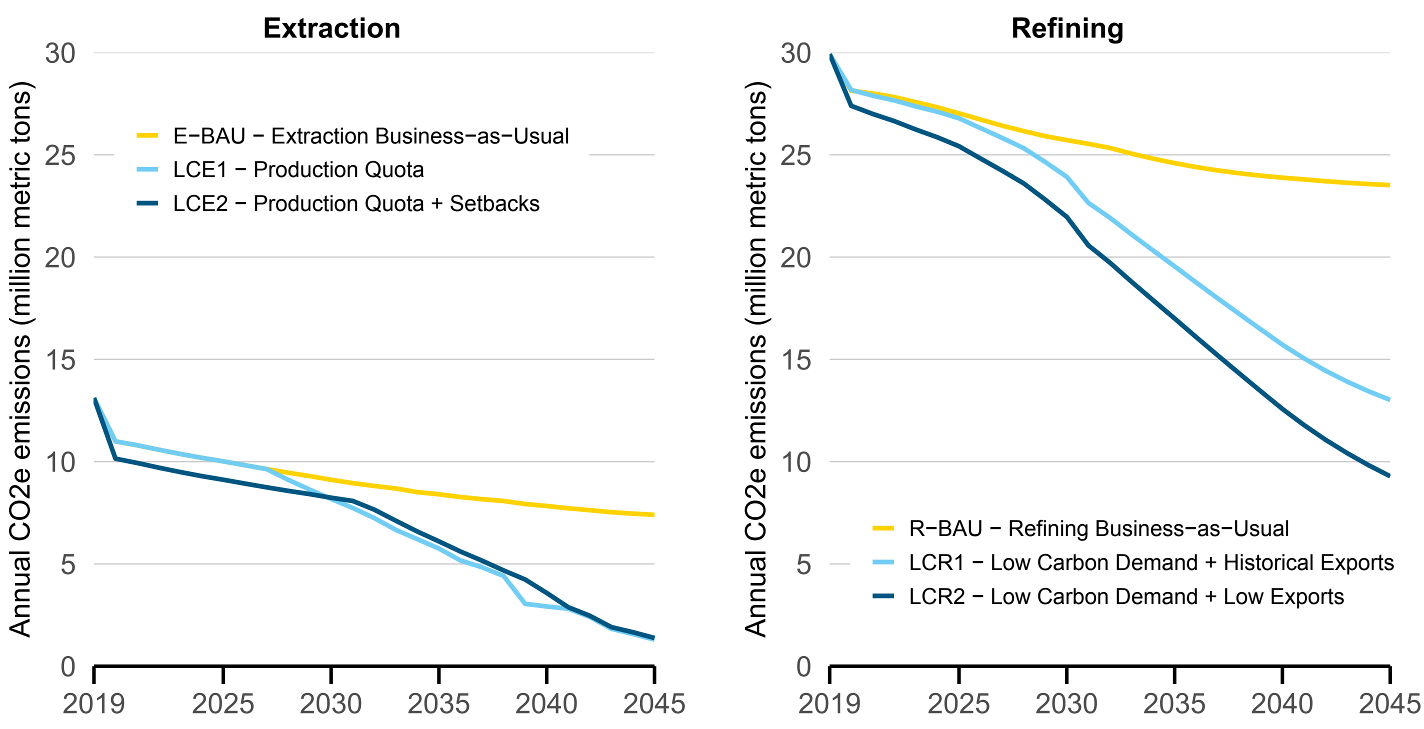

FIGURE ES.3. Annual GHG emissions ($MtCO_2e$) from California's extraction (left) and refining (right) segments, as modeled for different scenarios between 2019 and 2045. For extraction, GHG emissions in 2045, relative to 2019, decline by 44% for E-BAU, versus 82% for both LCE1 and LCE2. For refining, GHG emissions in 2045, relative to 2019, decline by 21% for R-BAU, versus 56% for LCR1 and 69% for LCR2. Persistent GHG emissions in the refining segment in 2045 reflect growing demand for liquid renewable fuels, continued demand for jet aviation fuel, and potential exports of refined products. This figure reproduces Figures IV.7. and IV.8. in the main text.

REFINING SEGMENT RESULTS

The refining segment is the largest source of GHG emissions within California's industrial sector. California's refineries produce—from both in-state and out-of-state crude sources—virtually all of the refined crude-based transportation fuels consumed in the state. To model California's refining segment, we consider two projections of refined fuel demand provided by Study 1: business-as-usual (BAU) and central low carbon (LC1). In addition, we assume that: i) refineries can produce additional quantities of refined fuels for export, ii) refineries produce additional jet fuel for interstate aviation transport, and iii) some refineries convert themselves to produce renewable fuels, specifically, renewable diesel, sustainable jet fuel, and drop-in renewable gasoline. If refined fuel demand follows the BAU projection and refineries continue to export at historical levels, GHG emissions from refining are projected to decline by 21% between 2019 and 2045 without new policy measures (Figure ES.3).

In addition to the R-BAU scenario, we consider two low carbon scenarios for the refining segment (Table ES.1.): i) a low carbon refining scenario (LCR1) wherein refined fuel demand follows the central LC1 projection from Study 1 and refineries continue to export at historical levels, and ii) a second low carbon refining scenario (LCR2) differing only in that refinery exports linearly decrease to zero by 2045. Under the LCR1 and LCR2 scenarios, refining GHG emissions are projected to decline by 56% and 69%, respectively, between 2019 and 2045 (Figure ES.3.).

We apply our full model to quantify the detailed equity, health and labor outcomes of refinery scenarios LCR1 and LCR2. Compared to business-as-usual (R-BAU) conditions, we estimate that these scenarios will lead to improvements in health (reduction in premature mortality and other adverse health outcomes) of 18% under LCR1 to 28% under LCR2, cumulatively over 2019–2045. Moreover, the refining segment scenarios lead to a larger share of health benefits for DACs (up to 39%) than the extraction segment scenarios (30%). For total labor market impacts in refining, we find that employment and worker compensation compared to R-BAU conditions are projected to decline by 18% to 22% for LCR1 and 30% to 37% for LCR2, cumulatively over 2019–2045. The larger impact range for the refining scenarios compared to the extraction scenarios reflects the larger spillover impacts of refinery production on employment and compensation in other economically-connected sectors. Labor market outcomes in Los Angeles County are the most impacted by the low carbon refinery scenarios.

Even when California's in-state demand for fossil-based refined products drops significantly to meet the state's carbon neutrality goals, GHG emissions from refineries are likely to persist. This is because refineries will continue to operate to produce refined products to meet demand for in-state liquid renewable fuels consumption, jet fuel for aviation transport, and potential exports of refined products. If in-state extraction is reduced to meet reduced demand as reflected in the two low carbon extraction scenarios (i.e., LCE1 or LCE2), any continued demand for petroleum-based fuels—primarily jet fuel—must be met by a greater proportion of crude oil imports. Exports of refined products may decrease if California's refineries are uncompetitive in global and regional markets or in response to state policies, whereas demand for renewable fuels that can potentially be produced by existing California refineries will likely persist. For California's TFFSS to completely decarbonize by 2045, the sector may need to explore and pursue other decarbonization pathways via mitigation options such as carbon capture and storage, direct air capture, and other negative emission technologies and natural lands solutions.

STUDY LIMITATIONS

This study has clear limitations, some of which are due to existing knowledge gaps. It is outside the scope of this study to examine how TFFSS decarbonization policies affect the price of final energy goods such as petroleum, renewable liquid fuels and electricity. Changes in the price of final energy goods may be consequential and may also be inequitable, possibly affecting low-income households disproportionately.

Modeling in this study does not include all policies that could drive actions to reduce emissions in the oil and gas extraction and refining segments. Notably, this study excludes the Low Carbon Fuel Standard (LCFS). LCFS has and continues to induce cleaner fuels and make oil and gas extraction and refining more efficient through the program's life cycle approach. One way in which the LCFS reduces the carbon footprint of the fuels from the TFFSS is by changing the mix of fuels demanded, increasing the substitution of low carbon intensity fuels. This aspect of the LCFS program is excluded from our study because we use projected fuel mixes provided by Study 1. Another way in which the LCFS reduces the carbon footprint of the TFSSS is through project-based credit opportunities for GHG mitigation measures, such as CCS projects. In this study, we only model CCS adoption in response to carbon prices from California's cap-and-trade program; more work is needed to model how the additional price signal from LCFS impacts CCS adoption and other GHG mitigation measures eligible for project-based crediting.

The estimated health impacts reported in this study do not account for all possible benefits of decarbonizing the TFFSS. Time constraints prevent us from modeling changes in ambient ozone concentrations and associated health benefits that would result from decarbonizing the TFFSS. Furthermore, more research is needed to conclusively establish other health impacts from the TFFSS, including health impacts from criteria air pollutants beyond $PM_{2.5}$, from TACs, and from impacts on water quality and ecosystems. Therefore, our modeling cannot capture those impacts on health outcomes, and the health benefits associated with decarbonizing California's TFFSS reported in this study are likely to be underestimated. Our study also omits consequences experienced outside of California.

There are also clear limitations associated with how labor market impacts are quantified, which, by construction, does not account for the extent to which workers displaced in various decarbonization scenarios may find employment in other jobs or sectors. As a result, the labor market impacts associated with decarbonizing California's TFFSS reported in this study are likely to be overestimated. Further, the labor impact analysis cannot account for future policy changes that operate outside of our model. In the main text, we detail how future research can fill in these and other knowledge gaps and limitations.

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CHAPTER 1
INTRODUCTION

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A. / SCOPE AND PURPOSE OF THIS STUDY

California's Budget Act of 2019 (AB 74) directed the Secretary for Environmental Protection to engage researchers at the University of California to conduct two studies in support of the state's goal of achieving carbon neutrality by 2045. Study 1, to be conducted by the University of California Institute of Transportation Studies, is tasked with identifying strategies to significantly reduce in-state transportation-related fossil fuel demand and emissions. Study 2, to be conducted by the University of California, Santa Barbara, is tasked with identifying strategic approaches to inform a just and equitable managed decline of in-state production of transportation-related fossil fuels. A key emphasis for Study 2 is to identify the impact that the transportation fossil fuel supply sector (TFFSS) has across California's communities, currently and in a carbon-neutral future.

The Scope of Work (SOW) for Study 2 (1) was developed in conjunction with the California Environmental Protection Agency (CalEPA) in fall 2019 and winter 2020. The SOW specifies the guiding principles for both studies, which are maximizing "equity and justice, health, high road jobs, environment, resilience and adaptation, affordability and access" for Californians while "minimizing impacts beyond our borders." The SOW details two tasks associated with Study 2: 1) detail current trends and characteristics in the supply of transportation fuels, which was publicly released as a Synthesis Report in October 2020 and is referenced to in Chapter I.b.; and 2) identify scenarios to manage the decline of the State's transportation fuel supply in conjunction with the fuel demand reduction outlined in Study 1, which composes the remainder of this report.

The sections that follow explore pathways for a managed decline of the TFFSS, with the overarching goal of reducing greenhouse gas (GHG) emissions from 2020 to 2045, consistent with the SOW. These pathways are based on results from modeling specific scenarios that consider the extraction and refining segments of the TFFSS. These scenarios explore the impact of both varying macroeconomic conditions and different policy levers, with quantification of changes in GHG emissions, $PM_{2.5}$ and $PM_{2.5}$ precursors (NO_x, SO_x, VOCs, NH_3), and toxic air contaminants (TACs), and with particular reference to health and labor equity impacts of alternative decarbonization strategies for this sector over the coming decades.

Throughout this report, California's TFFSS is defined as the industries whose activities are primarily and directly related to the extraction, distribution and refining of oil for the purpose of supplying transportation fuels in California. Attribution of GHG emissions, $PM_{2.5}$ and $PM_{2.5}$ precursors (NO_x, SO_x, VOCs, NH_3), TACs, and labor share to this sector follows the California Air Resources Board's (CARB) GHG Inventory accounting practice of attributing GHG emissions to their sources and not their end use. Hence, sectors that supply services and/or inputs to the TFFSS (e.g., grid electricity) are not included in this study, and related sectors such as natural gas extraction and supply are not considered. Moreover, as dictated by the SOW, our study also does not consider economy-wide effects of modeled changes in the TFFSS, such as how declines in the use of petroleum-based fuels will affect the price of energy substitutes, such as electricity or renewable fuels.

Our strategy throughout this study is to use a science- and data-driven approach to modeling potential scenarios for reducing transportation fossil fuel supply in California. To accomplish this goal, we have developed two entirely new quantitative models of both the extraction and refining segment of California's TFFSS. We use these models to evaluate business-as-usual and specific alternative policy scenarios for the two segments of the TFFSS from 2020 to 2045. The choice of alternative policy scenarios is guided by the SOW's request to "manage the decline of the State's transportation fuel supply in conjunction with the fuel demand reduction outlined in Study 1". As such, our policy scenarios are selected based on decarbonization policy levers that achieve supply-side GHG reductions that broadly match the GHG reductions modeled by Study 1 under their central low carbon scenario.

A recent MIT report quantifies the global importance of phasing out refined oil early in the fully considered decarbonization cycle, which the MIT report models from 2010 to 2150 (2). Of the 10 scenario elements considered, ranging from phasing out coal, oil and gas to reducing non-CO_2 GHG reductions, the largest single reduction in GHG emissions, amounting to about one-third of decarbonization between 2020 and 2150, is associated with phasing out refined oil in transportation. An alternative scenario with a fast phase-out of oil between 2020 and 2070, which encompasses the time frame over which California intends to phase out petroleum fuels, leads to much faster reductions in global CO_2 emissions. Although California's phase out of refined oil, as revealed herein, will make only a modest contribution to aggregate global GHG reductions, California can lead in this transition by demonstrating a range of effective policies and technologies.

B. / CURRENT TRENDS AND CHARACTERISTICS IN THE SUPPLY OF TRANSPORTATION FUELS

For current trends and characteristics of California's TFFSS, refer to the Study 2 Synthesis Report: Carbon Neutrality and California's Transportation Fossil Fuel Supply (3), which was published in October 2020 and is available on the CalEPA website. The report reviews California's current TFFSS, including GHG emissions, labor markets, air pollution and health impacts and current state policies. Because the Synthesis Report illustrates direct employment from the TFFSS ending in 2018, we describe baseline full-time equivalent (FTE) job-years and compensation for 2019 in Chapter V of this report.

CHAPTER 2
METHODS SUMMARY

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Our aim is to quantitatively analyze the equity and economic consequences of decarbonizing the transportation fossil fuel supply sector (TFFSS) from 2020 to 2045. Projections over such a time horizon are always uncertain and require assumptions to be made about future conditions that cannot be verified at the time of the projection. As such, we view these projections not as literal forecasts of the future, but rather as a set of possibilities that could occur given different plausible future macroeconomic conditions and policy levers.

To provide analytical rigor to our projections, the quantitative framework behind our projections adhere to the following principles:

- To the degree that it is possible, we use statistically estimated relationships based on data from the recent past.
- Assumptions about future macroeconomic conditions are based on the best available estimates of such trajectories.
- To examine as many possible future scenarios conceivable, our model is built with sufficient flexibility so as to not prejudge any specific outcome.

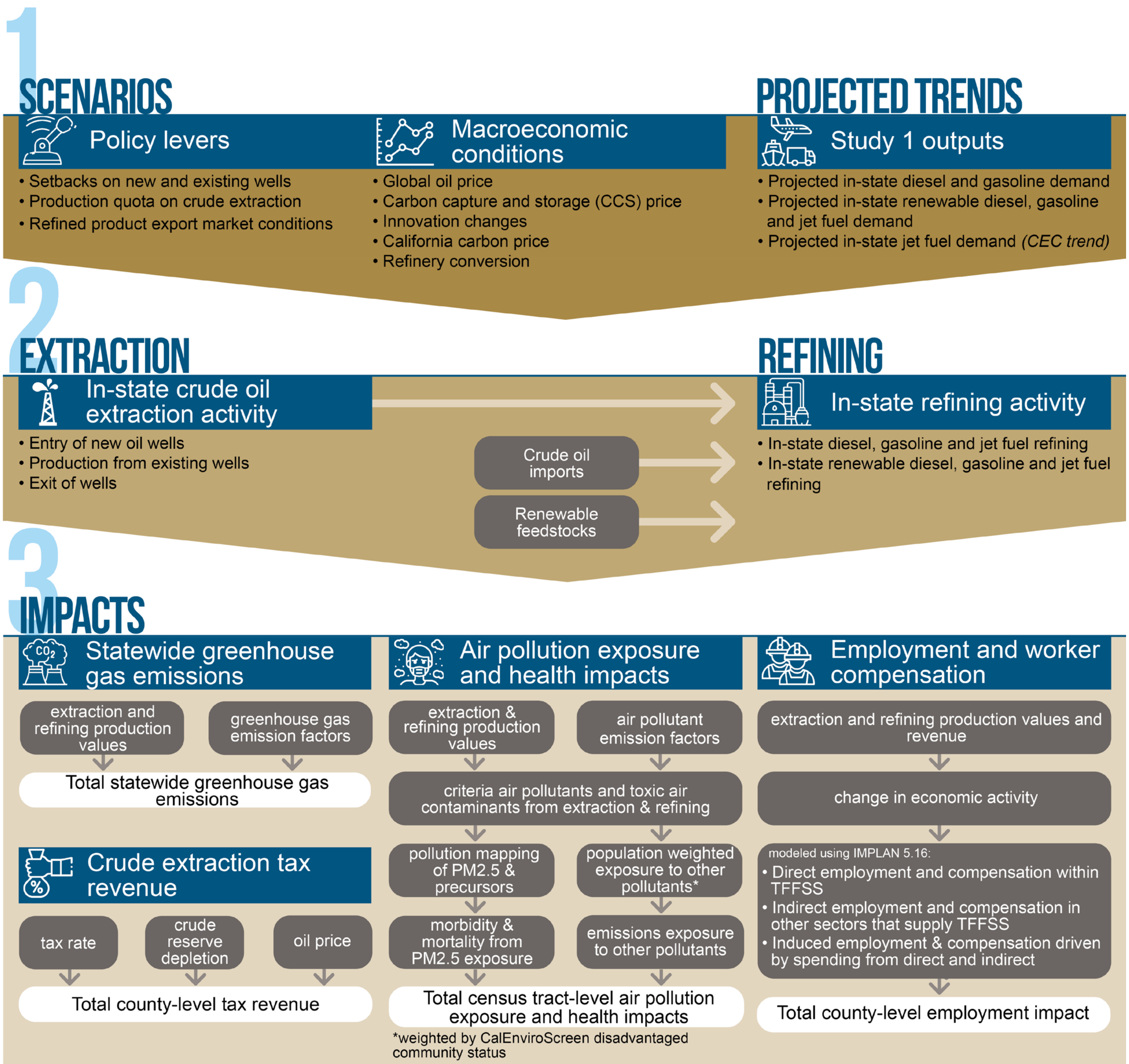


FIGURE II. 1. Illustration of methodology used in this study (see text for details).

This section summarizes how we analyze the various greenhouse gas (GHG) emissions, local air pollution and labor market consequences of decarbonizing the TFFSS. Our approach proceeds in three steps (Figure II.1.).

First, we build an empirically based, spatially explicit model of crude oil extraction and refining across California. The spatial representation of our model is at the crude oil field level for the extraction segment and the North and South cluster level for the refining segment. This model projects, annually from 2020 to 2045, field-level crude oil extraction and cluster-level refining quantities and revenue that are then used to determine statewide GHG emissions, spatially explicit local air pollution impacts and their health consequences, and spatially explicit labor market impacts.

A scenario drives each projection run; we define a scenario as a combination of a particular set of macroeconomic conditions and decarbonization policy levers. We consider different plausible values of the following macroeconomic conditions: global crude oil prices, California carbon prices, efficiency improvements (i.e., innovation), and the cost of carbon capture and storage. For the crude oil extraction segment, we consider the following policies: a statewide production quota and a setback policy for new and existing oil wells. For the refining segment, we consider in-state fuel demand trajectories obtained from Study 1 and limitations on exports of refined products.

This model enables us to consider a variety of decarbonization policy levers and various key future macroeconomic conditions that inform outcomes from 2020 to 2045. The combination of policy levers and macroeconomic conditions considered generates 1,440 scenarios for the extraction segment and 432 scenarios for the refining segment. Each scenario projects crude oil output (extraction segment) or consumption (refining segment), GHG emissions, local air pollution emissions and employment, at the oil field-level or refinery cluster-level annually between 2020 and 2045.

Doing thorough and highly resolved spatially explicit local air pollution, health impacts and labor market impacts analyses of each of our scenarios is computationally intractable. Instead, in our second step, we apply approximations of local air pollution and labor market impacts that enable us to evaluate broad patterns across these scenarios. Because our analysis of the extraction segment is more spatially explicit and empirically grounded, this second step enables us to consistently characterize scenarios and extract broad patterns across scenarios for the extraction segment along key climate, cost-benefit and equity criteria. Although this step allows us to compare across scenarios, the use of approximations for local air pollution and labor impacts prevents us from directly interpreting the value of projected impacts. In our third step, we undergo more detailed, spatially resolved analyses on several notable scenarios to quantify local health impacts from changes in local air pollution and local labor market impacts more precisely.

The following sections describe an overview of our extraction and refining models, GHG emissions quantification, labor impacts analysis, air pollution and health impacts analyses, the set of decarbonization policy levers analyzed, and the set of future macroeconomic conditions considered in our projections. Further details on our methodology can be found in Sections 7 and 8 of the Technical Appendix.

A. / OVERVIEW OF CRUDE OIL EXTRACTION MODEL

The decision to extract crude oil across oil fields in California is a function of expected revenue and costs for all existing and potential oil extraction sites across the state. We do not directly observe these variables, particularly for potential crude oil extraction sites. Instead, we use observable costs, global crude oil prices and historical well entry data to estimate how costs and prices have impacted historical entry of wells over the period 1978–2019. We obtain historical California extraction data from the Department of Conservation (DOC) and cost data from Rystad Energy (see Section 1.1 of Technical Appendix). Insofar as observed proxy cost variables and current crude oil prices are correlated with unobserved costs and expected crude oil prices, our statistical model provides an empirical relationship between the variables that we observe with extraction from new wells. There are three main components to our extraction model: 1) new well entry (i.e., wells that begin to produce crude oil) in each field; 2) field-level crude oil production from both new wells (i.e., those projected to enter during the forecast period 2020–2045) and existing wells (i.e. wells that began production before 2020); and 3) well exit (i.e., wells that stop producing permanently) in each field.

Our statistical new well entry model (see Section 2.1 of Technical Appendix) has several notable features. First, our model recognizes heterogeneity in oil characteristics across fields, such as sulfur content and differences in American Petroleum Institute (API) gravity, a measure of the density of oil. These characteristics affect the cost of extraction and the field-level crude oil prices. To incorporate these differences, we estimate heterogeneous entry responses to global crude oil prices across major oil fields. This statistical feature captures the fact that not all oil fields receive the same price for the sale of their crude oil due to variation in oil quality, and thus fields will respond differently to changes in global crude oil prices

Second, our model incorporates heterogeneity in the costs of extraction by incorporating field-specific cost data. We include both field-level capital and operational costs as explanatory variables for well entry. Third, our model includes the role of field-level depletion on new well entry. Increased depletion reduces reservoir pressure, making extraction more difficult. We estimate the effect of depletion on well entry over 1978–2019, holding all other factors constant, and use these estimates to incorporate depletion in our future well entry estimates over the forecast period 2020–2045.

To validate our model of new well entry, we use the model to predict historical entry based on our explanatory variables over the period 1978–2019. We report the results in the figures in Section 2 of the Technical Appendix: Figure 4 shows the modeled prediction of well entry at the state level and Figure 5 shows the modeled predictions of well entry among top producing fields. In both cases, our model reasonably predicts historical entry patterns. Similarly, in an out-of-sample validation exercise, our model reasonably predicts new well entry during 2010–2019 using fitted parameters estimated over 1978–2009 (see Figures 6 and 7 in Section 2.1 of the Technical Appendix for results from the out-of-sample validation exercise for state-level and top producing fields).

To project field-by-year new well entry between 2020 and 2045, we apply the estimated statistical parameters from our historical well entry model to forecasted field-level extraction costs and recent projections of future global crude oil prices. We forecasted field-level extraction costs by extrapolating historical field-level trends in costs (see Section 1.1.2 of the Technical Appendix). Projections of future global crude oil prices were obtained from the International Energy Agency (IEA) and reflect the latest COVID-19 recovery circumstances (see Section 8.2 of the Technical Appendix).

Oil wells decline in production over time. To quantify crude oil production between 2020 and 2045 from both existing wells drilled during the historical period of 1978 to 2019 and new wells that will enter into California's oil fields from 2020 to 2045, we fit production decline curves, similar to those used in the industry and academic literature, to historical production data to estimate curve parameters. We then apply the estimated parameters in the forecast years to obtain annual production volumes from each oil field between 2020 and 2045 (see Section 2.2 in the Technical Appendix). Well exits occur when forecasted well-level production is lower than a field-level production threshold, which is based on the average production of the field's plugged wells in each well's final production year (see Section 2.3 of the Technical Appendix). When a well exits, it does not produce crude oil for the remaining years in the forecast period.

Our extraction model quantifies crude oil production and revenue resulting from two state-level decarbonization policy levers. The first policy lever is a quota limiting the statewide production of crude oil with field-level limits based on the relative cost of extraction for each field. The second is a setback policy that restricts crude oil production from fields within a certain distance of sensitive sites, such as homes, schools, healthcare facilities, child daycare facilities, elderly housing and playgrounds. Chapter II.f. below details how we quantify the effects of these two policy levers with our model (see Section 7 of the Technical Appendix for further details).

Finally, we apply adjustments to our oil extraction model to accommodate alternative future macroeconomic conditions that could affect statewide crude oil production and revenue. The macroeconomic conditions applied to our model include alternative trajectories of crude oil prices, statewide carbon prices, assumptions about innovation in the TFFSS, and the implementing cost of carbon capture and storage (CCS). Chapter II.g. below discusses how these macroeconomic conditions are implemented in our model (see Section 8 of the Technical Appendix for further details).

B. / OVERVIEW OF REFINING ACTIVITY MODEL

The refining activity model estimates crude oil consumption and its associated GHG emissions for different demand projections of refined fuels, policy levers and macroeconomic conditions.

Fuel demand projections

Crude consumption at California's refineries depends on demand for refined fuels (gasoline, diesel and jet fuel) from within the state of California, demand for jet fuel for interstate aviation transport, and exports of refined fuels from California. Further, refineries can also produce renewable fuels (renewable gasoline, diesel and jet fuel), either by co-processing renewable feedstocks and crude oil or by converting operations to solely process renewable feedstocks. A refinery's total production of refined fuels determines both its capacity utilization factor (CUF)—operating level of a refinery compared to its rated processing capacity—and its GHG emissions.

Study 1 from The Institute of Transportation Studies at UC Davis (ITS-Davis) projects in-state refined fuels demand from 2020 to 2045 under two scenarios: business-as-usual (Study 1 BAU) and central low carbon scenario 1 (LC1). Of the fuels in Study 1's demand projections for California's transportation sector, we use projections for the following fuels as inputs to our refining model: gasoline, diesel, drop-in gasoline (renewable gasoline), renewable diesel and sustainable aviation fuel (renewable jet fuel). Our model assumes that all in-state demand for these refined products is met by in-state refineries. Although California currently imports refined renewable fuels (renewable gasoline, renewable diesel and renewable jet fuel), we assume that the recent announcements of refinery conversions to produce renewable fuels will allow California to meet renewable fuel demand with in-state refining.

Study 1 also projects jet fuel demand for intrastate aviation transport only. Because California refineries are responsible for producing jet fuel for both intrastate and interstate aviation transport, instead of Study 1 projections, we adopt the California Energy Commission's (CEC) "mid case scenario" projections for total in-state jet fuel demand until 2030 (4), which accounts for both intrastate and interstate aviation transport. We extrapolate this jet fuel demand to 2045 and include this projection in both the Study 1 BAU and LC1 in-state fuel demand scenarios. Lastly, we account for military jet fuel demand, which is excluded from the CEC's demand projection, by adding the average annual in-state military jet fuel demand from 2004 to 2012 uniformly to the CEC-based annual jet fuel demand projection.

Exports of refined products (gasoline, diesel and jet fuel) are also included in our fuel demand projections. We add net exports of fuels refined in California (5) to the in-state refined fuel demand. The amount of assumed net exports is dependent on the scenario (see Chapter II.f. for further details). In an earlier iteration of our model, we added total exports, instead of net exports, to in-state fuel demand, resulting in greater total fuel demand than the true estimated value. These original outputs were used in health and labor impacts analyses. We have since corrected our refining model outputs to use net exports instead of total exports. To correct the modeled health and labor impacts, we apply linear adjustments to annual crude oil consumed and refined fuel produced, at the individual refinery level and at the county level, using the difference between net exports and total exports.

In our model, we do not include demand for other fuels including electricity, hydrogen, renewable natural gas, ethanol and biodiesel projected by Study 1. Although hydrogen is produced by refineries through steam methane reformation (SMR) using natural gas as a feedstock, it is mainly used as an input to the refining process and not for direct use in the transportation sector. Future hydrogen demand could be met by SMR facilities outside of existing refineries or through electrolysis using electricity as input energy. Because of these uncertainties, we exclude hydrogen from this analysis.

Modeling refinery operations

California's refineries are spatially concentrated in two "clusters": the North cluster includes refineries in Contra Costa, Solano and Kern Counties and the South cluster includes refineries in Los Angeles County. Because publicly-available data on historic refined fuel production is available only at the cluster level and not refinery level, we model crude consumption at the cluster level. First, we assign refined fuel demand to each of the two clusters (North and South) by splitting the state-level demand using historical ratios of cluster-level production of each fuel. Second, we apply fuel energy intensities from the Energy Information Administration (EIA) to the volumes of fuel demand projections to convert demand into units of energy. We then apply the conservation of energy principle to estimate crude oil consumption at refineries in order to meet refined fuel demand.

We assume that all annual demand for renewable gasoline, renewable diesel and renewable jet fuel is first processed by California's crude oil refineries that have converted or announced their conversions to renewable fuel refineries. Residual demand for renewable gasoline, renewable diesel and renewable jet fuel that cannot be produced by these renewable fuel refineries is added onto the annual demand for crude oil-based gasoline, diesel and jet fuel for co-processing at the remaining California crude oil refineries. To account for renewable fuels co-processed at crude oil refineries, we define "equivalent crude demand" as a proxy for both crude oil and renewable feedstock consumed by refineries that either only produce crude oil-based products or co-produce both crude-based and renewable products. We assume renewable gasoline, renewable diesel and renewable jet fuel have the same energy intensities and GHG emission factors per barrel of "equivalent" crude oil consumed to produce as gasoline, diesel and jet fuel, respectively.

We model annual in-state refinery operations. To estimate total operating capacity, we take into account any retirement(s) of in-state refineries from the previous year within a scenario run, planned refinery installations and announced refinery conversions to process renewable fuels. The following planned refinery conversions and installations are included in our refinery model.

- Phillips 66 Rodeo San Francisco refinery separate unit is planned to begin operations in 2021—8,000 barrels per day of renewable capacity will be installed (6);
- Marathon Petroleum Golden Eagle Martinez refinery conversion is planned to begin operations in 2022—161,500 barrels per day of crude oil refining capacity will be shut down and 48,000 barrels per day of renewable capacity will be installed (6);
- Global Clean Energy is planned to begin operations in 2022—15,000 barrels per day of renewable capacity will be installed (7); and
- Phillips 66 Rodeo San Francisco refinery conversion is planned to begin operations in 2024—75,700 barrels per day of crude oil capacity will be shut down and 44,357 barrels per day of renewable capacity will be installed (8).

As California's demand for total refined products falls in certain scenarios, refinery production and refinery capacity utilization also decreases, making refineries increasingly unprofitable. To induce refinery retirements in the model, we assume that refineries are unprofitable at average CUFs below 60%. In our model, when the average CUF for a cluster during a year falls below 60%, the smallest refinery, which we assume to have the highest marginal cost, is retired. Refineries are retired until the average CUF exceeds 60%. The model determines the refineries in operation for each year. The model then distributes and assigns the cluster-level crude consumption to the remaining individual refineries using the proportion of refining capacity that each operating refinery contributes to its respective cluster. This split in crude oil consumption allows us to estimate revenue and labor impacts at the county-level and health impacts from local criteria air pollutants at the refinery-level.

Although we apply the 60% CUF limit for all refineries, actual CUF limits that will dictate individual refinery retirements will vary across refineries based on multiple factors. However, the assumption of a 60% CUF limit does not affect the cluster-level CUFs in our model. Because refineries in California are clustered, this assumption will have limited impact on results.

C. / OVERVIEW OF GHG EMISSIONS IMPACT ANALYSIS METHODOLOGY

Extraction

To estimate GHG emissions and analyze the impact of macroeconomic conditions, such as carbon prices on crude oil extraction, both spatial heterogeneity and temporal variability of GHG emission factors (kg CO_2/bbl) are important. Spatial heterogeneity in GHG emission factors across oil fields is driven by various factors, including the use of enhanced oil recovery methods (e.g., steam injection for oil extraction). Additionally, changes in GHG emission factors over time within fields are driven by changes in production processes, such as the increase in steam injection driven by a decrease in natural gas price relative to crude oil price.

A number of sources estimate GHG emission factors for crude oil extraction: CARB's GHG Inventory (9), CARB's Mandatory Greenhouse Gas Reporting Regulation (MRR) program (10), and CARB's Low Carbon Fuel Standard (LCFS) Crude Oil Life Cycle Assessment (11). The GHG Inventory provides yearly reported values of GHG emissions, which can be divided by reported oil production in the DOC WellStar dataset to calculate emissions factors; however, the GHG Inventory is reported at the state level and therefore does not have any spatial heterogeneity. The MRR dataset provides annual reported emissions by oil extraction firms, thus providing additional spatial specification. However, because oil extraction firms operate in multiple fields and a field can have multiple firms operating within it, there is no direct way to obtain field-level emission factors. CARB's LCFS Crude Oil Life Cycle Assessment has the finest spatial resolution for GHG emission factors, providing carbon intensities (gCO_2e/MJ) for 157 oil fields (40% of California's oil fields included in this study), representing 99.6% of 2019 crude oil production. The limitation of the LCFS Life Cycle Assessment dataset, however, is that the GHG emission factors were estimated using data on extraction activities from 2015 only. In reality, crude oil extraction practices, particularly the use of steam injection, are likely to change from year to year. However, given the importance of incorporating spatial heterogeneity to quantifying GHG emissions in order to understand the impact of carbon prices on field-level crude production, we use CARB's LCFS Crude Oil Life Cycle Assessment as the source of GHG emission factors.

CARB utilized The Oil Production Greenhouse gas Emissions Estimator (OPGEE) model (12) to develop the field-level GHG emission factors that account for the production, processing and transport of crude oil. The life cycle assessment was based on DOC 2015 data on crude oil production, steam injection, water injection and other field-level extraction practices. Because the CARB assessment provides life cycle GHG emission factors and our analysis is limited to GHG emissions from the extraction segment only, we recalculate the GHG emission factors using the OPGEE model and inputs from CARB but limit upstream emissions to those from exploration, drilling and crude oil production.

CARB's LCFS Crude Oil Life Cycle Assessment GHG emission factors are available for only 35% of California's total oil fields. To estimate GHG emission factors for fields not included in the LCFS Life Cycle Assessment, we first split the fields included in the LCFS Life Cycle Assessment into two groups—fields with steam injection and without steam injection—and estimate median upstream GHG emission factors within the two groups. Using DOC WellStar data (13), we then determine whether steam injection was used within the excluded oil fields in 2015. Based on whether the excluded oil fields utilized steam injection or not, we assign the corresponding median upstream GHG emission factor of fields included in the LCFS Life Cycle Assessment.

Our total modeled GHG emissions for past years differ from those reported in the GHG Inventory because of differences between the two methodologies. Further, although crude oil extraction practices including steam and water injection are likely to experience interannual variation within fields, the LCFS Life Cycle Assessment GHG emission factors are based on 2015 only. We estimate the 2019 GHG emissions baseline for the extraction segment using historical crude extraction from the DOC WellSTAR monthly extraction data (14) and the estimated field-level GHG emission factors described above.

To compare our modeled GHG emissions from the extraction segment, we utilize the 2019 edition of the GHG Emissions Inventory data in this study. Note that historical GHG emissions data were adjusted by CARB in the 2020 edition.

Refining

To calculate refining GHG emission factors, we use the CARB MRR dataset with reported 2018 annual emissions from individual refineries (10). However, because crude oil consumption data is available at the cluster level only and not the individual refinery level, we are unable to calculate refinery-level GHG emission factors. Thus, we aggregate the GHG emissions reported in the MRR dataset to the cluster level (North and South) based on each refinery's location. We then divide the cluster-level GHG emissions by the cluster-level crude oil consumption in 2018 (15). The 2019 baseline for GHG emissions from the refining segment used in this study is estimated by multiplying the 2018 cluster-level GHG emission factors with 2019 reported crude consumption.

For comparing our modeled GHG emissions from the refining segment, we utilize the 2019 edition of the GHG Emissions Inventory data in this study.

D. / QUANTIFYING LABOR IMPACTS

To quantify the labor market impacts associated with each modeled scenario, we use IMPLAN (version 5.16), an input-output model of the relationship between a given set of demands for final goods and services and the inputs required to satisfy those demands. IMPLAN is an industry input-output model routinely used by government agencies and analysts to preemptively estimate the labor market impacts of proposed policies and/or when industry-level data is limited. We chose the IMPLAN model instead of alternatives such as REMI because of IMPLAN's greater level of detail on industries (i.e., there are 546 sectors in IMPLAN versus 160 in REMI). Given that the key industries underlying the TFFSS are narrowly defined, this distinction is essential.

IMPLAN generates three types of impacts using measures of existing supply chains and spending patterns: direct, indirect and induced impacts (defined below).

- **Direct** quantifies the impact on industries primarily affected by a change in economic conditions.
- **Indirect** quantifies the impact of a change in economic conditions on industries connected to primary industries through a supply chain.
- **Induced** quantifies the impact of a change in economic conditions on industries where workers employed by direct and indirect industries spend their income.

For example, consider a production quota, or limit, on the amount of crude oil extracted in California (see Chapter II.f.i. for further details on the production quota considered in this study). The quota will directly impact employment and compensation in the crude oil extraction industry by decreasing employers' demand for labor. Because the crude oil extraction industry is connected to the crude oil pipeline transportation industry through a supply chain, the production quota on barrels extracted also impacts employment and compensation in the pipeline transportation industry. These are indirect impacts. Finally, because the production quota has a direct impact on employment and compensation of workers in the crude oil extraction industry and an indirect impact in numerous other industries, these impacted workers will likely change their spending patterns, affecting additional industries that they financially support (e.g., food and accommodation services). The impacts that occur through changes in spending patterns are induced effects.

In this report, the total impact of a scenario refers to the sum of the direct, indirect and induced impacts. We quantify the direct, indirect and induced impacts associated with each scenario on employment and total compensation. Employment refers to full-time equivalent (FTE) job-years. Following IMPLAN's definition, we classify full-time employment as working 2,080 hours in a year (16). Furthermore, a job-year refers to the number of jobs supported by an industry for one year. For example, if a scenario leads to a decrease of one FTE job-year in the California crude oil extraction industry, this can be interpreted as a loss of either one full-time employee working one year, two full-time employees working six months, or any other equivalent combination of employees and months. This measure differs from employment counts that are reported by agencies, such as the U.S. Bureau of Labor Statistics and California's Employment Development Department. These employment counts capture the number of workers employed by an industry at a given point in time. For example, reported employment of 5,000 in the oil and gas extraction industry for Quarter 1 of 2020 indicates that there were 5,000 workers in this industry at that time. These workers could be full- or part-time and the employment measure does not capture how long the jobs will last. In this study, total compensation reflects the total payroll cost of employees, including wages and salaries, benefits and payroll taxes (17).

This report estimates the employment and total compensation impacts for each of California's 58 counties. We use IMPLAN's Multi-Regional Input-Output (MRIO) model to account for indirect and induced impacts that occur through inter-region supply chains and spending patterns. The MRIO model uses current data on inter-region supply chains, commuting patterns and spending patterns to quantify indirect and induced impacts. Because the MRIO model is highly computationally intensive, we use it to quantify inter-regional economic linkages across seven regions of California. Figure II.2. displays the seven regions that are based on the 10 California Census regions. We combine Census regions 1 and 2, 8 and 9, and 7 and 10 in our analysis. We assign regional impacts to the county-level using each county's share of regional total employment in 2019. Section 6 of the Technical Appendix provides more detail on the MRIO analysis and the projection of county-specific impacts.

There are important limitations to IMPLAN, and the input-output analysis has broad limitations that are important to note. First, IMPLAN reports impacts on FTE employment and worker compensation at the county level by industry. More disaggregated analyses, for example, at the census tract-level by industry, are not possible. Further, the FTE employment and worker compensation impacts are not available by occupation or worker characteristics (e.g., blue collar vs. white collar, educational attainment, union status, contracting arrangement). We are not aware of any input-output modeling software that includes this level of detail. Further, the model is static; after an initial shock (e.g., a decrease in demand for crude oil refining activity in Los Angeles County) relative prices are fixed and do not readjust to new economic circumstances. Within the IMPLAN model, displaced workers do not relocate to other industries, and more broadly, general equilibrium effects are not modeled. Production functions and the state of technology are also assumed to be constant. Thus, the 2020–2045 projections in this study reflect the static nature of IMPLAN and do not take into account factor price and quantity readjustment, and technological progress. In addition, indirect effects only reflect the economic interconnections between industries as they are observed historically. For example, any employment impact of a future program to plug and secure abandoned oil wells cannot be estimated with our approach and are not considered in this analysis.

In order to estimate labor market impacts, we specify which industries experience direct, indirect and induced impacts that result from changes to the crude oil extraction and refining segments. Table II.1. presents North American Industry Classification System (NAICS) codes for industries within the TFFSS used in this study and highlights which industries are included in each reported impact. IMPLAN uses its own industry classification system, which includes 546 industries and is loosely based on NAICS. For each NAICS code, we report the corresponding IMPLAN industry code, the TFFSS segment it belongs to, the type of impact it contributes to (e.g., direct, indirect/induced), and whether it is included in the total compensation and job-years supported by the TFFSS in 2019.

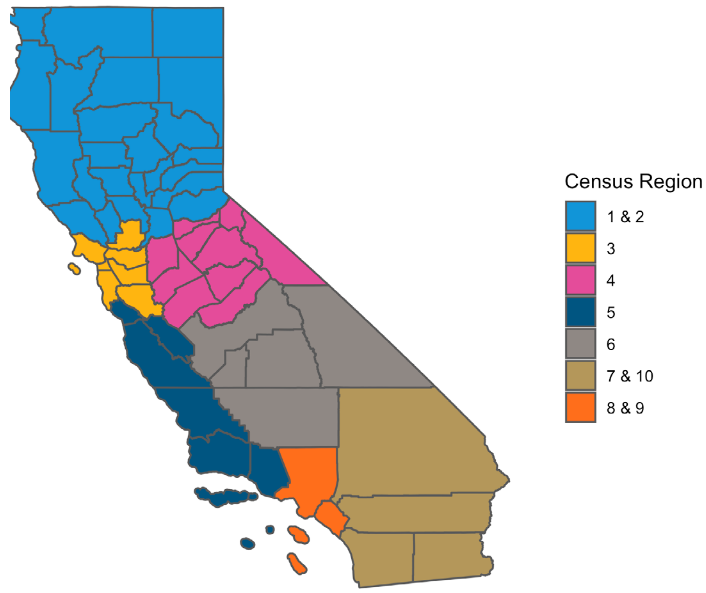


FIGURE II.2. Regions of California used in the Multi-Regional Input-Output (MRIO) analysis to quantify labor market impacts.

TABLE II.1. Transportation fossil fuel supply sector industry classification in NAICS and IMPLAN used in this study

Industry	NAICS Code	IMPLAN Code	IMPLAN Industry	Segment	Indirect or Induced Effect?	Direct Effect?
Crude Petroleum Extraction	211120	20	Oil and Gas Extraction	Ext.	Yes	Yes
Nautral Gas Extraction	211130	20	Oil and Gas Extraction	Ext.	Yes	Yes
Drilling Oil and Gas Wells	213111	35	Drilling Oil and Gas Wells	Ext.	No	Yes
Oil and Gas Pipeline Construction	237120	n/a	n/a	Dist.	No	Yes
Pipeline Transp. of Crude Oil	486110	419	Pipeline Transportation	Dist.	No	Yes
Pipeline Tranps. of Refined Petroleum Products	486910	419	Pipeline Transportation	Dist.	No	Yes
Petroleum Products Merchant Wholesalers	424720	399	Wholesale- Petroleum Products	Dist.	No	Yes
Petroleum Bulk Stations and Terminals	424710	399	Wholesale- Petroleum Products	Dist.	No	Yes
Petroleum Refineries	324110	154	Petroleum Refineries	Ref.	Yes	Yes
Ethyl Alcohol Manufacturing	325193	163	Other Basic Organic Chemical Mfg.	Ref.	No	Yes

Ext. = extraction segment, Dist. = distribution segment, Ref. = refining segment

Although the NAICS code for oil and gas pipeline construction does not have an IMPLAN industry code associated with it, our labor market impacts analysis captures indirect or induced impacts on this industry. Because the scenarios considered in this study affect crude oil extraction and refining, these are the only directly impacted industries in our analysis. Indirect and induced impacts analyses through IMPLAN capture the labor market effects associated with each scenario on all industries in the TFFSS and all other industries within California that are economically connected to the TFFSS.

Concordance between data in QCEW and IMPLAN

To ease comparisons between TFFSS labor market impacts described in this report and the chapter on current TFFSS labor market characteristics presented in this study's Synthesis Report, we reconcile the data on TFFSS FTE job-years and total compensation in IMPLAN with the labor market information reported in the Study 2 Synthesis Report (see Chapter I.b. for further information on the Synthesis Report), which is taken from the Quarterly Census of Employment and Wages (QCEW). The Synthesis Report reports employment counts and total compensation directly employed by the TFFSS because information on inter-industry economic linkages is not available in the QCEW data. Therefore, the employment and total compensation figures reported in the Synthesis Report are only comparable to the direct effects presented in this report.

In addition, there are two remaining sources of discrepancies between the direct job-years and total compensation in this report and labor market indicators from this study's Synthesis Report (see Chapter I.b.). First, the Synthesis Report uses administrative data from the QCEW that reports employment and compensation for all private firms covered under federal unemployment insurance programs (i.e., excluding self-employed individuals or proprietorships). IMPLAN, however, supplements the QCEW data with additional data on establishments that are not covered by federal unemployment insurance programs using data from the Census' County Business Patterns data files. Second, IMPLAN reports FTE 'job-years' rather than employment counts, whereas the QCEW reports employment counts only. Whereas employment refers to the number of part- or full-time workers formally tied to a firm at a point in time, FTE job-years refer to the number of full-time jobs supported by a firm for one year.

E. / QUANTIFYING HEALTH IMPACTS

We now briefly describe the conceptual framework and methodology underlying the health impact analysis (see Section 5 of the Technical Appendix for further details on health impact analysis methods). The goal of the health impact analysis is to estimate projected health outcomes associated with emissions from the TFFSS under the business-as-usual scenarios (E-BAU, R-BAU) and the low carbon scenarios (LCE1, LCE2, LCR1, LCR2) across California from 2019 to 2045 (see Table IV.1. for further information on scenarios). The difference in the estimated health outcomes between low carbon TFFSS scenarios and the BAU scenarios is interpreted as the net health impact of the low carbon scenario.

The projected extraction and refining production quantities under the BAU and low carbon scenarios are the first input in the health impact analysis. The scenarios are combinations of macroeconomic conditions up to 2045 (i.e., the future crude oil price path), and statewide decarbonization policies for the extraction and refining segments. More details on the parameters used in constructing the scenarios are available in Chapter II.f. and Chapter II.g.

In the next step, we derive the projected level of production in extraction and refining associated with the BAU and low carbon scenarios using the supply-side production models described in Chapter II.a. and II.b. from 2019 to 2045. From the application of the model, we obtain a projected level of extraction in barrels per year at the field-level for 262 fields in California, and a predicted level of refining in barrels per year at the site level for the 16 refineries sites in California.

These production quantities at the site level and by year from 2019 to 2045 are the main inputs in the health impact analysis. In the health impact analysis, we: (i) convert quantities of extracted crude oil and refined fuels into $PM_{2.5}$ and $PM_{2.5}$ precursors (NO_x, SO_x, VOCs, NH_3) and toxic air contaminant (TAC) emissions; (ii) model exposure to ambient $PM_{2.5}$ and other pollutants; and (iii) quantify the health impacts of exposure.

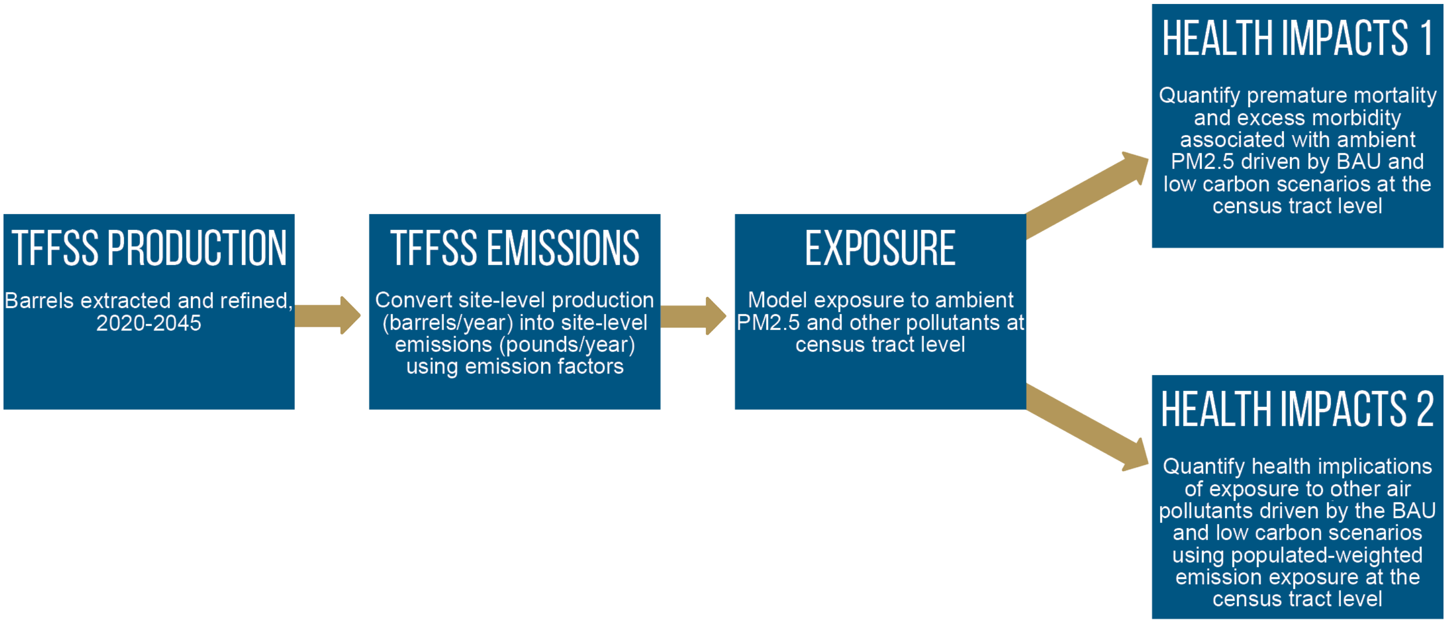


FIGURE II.3. Conceptual framework for the health impact analysis.

These production quantities at the site level and by year from 2019 to 2045 are the main inputs in the health impact analysis. In the health impact analysis, we: (i) convert quantities of extracted crude oil and refined fuels into $PM_{2.5}$ and $PM_{2.5}$ precursors (NO_x, SO_x, VOCs, NH_3) and TAC emissions; (ii) model exposure to ambient $PM_{2.5}$ and other pollutants; and (iii) quantify the health impacts of exposure.

Emission factors

In order to model how changes in crude oil extraction and refining driven by the BAU and low carbon scenarios affect emissions of $PM_{2.5}$, $PM_{2.5}$ precursors (NO_x, SO_x, VOCs, NH_3) and TACs, we use estimates of emission factors—the amount of pollutant emitted per barrel of crude oil extracted or refined—for extraction and refining. For emission factors for emissions of $PM_{2.5}$ and its precursors, we rely on published scientific estimates for refining and extraction activities (18), which are reported in Section 5 of the Technical Appendix. To the best of our knowledge, there are no published emission factors for TACs in the scientific literature. Therefore, we use California Emissions Inventory Development and Reporting System (CEIDARS) data on emissions from reporting facilities matched with oil fields and refineries and calculate the emissions per barrel extracted or refined using data for the 2008–2016 period. The estimated emission factors for TACs are reported in Section 5 of the Technical Appendix. Due to data limitations, we cannot adequately estimate the emission factors for all TACs released by extraction and refining sites in California.

Modeling exposure to ambient $PM_{2.5}$

The health impact analysis focuses first on quantifying primary emissions of $PM_{2.5}$ along with secondary emissions from precursor criteria pollutants (NO_x, SO_x, VOCs, NH_3) from the TFFSS under the BAU and low carbon scenarios. We focus on the health impacts of ambient exposure to $PM_{2.5}$ because of its well-documented negative effects on health, including premature mortality, increased incidence of heart and lung problems, and severe acute effects (e.g., increased risk of heart attack and congestive heart failure). Moreover, the main long-term human health effects from NO_x, SO_x, VOCs, and NH_3 emissions operate through their role as precursors of secondary $PM_{2.5}$ and ozone. For these reasons, as described in the Synthesis Report, the majority of air quality impact evaluations performed by leading agencies, including the U.S. Environmental Protection Agency (U.S. EPA) and CARB, focus on $PM_{2.5}$.

We project $PM_{2.5}$ emissions associated with a given scenario and convert them into exposure to ambient $PM_{2.5}$ across California at the census tract level using an atmospheric transport model that calculates both the primary and secondary release of $PM_{2.5}$. Specifically, we use the InMAP (Intervention Model for Air Pollution) model, which produces estimates of annual-average changes in primary and secondary $PM_{2.5}$. Importantly, InMAP uses physical and chemical information from the output of a state-of-the-science chemical transport model (19). Furthermore, InMap uses additional variables for calculating transport, including annual averages of wind vectors, wind speed, temperature, pressure, friction velocity, boundary layer height, dry and wet deposition rates, gas/particle phase partitioning for pollutants, and parameters relevant to the calculation of emissions plume rise. With this method, we project emissions by segment (extraction or refining), site and year. The atmospheric transport model is then coupled with individual characteristics of the emitters and their technology, such as stack height, temperature, diameter and velocity obtained by CARB.

The InMAP model produces a grid of ambient concentrations of primary and secondary $PM_{2.5}$. We then link the grid cells provided in InMap to census tracts in California. In cases where one census tract contains more than one grid cell, we assign the mean of the grid cells that correspond to the census tract. InMap has two options for calculating ambient concentrations of $PM_{2.5}$: a uniform 1.5 km grid resolution and a varying 1 km to 48 km grid resolution, where the lowest resolution is associated with urban areas (19). We use the grid resolution of 1 km to 48 km, given its faster computational time, where the threshold for population is 40,000 and the threshold for density is 0.0055—both the default values for InMap.

FIGURE II.4. Example of wind transport trajectories for a Los Angeles County refinery.

Quantification of health impacts associated with ambient $PM_{2.5}$ and its precursors

Our approach to predict health impacts from changes in exposure to ambient $PM_{2.5}$ associated with the modeled scenarios closely follows the methodology in the U.S. EPA BenMAP software (20). This approach is used by CARB and is standard for evaluating health impacts associated with changes in concentrations of ambient air pollutants (21). We recode the BenMAP software in the programming language R to allow for a census tract-level analysis, which is not readily available in BenMAP. This allows us to contrast health impacts across census tracts and compare impacts between disadvantaged and non-disadvantaged communities. Throughout this chapter we follow the definition of disadvantaged community from OEHHA's CalEnviroScreen 3.0, as census tracts that include populations with high exposure to cumulative pollution and who are particularly vulnerable to adverse health impacts due to socioeconomic and environmental factors, and label those as DACs. We estimate two categories of health impacts from changes in ambient $PM_{2.5}$ exposure: mortality effects and morbidity effects (non- fatal adverse health effects, such as hospital visits, emergency room visits, and number of asthma conditions).

We proceed in two steps: first we calculate the change in health outcomes (i.e., mortality and morbidity effects) associated with a change in ambient $PM_{2.5}$ concentrations, and second, we convert the changes in health outcomes in monetary values using the value of statistical life approach (VSL) or the willingness to pay (WTP) approach (when applicable). The value of statistical life is an estimate of willingness to pay for small reductions in mortality risks. The scientific literature also provides estimates of the WTP for small reductions in the risks of suffering non-fatal adverse health outcomes (22).

Step 1: **Estimating health impacts at the census-tract level.** For a census tract j, age-group α and year t, we calculate the change in health associated with the change ambient concentrations of $PM_{2.5}$ under a given BAU or low carbon scenario for year t as the following equation.

$$\Delta health_{j\alpha t} = population_{j\alpha t} \times \Delta rate_{j\alpha t}(baseline\_rate_{j\alpha t}, \beta_{\alpha}, \Delta PM_{2.5jt})$$

The five components of this equation are:

- Population: This term represents an estimate of the number of people affected by a change in ambient $PM_{2.5}$ concentration. In practice, $population_{j\alpha t}$ is the number of individuals in census tract j in age group α from the 2010 decennial census and projected to future time period t using age-group specific population growth rates at the county level from California Department of Finance population projections (see Section 5 in the Technical Appendix for additional information).
- $\Delta rate$: This term represents a function that estimates the percentage change in the risk of a health effect due to a one unit change in ambient $PM_{2.5}$ concentrations. This function can take a linear, log-linear or logistical form. The function depends in turn on the baseline incidence rate, β_{α}, and the change in ambient $PM_{2.5}$ concentrations.
- Health baseline incidence: The health baseline incidence rate is an estimate of the number of people who die prematurely or suffer from an adverse health effect in a given population over a year, under the baseline level of ambient $PM_{2.5}$ concentrations. We obtain baseline incidence data from BenMAP. For mortality incidence between 2019 and 2045, BeWnMAP uses both the U.S. Centers for Disease Control (CDC) WONDER database and the U.S. Census Bureau national mortality rate tables. Morbidity incidence rates are from the Healthcare Cost and Utilization Project.
- The coefficient β_{α}: β_{α} represents the percentage change in a health outcome associated with a 1 ug/m3 increase in $PM_{2.5}$ exposure for age group α. This parameter summarizes the concentration-response relationship between $PM_{2.5}$ and health outcomes. These coefficients come from epidemiology studies used by CARB to study the health effects of $PM_{2.5}$, and by the U.S. EPA's Regulatory Impact Analysis (RIA) for the National Ambient Air Quality Standards (NAAQS) for PM (23,24). These coefficients are assumed to be the same for all census tracts and time periods, in accordance with our review of the scientific literature (see Section 5 in the Technical Appendix for additional information and for a table summarizing the concentration-response parameters used in this study).
- $\Delta PM_{2.5}$: $\Delta PM_{2.5}$ represents the change in ambient concentrations of $PM_{2.5}$ under a BAU or low carbon scenario relative to a baseline with null ambient $PM_{2.5}$ concentrations. Changes in ambient $PM_{2.5}$ are driven by changes in direct emissions of $PM_{2.5}$ and by changes in the emission of precursors (NO_x, SO_x, VOCs, NH_3). We obtain the change in ambient $PM_{2.5}$ from the application of the InMap model. Ambient $PM_{2.5}$ should be interpreted as the difference between ambient $PM_{2.5}$ concentrations due to productivity activities in the TFSSS in a given scenario minus the (null) level of ambient $PM_{2.5}$ concentrations from the TFSSS if production activities in the sector were to stop.

The change in health outcomes for a given census tract in a given time period is the sum of the age-specific impacts for that census tract. We also calculate health outcomes at the census tract level separately for DACs and non-DACs, based on the CalEnviroScreen classification.

Step 2: Monetize the change in health outcomes. Following the standard approach in benefit-cost analyses of environmental policies conducted by the U.S. EPA, we use an estimate of the VSL to convert the changes in premature mortality associated with a given scenario to monetary values. The VSL does not correspond with the value of an individual life, but rather is derived from estimates of how much people are willing to pay for small reductions in the risk of dying from adverse health conditions caused by air pollution. We use the 2019 inflation adjusted value of the VSL of $9.4 million ($2019), which follows the U.S. EPA recommendation of $7.4 million ($2006).

The value of avoided morbidity impacts has two components: (1) the cost of illness (COI), such as the total medical cost plus the value of lost productivity, and (2) the willingness to pay (WTP) to avoid those health conditions. Because of the absence of WTP estimates for the four morbidity outcomes considered, we solely use COI estimates from the published scientific literature (25–27). We choose the estimates based on the approach and estimates used in U.S. EPA impact analyses to monetize morbidity outcomes. Therefore, the monetized morbidity impacts reported below should be interpreted as lower-bound estimates of morbidity costs. Further, we assume COI estimates will remain constant between 2019 and 2045 in the projections below.

Given an estimate of the VSL or of the valuation of morbidity health benefits, the monetized value of the change in health associated with a BAU or low carbon scenario at the census tract level is:

$$health\_benefits_{jt} = \Delta health_{jt} \times monetary\_value_{t}$$

We adjust monetized values of the health benefits in future periods according to income growth rates using national output projections from the Congressional Budget Office and the income elasticities used in BenMAP. Because the health benefits associated with projected BAU and low carbon scenarios will occur in the future (i.e., between 2020 and 2045), we convert future benefit estimates to present time values using a discount factor of 3%.

Exposure to TACs and related health impacts

A toxic air contaminant (TAC) is “an air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health” (28). As described in the Study 2 Synthesis Report (see Chapter I.b.), the health impact function approach used to quantify the health impacts associated with exposure to ambient $PM_{2.5}$ was not applied to TACs because of scientific uncertainties in β coefficients and estimating exposures.

Like in the Study 2 Synthesis Report, we focus on the nine TACs that have the highest toxicity-weighted quantity emitted in the TFFSS: formaldehyde, benzene, nickel, arsenic, cadmium, chromium, acrolein, PAH and 1,3-butadiene. The toxicity weights are defined by the U.S. EPA and account for both cancer and non-cancer health risks associated with exposure to the chemical compounds in TACs.

In order to construct a metric that captures the potential health impacts attributable to exposure of TACs, we construct a measure called the “population-weighted emissions exposure” (PWEE). The basic principle underlying PWEE is the assumption that the magnitude of health impacts associated with TACs and other air released pollutants should reflect the intensity of the release (i.e., the quantity emitted), the population at risk of exposure (i.e., how many people are residing close to the site where the emission occurred), and the distance to the refining or extraction site. A disadvantage of the PWEE measure is that it is better interpreted as an exposure measure as opposed to a health endpoint.

Therefore, we define PWEE for census tract *j* and year *t* as the product of the quantity of TACs emitted at a site in census tract *j* in year *t* and the population at risk of being exposed. In practice, we assume that the entire population living within 2 miles from a TAC-emitting extraction or refining site is at risk of being exposed. The 2 mile cutoff was determined based on the evidence about TAC air travel reported in published scientific studies (29).

To derive the PWEE, we calculate the distance from each TFFSS extraction and refining site to each census tract within 2 miles based on distance to the census tracts’ centroids. We obtain the TACs emitted, weighted by distance for each census tract, and multiply this value by the total census tract population to obtain the PWEE. Figure II.5. illustrates the methodology and results for two TFFSS sites in California: a refinery and an extraction site in Los Angeles County.

Panels A and B in Figure II.5. show the TFFSS site indicated with a red dot and bounding box. The gray boundary lines correspond to census tract boundaries. To compute the PWEE, we select all census tracts that intersect at any point with a 2 mile radius from the centroid of each TFFSS site. These census tracts with the 2 mile band are shown in blue in the figure, with darker shades indicating larger population in the census tract. Finally, we evaluate the distance between the centroid of each census tract in the blue region and the centroid of the TFFSS site. We construct the PWEE by multiplying the amount of TACs emitted by each site (in kg) with the population of each census tract in the 2 mile blue region, weighting the census tracts’ populations according to the inverse of the distance between the tract and the TFFSS site, so that the populations of census tracts closer to the TFFSS site are given more weight in the calculation.

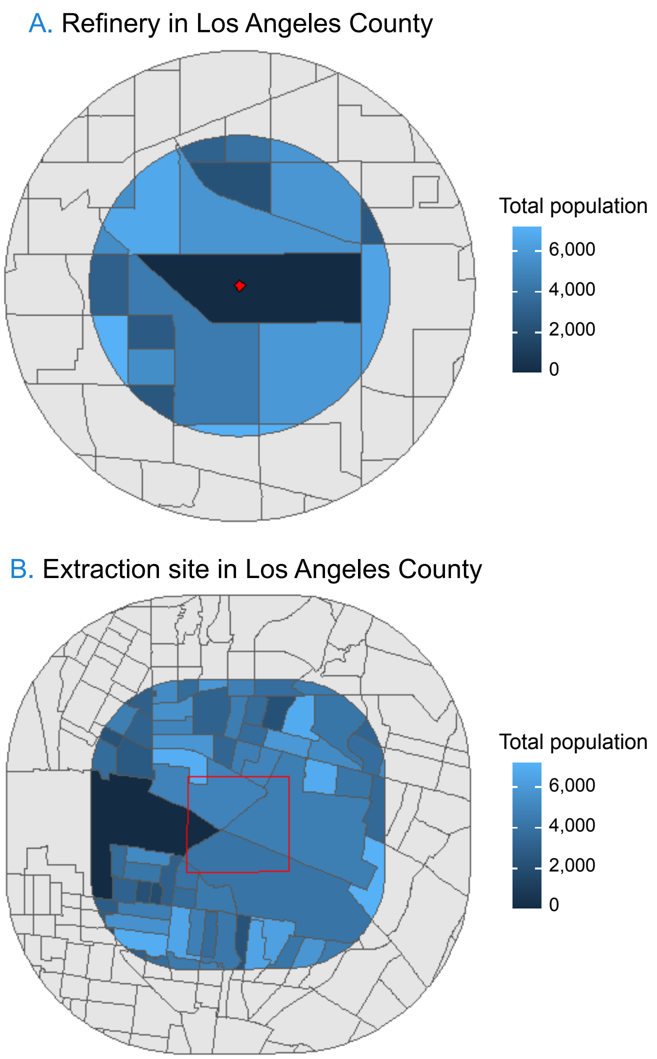


FIGURE II.5. Population-weighted emissions exposure (PWEE) and census tracts within 2 miles of transportation fossil fuel supply sector (TFFSS) sites (shown in blue).

F. / POLICY LEVERS

We seek to evaluate state-level policies specifically intended to reduce GHG emissions from the TFFSS within California. Within that set of decarbonization policies, we consider not just GHG emission consequences, but also a variety of economic and equity outcomes. To inform the choice of policies, we reviewed policy and legislative proposals, reports by research and consulting groups and academics, and proposed regulations both in California and elsewhere. Several key policy archetypes emerged that can reduce GHG emissions from this sector: limiting oil production through a production quota or a limit on the approval of new well permits, imposing an excise tax on oil production, and establishing a setback policy that requires a minimum distance between wells and sensitive areas.

Based on these archetypes, we design and implement two decarbonization policy levers in our model to explore the emissions, health and labor outcomes of differing policy approaches. The first lever is a quota, or limit, on the quantity of oil production from new and existing wells with auctioned production permits. This policy is equivalent to setting an excise or severance tax on crude oil extraction (see Section 7.1 of Technical Appendix). Second, we consider setting a setback distance between oil wells and sensitive sites. The motivation behind these policy levers and how they are implemented in our analysis are discussed below.

i. Production quota on in-state oil production

Motivation

Legislators, academics and non-governmental organizations (NGOs) have proposed limits on crude oil production and new oil well development in California through a number of mechanisms and to various degrees. In February 2019, Assemblymember Marc Levine introduced Assembly Bill (AB) 1440, which would have required the California Geologic Energy Management Division (CalGEM) to consider the impacts that proposed oil or gas wells would have on the environment and public health when reviewing an application for a new oil or gas drilling permit (30). More specifically, AB 1440 would have prohibited oil and gas permits when operations would create a risk of damage of life, health, property and natural resources, damage to underground oil and gas deposits from infiltrating water and other causes, loss of oil, gas or reservoir energy, or damage to underground and surface waters suitable for irrigation or domestic purposes by the infiltration of, or the addition of, detrimental substances. In October 2019, Governor Gavin Newsom vetoed AB 1440, stating that the bill is “unnecessary and does not go far enough in protecting public health and safety.”

Academics and NGOs have gone further to suggest ceasing the issuance of new oil well permits entirely, limiting new production in areas with disproportionate pollution vulnerability, or setting emissions thresholds or performance standards for new permits. The Berkeley Center for Law, Energy and the Environment’s Legal Grounds report identifies Colorado’s SB 19-181 as a potential example of a production quota to be improved upon for California, noting that the required publishing of permit rejection criteria has been delayed due to the contentious rulemaking process and in the meantime, local governments have been able to institute moratoriums on permits (31).

Implementation

A statewide limit on crude oil production could be achieved through a variety of policy mechanisms and implementation designs. For example, the state could auction off the rights to operate an oil well, where the number of auctioned rights is limited such that associated production does not exceed a desired level. Implementation of such a system would be similar to California's current auctions for compliance instruments for its cap-and-trade (C&T) program. As with the C&T program, such an auction would generate revenue for the state. Alternatively, the state could set a limit on the number of well permits that are provided to achieve the desired production level and distribute those permits for free with an allocation mechanism based on some given criteria, such as location, cost or historical operation.

We incorporate a production quota into our model by establishing an annual upper limit on statewide crude oil production. When total modeled production for a given year exceeds the quota, production from individual oil fields is removed until aggregate production is less than the quota. Production from the most costly oil fields is removed first until the production quota is satisfied. The removal of production on a least-cost basis is consistent with outcomes that would occur under a statewide auction of well permits. Methodological details are documented in the Section 7.1 of the Technical Appendix. Specifically, we consider the following four crude oil production quotas:

- 60% reduction: annual quota declines linearly from 2019 production (155.7 million barrels) to 40% of 2019 production (62.3 million barrels) in 2045
- 80% reduction: annual quota declines linearly from 2019 production (155.7 million barrels) to 20% of 2019 production (31.1 million barrels) in 2045
- 90% reduction: annual quota declines linearly from 2019 production (155.7 million barrels) to 10% of 2019 production (15.6 million barrels) in 2045
- 100% reduction: annual quota declines linearly from 2019 production (155.7 million barrels) to 0 barrels in 2045

Correspondence with excise taxes

The outcomes from a statewide crude oil production quota, achieved by phasing out oil fields from most to least costly by field, can be similarly obtained through an excise tax, or severance tax, on crude oil production set at an appropriate level. Section 7.1 of the Technical Appendix details the correspondence of these two policy mechanisms. This correspondence is important because excise taxes are also frequently proposed as mechanisms to address GHG emissions in the extraction segment, and, like a production quota with auctioned permits, an excise tax can generate revenue for the state.

Since 1981, statewide excise taxes on oil and gas extraction have been proposed over a dozen times in the California legislature and twice as initiatives proposed by California citizens. The majority of these proposals have been excise taxes on the gross market value of oil and/or gas. None of these attempts have succeeded, making California the only major oil producing state without an excise tax on oil production (32).

The details of excise taxes proposed in California and elsewhere, including the tax rate, exemptions, and use of revenue, have varied among proposals. Proposed tax rates for California oil production have varied between 6% and 15% of the gross market value of oil. The most recent proposal, SB 246 (33), would have set a 10% severance tax on oil and gas production, directing the revenues to the state's general fund. Thus far, proposed legislation in California has directed the tax revenue towards the state General Fund, education, state parks and disaster reserve accounts, but scholars have also suggested investing the revenues in climate mitigation and/or just transition efforts (31).

ii. Setbacks

Motivation

Mandating setbacks at the state level would restrict drilling activity within a specified distance of certain land uses. This policy approach would protect Californians from the local health risks associated with drilling and oil production. Proposals have varied in regard to the required distance of the setback, the land uses that the setback would protect, and whether the setback applies to future development or existing development. Commonly proposed protected sensitive receptors include residences, schools, playgrounds, daycare centers, elderly care facilities and hospitals. AB 345, the first and only oil and gas setback legislation proposed in California, proposed a 2,500-foot buffer zone between future well development and sensitive receptors when it was first introduced in February 2019 (34). The bill was later amended to delete the explicit distance requirement and to instead require CalGEM to set an appropriate setback distance.

Although the scientific community has yet to reach consensus on a safe distance between drilling and sensitive receptors, 2,500 feet is the most commonly used setback distance in policy proposals and is the distance suggested by the Berkeley Center for Law, Energy and the Environment's Legal Grounds report (31,35,36). Most research behind the need for a setback has focused on the impacts of oil and gas development on birth outcomes (37–40). A recent study of mothers residing in rural areas within 10 km of oil and gas development found that proximity of maternal residences to oil and gas development in California was associated with adverse birth outcomes, babies low in birth weight and small for gestational age (37). Research from outside of California indicates that the risk of inpatient hospital admissions, childhood leukemia, fatigue, migraines and depression increase with increasing density or proximity to unconventional oil and gas production (41). There is also growing research on the environmental justice implications of well locations, as people of color are disproportionately more likely to live within 1 mile of an oil or gas well than white people (42). In light of the scientific uncertainty around the health impacts and geographic extent of oil and gas well emissions, the Legal Grounds report emphasizes the importance of a statewide setback policy that allows for more stringent local rules (31).

Implementation

In our study, we evaluate three setback policy options that restrict new and existing production at 1,000 feet, 2,500 feet and 5,280 feet (1 mile) from sensitive sites, or areas in which people are more susceptible to the negative effects associated with exposure to toxic chemicals and pollutants. To forecast oil extraction under setback policy options, we determine which wells would be affected by each of the three setback distances. We use geospatial software to establish circular buffers at these three radial distances from sensitive sites, which include homes, schools, healthcare facilities, daycare facilities, elderly housing and playgrounds. Data representing sensitive receptors in California was created by the nonprofit organization FracTracker and last updated on July 28, 2020 (43). Wells that are within the setback buffers do not produce oil in the projection. Production from wells that are projected to enter in the forecast period are affected by setbacks through a reduction in production potential proportional to the percentage of a field that is covered by a given setback. For example, if a setback covers 50% of Field A, production from a new well predicted to enter Field A is reduced by 50%. Further implementation details are provided in Section 7.2 of the Technical Appendix.

iii. The impact of exports of finished crude-based products on refining demand

California refiners currently export a share of refined crude-based products out of the state (see Figure 24 in the Study 2 Synthesis Report). Predicting exports in future years and scenarios is very difficult, as it requires knowing how out-of-state demand and supply will change over time, as well as in-state demand and supply. Given this difficulty, instead of predicting exports, we consider three different cases for future exports for the 2020–2045 forecast period. In the first case, California refiners export refined products in an amount equal to the average annual volume of net exports during 2015–2019. In the second case, California refineries increase exports as in-state demand decreases, such that historical levels of total refinery production remain constant. Finally, in a third 'low' export scenario, refineries experience a linear decline in exports of gasoline, diesel and jet fuel from 2019 levels to zero by 2045.

G. / FUTURE MACROECONOMIC CONDITIONS

This section provides a summary of the future macroeconomic conditions considered in our model for the 2020-2045 projection period. Additional details about each condition are provided in Section 8 of the Technical Appendix.

i. Global oil prices

A key determinant of well entry and profitability is the crude oil price faced by extracting firms. As discussed in Chapter II.a., although California oil extraction firms may not be paid the global oil price, we use variation in global oil prices to capture global oil market conditions. Our model estimates oil field-specific responses to global oil prices using historical data, which allows us to project oil field-specific responses to future oil price changes and incorporate oil-field specific heterogeneity in oil quality.

Global oil prices are difficult to predict, as they are determined by local and global economic conditions. For example, the recent COVID-19 crisis induced unprecedented and unpredicted changes to the oil industry and prices. Given the difficulty of predicting future prices, this study draws on standard sources for projections of 2020–2045 crude oil prices and consider multiple oil price trajectories for sensitivity checks.

The central case for the oil price path is taken from the International Energy Agency's (IEA) delayed recovery scenario in the World Energy Outlook 2020 that was released in October 2020 and reflects recent expectations regarding the trajectory of global economic recovery under COVID-19 conditions (44). As alternative price paths, we also consider the Energy Information Administration's (EIA) Annual Energy Outlook 2020 (AEO2020) high, and low and reference oil price cases (45). AEO2020 was released in January of 2020 and thus does not provide crude oil price projections that reflect COVID-19 circumstances. Each oil price trajectory is shown in Figure 20 of the Technical Appendix.

ii. California carbon market allowance prices

Oil extraction firms and refineries are regulated by California's GHG cap-and-trade (C&T) program. The program introduces a carbon price, which alters the cost of production for regulated entities, including extracting and refining facilities. Because the C&T policy is an economy-wide policy, and not a TFFSS-specific policy, we view it as a macroeconomic condition in the context of our analysis. Future carbon prices are impacted by many factors, including future carbon abatement technologies, stringency of other climate change policies, and demand for carbon-intensive goods. Thus, rather than modeling carbon prices, we evaluate our model across three plausible low, middle and high carbon price paths during the 2020–2045 forecast period.

The low carbon price path follows the carbon price floor established in the C&T program. The high carbon price path corresponds to the price ceiling stipulated in Section 95915 of C&T regulation. The middle path follows the central estimate for the social cost of carbon determined by the United States Government Interagency Working Group on Social Cost of Greenhouse Gases in 2016 (46). Each carbon price trajectory is shown in Figure 23 of the Technical Appendix.

The low carbon price path could be induced, for example, by low oil prices, proliferation of low-cost carbon neutral technology, such as renewable energy, reduced costs or direct sequestration technologies, and other macroeconomic conditions that reduce demand for fossil fuels. A high carbon price path would arise in a setting in which demand for GHG intensive products and activities increases and costs of abatement technologies are high.

iii. Carbon capture and storage (CCS) costs

Carbon capture and storage (CCS) is a GHG mitigation technology that combines the capture of CO_2 from concentrated industrial (flue) sources with transport of CO_2 to suitable sites for permanent geological sequestration, either in deep saline formations or depleted oil and gas fields. The capture of CO_2 from industrial sources is well demonstrated and is currently taking place in 26 large-scale commercial projects around the world; most of these are for enhanced oil recovery (47). Permanent geological storage relies on injecting CO_2 into porous and permeable rock formations, wherein CO_2, at a temperature more than 31°C and pressure more than 7 MPa, typically found at a depth of over 800 m (2,700 feet), is converted to a supercritical fluid that has a similar density and viscosity as oil. The stored CO_2 is confined by overlying impermeable formations (caprocks) similar to those that have confined oil and gas for millions of years (47,48). California's geology is well suited for safe, permanent CO_2 storage, because deep saline (>10,000 ppm, approximately 30% of seawater salt content, and hence, not potable) aquifers that could trap dense supercritical CO_2 underlie a number of California's major geological basins, providing virtually unlimited storage, even after applying screening criteria, equivalent to 69,000 Mt CO_2, or 160 times California's current GHG emissions (47,48). California also has many depleted oil and gas fields that could provide additional, more limited storage of 2,000 Mt CO_2 (47). Potential geological storage that meets multiple screening criteria (e.g., excluding areas of seismic risk, sensitive habitats, high population density) is concentrated in the Central Valley and Ventura Basin, proximal to major industrial sources (47,48).

CCS is an example of a GHG mitigation option that could reduce emissions in the TFFSS under certain circumstances, such as the current incentives provided by the Low Carbon Fuel Standard (LCFS) and Section 45Q tax credit and/or higher carbon prices. Because CCS cannot be used to abate emissions from mobile sources (except indirectly through the use of Direct Air Capture), its application in the context of these studies is restricted to stationary-emitting facilities on the supply-side. Carbon capture technology is most effective and least costly when applied to point sources that have a relatively high concentration of CO_2 in the flue stream (49). In the TFFSS, these point sources include Combined Heat and Power (CHP) cogeneration units employed in both extraction and refining, as well as direct application to refineries producing both crude-based and renewable fuels (including ethanol), and hydrogen production.

Annual GHG emissions in the extraction segment in 2017 include 17.2 Mt CO_2e from all activities other than CHP and 3.6 Mt CO_2e from CHP used in extraction (see Chapter I.b.). CHP cogeneration is used extensively in California oil extraction to generate electrical power and steam for enhanced oil recovery (50). The estimated cost (low-central-high) of applying CCS to industrial CHP emissions is \$75-\$95-\$145 per tCO_2, which includes a capture cost of \$60 to \$131, a transportation cost of \$4 per tCO_2, and a storage cost of \$10 per tCO_2 (47). Annual GHG emissions in the refining segment in 2017 include 29.8 Mt CO_2e from activities other than CHP and 2.2 Mt CO_2e from CHP used in refining (see Chapter I.b.). The estimated cost (low-central-high) of applying CCS to refining emissions is \$70-\$80-\$85 per tCO_2, which includes a capture cost of \$58 to \$73, a transportation cost of \$4 per tCO_2, and a storage cost of \$10 per tCO_2 (47).

Given the uncertainties and difficulty of predicting future CCS prices, rather than predicting the future costs of CCS, we use the model to evaluate emissions outcomes under three alternative cases for the future costs of the CCS, based on the low, central and high aforementioned CCS cost estimates for oil fields and refineries. We interpret these estimates from the literature as averages across the oil fields and refineries in our model, respectively. Then, we estimate oil field- and refinery-specific CCS costs by developing a simple model of costs as a function of the oil field/refiner's total GHG emissions, where marginal costs of CCS are diminishing in total emissions quantity. Details of this procedure are provided in the Technical Appendix Section 7.

The current (December 2020) prices for LCFS credits are much higher than carbon prices under the C&T program: ~\$200 per ton CO_2 for LCFS vs. ~\$17 per ton for C&T (51,52), and if these higher LCFS prices persist, they would continue to provide stronger incentives for adoption as compared to the carbon price. Further, although the current C&T regulation does not include a protocol for CCS, our modeling approach considers that in the future entities regulated by the carbon price may be able to subtract any sequestered emissions from their compliance requirement (for further discussion on CCS in California's C&T program, see the California Decarbonization Partnership letter to CARB on Carbon Capture (2020) (53).)

For the purposes of this study, we did not consider CCS incentives provided by Section 45Q federal tax credits nor from the LCFS, which provides incentives for CCS adoption by allowing projects that sequester carbon to receive LCFS credits under the CCS protocol (54).

If an oil field adopts CCS, the benchmark GHG emission factor is reduced by an efficiency of 87.5%, which corresponds to a typical average capture efficiency (47). If a refinery adopts CCS, the benchmark GHG emissions factor is reduced by 58%, based on the high investment refinery scenario of Jing et al., 2020 (55).

This high-investment emissions reduction scenario for refineries includes the use of CCS at all possible process units that can generate CO_2, plus the adoption of both low-carbon electricity and steam. This scenario does not include capture of CO_2 associated with hydrogen production via steam methane reformation (SMR), which can contribute up to 30% of refinery emissions in California (56). Capture of SMR emissions represents another pathway to reduce refinery emissions, but because it was excluded by Jing et al (2020) in their comprehensive refinery analysis, we also excluded SMR emissions (55). Since our modeling excludes the incentives provided by LCFS and Section 45Q tax credits, we would expect to see faster and potentially broader uptake of CCS and thus lower GHGs from refineries than presented in this study.

iv. Innovation environment

Even in the absence of climate change policy, oil extraction firms and refineries are incentivized to improve their efficiency of production to lower operational costs. Efficiency improvements that reduce the quantity of polluting inputs used in production will also lead to a reduction in the emissions intensity of production. The model evaluates two innovation environments that govern the extent to which oil extraction firms and refineries can find new ways to reduce future operational costs and emissions intensities.

A low innovation environment preserves current levels of operational costs and emissions intensities in extraction and refining. This environment is consistent with a world in which the current energy and emissions intensities of production persist to 2045. A high innovation environment considers a world in which innovation leads to new technologies and/or increases productivity in extraction in refining that reduce the emissions intensities of these activities. Section 8.5 of the Technical Appendix provides further details.

H. / KEY LIMITATIONS AND IMPLICATIONS

This section describes several key limitations to our analysis. Some of these limitations arise from the specifications of our Scope of Work (SOW), developed in conjunction with CalEPA, whereas others are due to data limitations and/or inconclusive findings in the existing academic literature.

Limitation #1: Absence of energy price effects

Dramatic decarbonization of California's TFFSS will likely induce increases in final energy prices across California, whether that is the price of electricity, fossil-fuel based liquid fuels or renewable liquid fuels. For example, if the ramp down of crude oil production in California coincides with a similar ramp down of consumption in gasoline and other transportation fuels, then there is likely a demand shift from liquid fuels to electricity (via EVs) in the transportation sector. All else equal, a positive demand shift in electricity will raise electricity prices. Similarly, if policies considered in this report shift demand from fossil-fuel based liquid fuels to renewable liquid fuels in the transportation sector, the price of renewable liquid fuels will also increase. Such final energy price effects may be substantial. They are also an important input for understanding the overall welfare effect of any decarbonization policy, which will include not just changes to labor markets and air pollution, but also the energy prices faced by households. There may also be important distributional consequences as the energy share of household expenditures generally tend to be larger for poorer households.

Projections of final energy price effects require estimates of their own price demand elasticities for each final energy good, as well as cross-price demand elasticities. Such elasticities are not consistent with the fixed quantities of fuel demand obtained from Study 1. As such, final energy price effects cannot be projected in this current study.

Limitation #2: Absence of costs and benefits borne by other sectors

Efforts to decarbonize the TFFSS will likely lead to a shift in inputs to other sectors. For example, a phasedown of oil extraction may induce workers from that sector to eventually find jobs in other sectors that require a similar skill set. Likewise, reduced demand for gasoline may shift demand to electricity, which in turn may lead to increased pollution from electric power plants with associated health consequences. By focusing on the transportation sector in isolation, this study is unable to quantify the consequences borne by other sectors as a consequence of decarbonizing the TFFSS.

Limitation #3: Limitations in modeling the refining segment

Refineries are a major source of GHG emissions and local air pollution from the TFFSS, (accounting for 60% of GHG emissions, 77% of criteria air pollutants and 71% of TACs (see Chapter I.b.)). To fully model how decarbonization policies alter the economic and equity impacts from the refining segment, one needs detailed data on operating costs. Unfortunately, these data are not publicly available. As such, we develop a parsimonious modeling approach for refineries that does not require refinery cost data as inputs and thus does not allow refineries to respond to changes in costs.

Furthermore, refineries can respond to changes in shares of demand for refined products but technical constraints limit the maximum shares of each product. However, data on existing refinery configurations and potential changes to those configurations that would dictate the limits to future shares of refined products are unavailable. Further, data on limits to co-processing of renewable feedstocks in existing refineries are also not available. As such, we assume in our model that refineries are not constrained in their ability to respond to future demand for any mix of refined products or renewable fuels (e.g., renewable gasoline, diesel and jet fuel), except for their total rated processing capacity. In reality, refineries may hit limits on maximum shares of certain refined products (e.g., jet fuel), which may lead to imports of jet fuel into California and potential leakage of GHG emissions—a scenario that we do not capture in our analysis.

Our refinery modeling is based on the BAU and LC1 scenarios provided by Study 1 in October 2020. These fuel mixes were further refined by Study 1 as they finalized their report in late 2020, but we did not incorporate these subsequent changes into our modeling.

Existing refineries produce hydrogen as an input to their refining processes. Although hydrogen is a part of the future transportation fuel mix, as provided by Study 1, and refineries could potentially produce hydrogen for end use, we do not include hydrogen as a refinery end product in this analysis.

Limitation #4: Omission of the fuel distribution segment

Distribution of crude oil to refineries and distribution of refined products to end uses represent less than 1% and approximately 4% to 8% of lifecycle GHG emissions, respectively (see Chapter I.b.). These GHG emissions are not separately reported in CARB's GHG Inventory. Much of these emissions are captured under different sectors or segments in CARB's GHG Inventory; for example, emissions associated with electricity usage for pumps in pipeline transportation are reported under the electricity sector and those from transportation of crude oil and refined products by road, rail or barge are captured under the transportation end-use segment. To model the distribution segment will require detailed historical data on transport of fuels, which are not available. As such, we omit the crude oil and refined product distribution segment from our analysis.

Limitation #5: Omission of global consequences

Our analysis takes macroeconomic conditions outside of California as inputs. In other words, our model does not forecast macroeconomic conditions. This is for tractability. A full analysis of how TFFSS decarbonization within California may affect, for example, the global oil market, requires modeling the supply and demand curves of every other entity in the world. Instead, we assume that TFFSS decarbonization policies in California do not affect the global crude oil prices. Among other consequences, such a modeling restriction omits the possibility of global GHG leakage. Depending on California-specific and global oil supply and demand elasticities, different TFFSS decarbonization policies may in fact change the global oil price, which would then determine whether GHG reductions in California lead to GHG emission changes elsewhere. Similar complexities arise when considering the labor market and health consequences of California's TFFSS decarbonization policies beyond the state's boundary.

Limitation #6: Health impact estimates

Our health impact analysis only considers a subset of air releases of pollutants by TFFSS facilities. For emissions of primary $PM_{2.5}$ and its precursors (NO_x, SO_x, VOCs, NH_3), we quantify health impacts in terms of premature mortality and selected morbidity outcomes (e.g., hospital visits and non-fatal heart attacks). Due to the short timeline of this study, many additional health endpoints were not considered (e.g., incidence of low birth weight and other adverse birth outcomes). For emissions of TACs, scientific uncertainties and lack of data preclude the direct quantification of health impacts. Instead, we report a measure of population-weighted emission exposure (PWEE). Emitted pollution through water and land from TFFSS can have additional health impacts that are not documented in this report. Further, the estimated health impacts do not take into account the possible augmenting effect that climate change, in particular heat waves, can bring to health impacts due to air pollution. In addition, the health effects related to other externalities caused by the TFFSS, such as pipeline and storage tank leaks, fires, and water contamination, are not quantified. These omissions mean that the health impact estimates likely understate the true total effect of TFFSS pollution on health.

The health impact functions we employ also have limitations. The concentration-response parameters (β) taken from the scientific literature are estimated from samples that may not be representative of the population of California or be applicable to future time periods. The concentration-response parameters for mortality represent the long-term associations between health outcomes and $PM_{2.5}$, and so the results in Chapter VI do not capture the acute and short-term impacts of exposure on health. Some of the concentration-response parameters for morbidity outcomes are based on short-term associations and should be interpreted as such. Estimates of the concentration-response parameters in the literature use variation in exposure to ambient $PM_{2.5}$ that may not be representative of the variation observed across census tracts in California. Uncertainty in the estimates of the β parameters is not taken into account in the health impact analysis results. Estimates of the concentrations-response parameters are not available for specific sub-groups, including racial and ethnic groups, age groups, economically disadvantaged groups, and vulnerable populations. The estimates of the concentration-response parameters for $PM_{2.5}$ from the scientific literature may not accurately reflect the health effects of $PM_{2.5}$ emitted by TFFSS facilities.

The emission factors used in Chapter IV are estimates and subject to statistical uncertainty. As a result, the estimates of emissions of $PM_{2.5}$ and its precursors (NO_x, SO_x, VOCs, NH_3), and TACs by TFFSS facilities may not accurately reflect actual emissions that would occur under the scenarios. In our full model, we apply the InMap air transport model to emissions of $PM_{2.5}$ and its precursors for five-year increments. Values were linearly interpolated between each five-year estimate. Due to the limited timeline for this study and to data limitations, we cannot undertake the modeling of ozone formation, dispersal, and ultimately, health impacts. While known long-term health effects from exposure to ground-level ozone exist, modeling the complex changes in ambient ozone exposure from changes in emissions of air pollutants is beyond the scope of this study.

The projections from 2019 to 2045 on population, mortality rates and income produced by other agencies and used in the analysis may not accurately predict future populations and incomes. These projections may be less accurate for vulnerable populations. Further, the spatial resolution of the various data inputs to the health benefit calculations varies across data sources, which introduces statistical uncertainty in the estimates. As a result, census tract- or zip code-level estimates of health impacts should be interpreted with caution.

There are also limitations inherent to InMap. The baseline meteorological conditions used correspond to 2005 as in the standard application of the tool. Including current meteorological conditions could improve precision; however, it would increase the processing time considerably. Further, InMap mainly considers aerosols formed from anthropogenic sources rather than biogenic VOC sources. Finally, InMap adjusts for population grids, which could cause measurement errors in some areas, especially if they have a lower population. Alternative models, such as CMAQ, could be implemented in future studies and assess robustness.

Limitation #7: Omission of other benefits

This study focuses on the health benefits associated with a reduction in $PM_{2.5}$ and $PM_{2.5}$ precursors (NO_x, SO_x, VOCs, NH_3), which we can quantify in terms of changes in mortality and selected morbidity outcomes. We also consider changes in the exposure to TACs, although data limitations prevent quantification of mortality and morbidity effects associated with TACs. Other benefits are possible, such as health benefits due to improvements in water quality and ecological improvements from reduced oil extraction. Unfortunately, data limitations prevent this study from quantifying these potential benefits. Thus, any additional health impacts associated with the decarbonization of the TFFSS—except for those that arise through changes in ambient $PM_{2.5}$ and the TACs originating from extraction and refining sites—are not accounted for in this study. For example, reductions in ambient $PM_{2.5}$ stemming from decarbonizing the TFFSS may lead to increased productivity of workers who work primarily outside or in exposed settings, and improve educational outcomes for school-aged children. These omissions mean that the health impact estimates likely understate the true total benefit of decarbonizing the TFFSS.

Limitation #8: Labor impact analysis

There are several limitations and uncertainties associated with the labor impact analysis. Input-output impact analysis tools such as IMPLAN are based on many assumptions that may not be applicable to a given context (57). In particular, the IMPLAN model is static, so multipliers do not change over time or in response to changes in relative prices. This implies that the job-year and compensation impacts reported in this study assume that the supply chain linkages and spending patterns within and across regions of California do not change over time and reflect the state of the economy in 2018. Further, the projected labor market impacts do not capture any changes in supply chain linkages or spending patterns caused by implementation of a policy lever (or a macroeconomic condition, etc.) in the scenario analysis.

IMPLAN lacks job quality indicators. Information on employment or compensation by occupation, retirement packages and health benefits is not available, and so our analysis cannot provide an impact projection on these important outcomes. IMPLAN does not provide information about the time period in which an impact occurs. For example, if an industry experiences an increase in expenditures in year *t*, the year in which the impact occurs (e.g., *t*, *t*+1, etc.) is undetermined by the model. Therefore, we assume that all labor market impacts associated with changes in extraction and refining activity, as specified in the scenarios, occur between 2020 and 2045.

Further, input-output models like IMPLAN assume fixed input structure so that no input substitution occurs as conditions change. This assumption implies that indirectly impacted industries do not substitute transportation fossil fuels as the sector contracts. The model also assumes that each industry uses a unique combination of inputs to produce the commodities in fixed proportions that are constant over time. In addition, the multipliers used by IMPLAN are statistical estimates that are subject to sampling and modeling uncertainty, which is not accounted for in this analysis. Research also suggests that these multipliers routinely used in input-output are often too large, sometimes by as much as 25% (58). If the underlying multipliers are overestimated, the labor impact estimates reported in this study are likely to overstate the true total effect of projected TFFSS economic activity on labor outcomes.

Consistent with the scope of analysis for this study, we do not quantify the indirect and induced impacts on economies outside of California. Thus, this study captures the labor market impacts associated with each scenario within the boundaries of California. Any indirect and induced impacts on economies outside of California are not accounted for in this analysis.

Finally, the labor impact analysis does not model direct impacts on the TFFSS distribution segment, as in the rest of this report. Impacts on the TFFSS distribution segment are taken into account in the labor impact analysis that reports the total impacts inclusive of indirect (supply-chain) effects. Like the rest of this report, the labor impact analysis assumes no interplay between the extraction and refining segments; and therefore, labor impacts associated with extraction policies are independent of those associated with refining. Impacts associated with government spending of any revenues raised using the low carbon scenarios are also not accounted for.

Limitation #9: CCS cost and incentives estimates for California's TFFSS

There are currently no CCS projects in California, and the implementation of CCS in California presents many challenges (47). In this report, we do not speculate on whether those challenges, which are considerable, can be overcome. Most of the limitations outlined by the recent EFI-Stanford report on CCS opportunities in California are not technical in nature, but rather center on: 1) the ambiguity of state policies in encouraging project developers and investors; 2) the need for new planning and permitting requirements; 3) heavy dependence on public policy incentives, with consequent revenue and cost uncertainty; and 4) lack of public understanding and support of CCS.

The application of CCS to both the extraction and refinery segments in California is highly uncertain. A pathway for capturing CO_2 from various potential disaggregated sources in the extraction segment (e.g., CHP, steam generation) is not well established; the application of CCS to the extraction segment globally has been mainly for the purpose of enhanced oil recovery (EOR). Existing world-wide applications of CCS to refineries are limited to one oil refinery, one ethanol refinery and two hydrogen production facilities (59). Hydrogen production via steam methane reformation (SMR) can contribute up to 30% of refinery emissions (55). Because petroleum refining and hydrogen production are not always co-located in California, it is not known if both CO_2 streams could be captured.

Another uncertainty is whether CCS can also capture emissions of $PM_{2.5}$ and its precursors. Sour gases such as NO_x and SO_x are removed along with CO_2 by alkaline absorbing amines, but this can also inhibit CO_2 absorption (60). We have applied no assumption about criteria air pollutant removal because the technology is not yet proven.

An additional uncertainty in CCS costs regards the size of policy incentives supporting CCS adoption. Modeling in this study does not include all policies that could incentivize CCS adoption.

In this study, we model CCS adoption solely in response to carbon prices in the C&T program. We view these prices as reflecting the value of carbon abatement over time, which incentivizes CCS adoption. The current (December 2020) prices for LCFS credits are much higher than carbon prices under the C&T program: ~$200 per ton CO_2 for LCFS vs. ~$17 per ton for C&T (51,52). Through the established CCS protocol, LCFS provides strong additional financial incentives for CCS adoption (62). Federal tax credits through Section 45Q may also promote and facilitate CCS adoption. Further modeling is needed to better understand the specific impact of LCFS and other incentives on future CCS development and implementation in California.

Limitation #10: Forecasting technological change

As is typical of most projection exercises, it is difficult to forecast technological change, particularly in the form of the emissions (local air pollution and GHGs) and labor intensities associated with oil extraction and refinery production. Furthermore, limited time series data prevent us from reliably extrapolating past trends in emissions and labor intensities onto our projection period. Instead, we employ emissions and labor intensities from the most recently available year and assume these intensities are constant during our projection period. This implies that outside of changes in macroeconomic parameters that may be driven by technological change, our projections hold current technology levels fixed.

CHAPTER 3
SCENARIO ANALYSIS

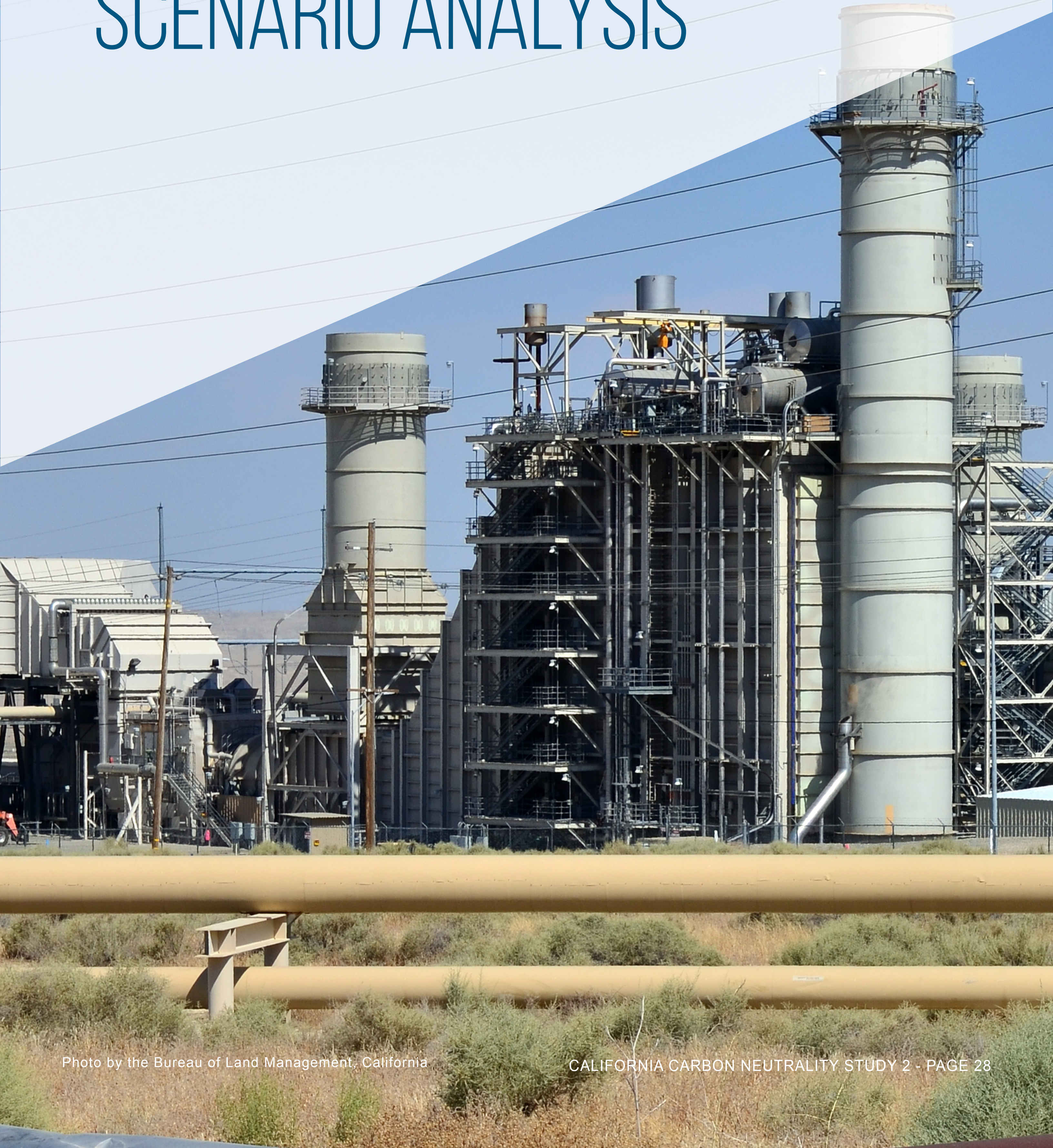


Photo by the Bureau of Land Management, California

There are many ways to reduce greenhouse gas (GHG) emissions in California's transportation fossil fuel supply sector (TFFSS). Each of those ways involves trading off health benefits and labor market impacts. Furthermore, each method leads to different equity outcomes.

For the extraction segment, the combination of macroeconomic conditions and policy levers considered allowed our model to generate 1,440 unique scenarios between 2019 and 2045. For the refining segment, the combination of macroeconomic conditions, policy levers and fuel demand projections from Study 1 generate 432 different scenarios between 2019 and 2045. We utilize 2019 as our baseline year for all comparisons with our model projections. To systematically examine these scenarios, we first consider effectiveness and equity consequences across policy levers, holding macroeconomic conditions to benchmark values. We then examine the effects of different macroeconomic conditions.

To facilitate internally-consistent comparisons across a large suite of scenarios, we employ a simplified version of our model with approximated labor and health impacts. These comparisons reveal broad patterns across policy levers and macroeconomic conditions and enable us to select particular scenarios for further study with our full model. Because outcomes are approximated, this step does not generate sufficiently fine-scale forecasted impacts for each of the hundreds of scenarios. More detailed quantification for selected scenarios using the full model are presented in Chapters IV, V and VI.

A. / FRAMEWORK FOR CONSIDERING TRADEOFFS

We consider decarbonization costs that arise from changes in employment in the TFFSS. We further consider benefits that arise from changes in local air pollution exposure due to TFFSS emissions. Other dimensions of costs and benefits are either limited by data availability or are outside of the scope of this study, which we detail in Chapter II.h.

Figure III.1. provides a schematic of this tradeoff between statewide total reduction in TFFSS employment (vertical axis) against statewide total reduction in air pollution exposure from the TFFSS for the 2019–2045 period. The dots represent illustrative outcomes for the purpose of explaining our framework and not actual modeled data. The no-policy, business-as-usual (BAU) case is indicated by the orange dot. Consistent with the decline in crude oil production across California since 1985, continued trends imply that employment and air pollution from TFFSS both fall in 2045 compared to 2019 even in the absence of additional decarbonization policies. The dark and light blue dots show the outcome of two illustrative policy scenarios. The dark blue dot shows changes in total employment and air pollution under policies that lead to moderate GHG reductions relative to BAU. The light blue dot shows changes in total employment and air pollution under policies that lead to greater GHG reductions relative to BAU. Figure III.1. makes clear that as GHG reductions increase, so too does the degree in which employment costs must be traded off against air quality benefits. Within this framework, we evaluate scenarios across two criteria: effectiveness and equity.

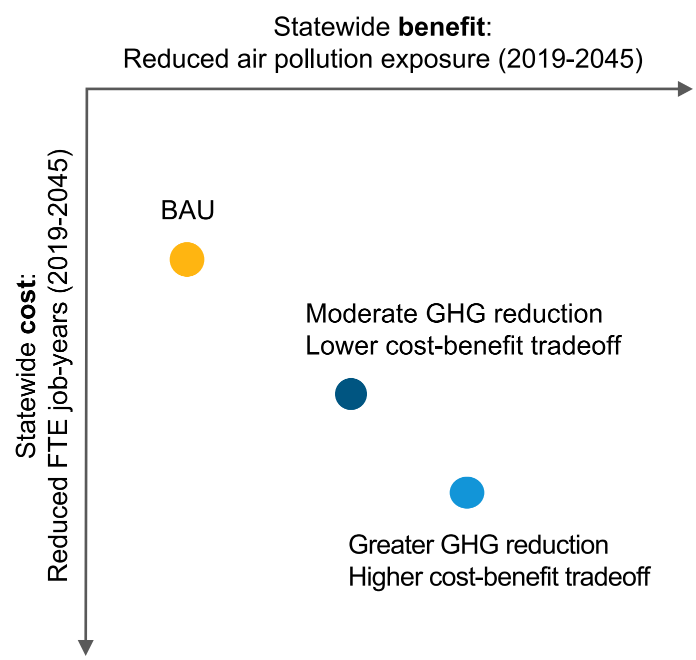


FIGURE III.1. An illustrative schematic showing statewide total reduced FTE job-years during 2019–2045 (vertical axis) trades off with statewide total reduced air pollution exposure during 2019–2045 (horizontal axis) across business-as-usual (BAU) (orange dot), moderate GHG reduction (dark blue dot) and greater GHG reduction (light blue dot) illustrative scenarios.

i. Effectiveness

Effectiveness examines the total cost across scenarios with the same total benefit. That is, it asks whether the same drop in statewide total air pollution exposure can be achieved with greater or less reductions in statewide total employment. More effective scenarios achieve the same drop in total air pollution exposure with smaller labor market impacts.

Effectiveness is illustrated in Figure III.2. Relative to BAU, two illustrative scenarios are considered. The dark blue dot shows a more effective scenario than the light blue dot. For the same reduction in aggregate air pollution exposure in 2045 compared to 2019, the dark blue dot indicates a scenario involving smaller labor market impacts.

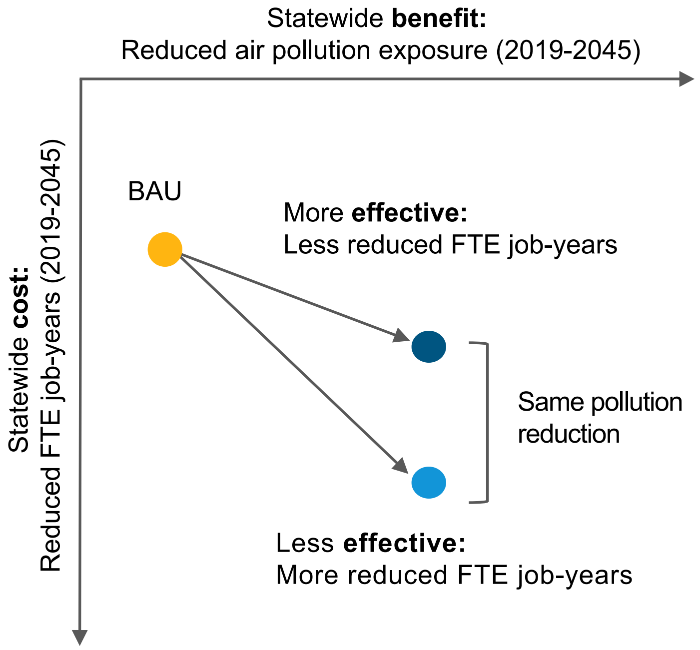


FIGURE III.2. An illustrative schematic showing statewide total reduced FTE job-years during 2019–2045 (vertical axis) and statewide total air reduced pollution exposure during 2019–2045 (horizontal axis). The orange dot shows the business-as-usual (BAU) scenario. The dark blue dot illustrates the more effective scenario compared with the light blue dot in that the former scenario achieves the same reduction in total air pollution exposure as the latter but with smaller labor market impacts.

ii. Equity

We next consider who benefits from a reduction in statewide total air pollution exposure across decarbonization scenarios. Specifically, we ask: are the air pollution exposure gains borne more by disadvantaged communities (DACs), who are historically exposed to more local air pollution from TFFSS and other sectors, or are those gains borne more by non-disadvantaged communities (non-DACs)?

Each panel of Figure III.3. illustrates a different manner in which statewide aggregate reductions in air pollution exposure are distributed across DACs and non-DACs. Across all panels, the horizontal axis is the statewide aggregate change in pollution exposure between 2019–2045. The vertical axis shows the pollution exposure in 2045. The dark blue line indicates the pollution exposure experienced by DACs and the light blue line indicates the exposure experienced by non-DACs. The difference between these two lines is the pollution exposure gap between DACs and non-DACs. This gap is generally positive reflecting existing inequities in pollution exposure: DACs are in general exposed to more air pollution non-DACs.

Across all three panels, pollution exposure for DACs and non-DACs are falling along with reduced total pollution exposure. What differs across the three panels is how much that decline in air pollution is borne by DACs. In the top panel, the DAC and non-DAC exposure lines are parallel implying that cleaner air is experienced equally in DACs and non-DACs. Because there is no change in the pollution exposure gap, the existing inequality in pollution exposure found in 2019 does not change in 2045.

In the middle panel, the drop in pollution exposure for DACs is larger than that for non-DACs. Under this scenario, there is an “equity co-benefit” that comes with reduced total air pollution. As total air pollution goes down, more of that gain flows to DACs such that the inequality in pollution exposure between DACs and non-DACs also falls.

Finally, in the bottom panel, the pollution exposure drop in DACs is smaller than that for non-DACs. While the entire state benefits from less pollution, the pollution exposure gap between DACs and non-DACs widens, implying a greater inequality in pollution exposure.

The following sections present our main findings from our projected scenarios. We begin by analyzing across scenarios along the effectiveness and equity criteria presented in this section, separately for the extraction and refining segments of the TFFSS. We first present findings under benchmark macroeconomic conditions

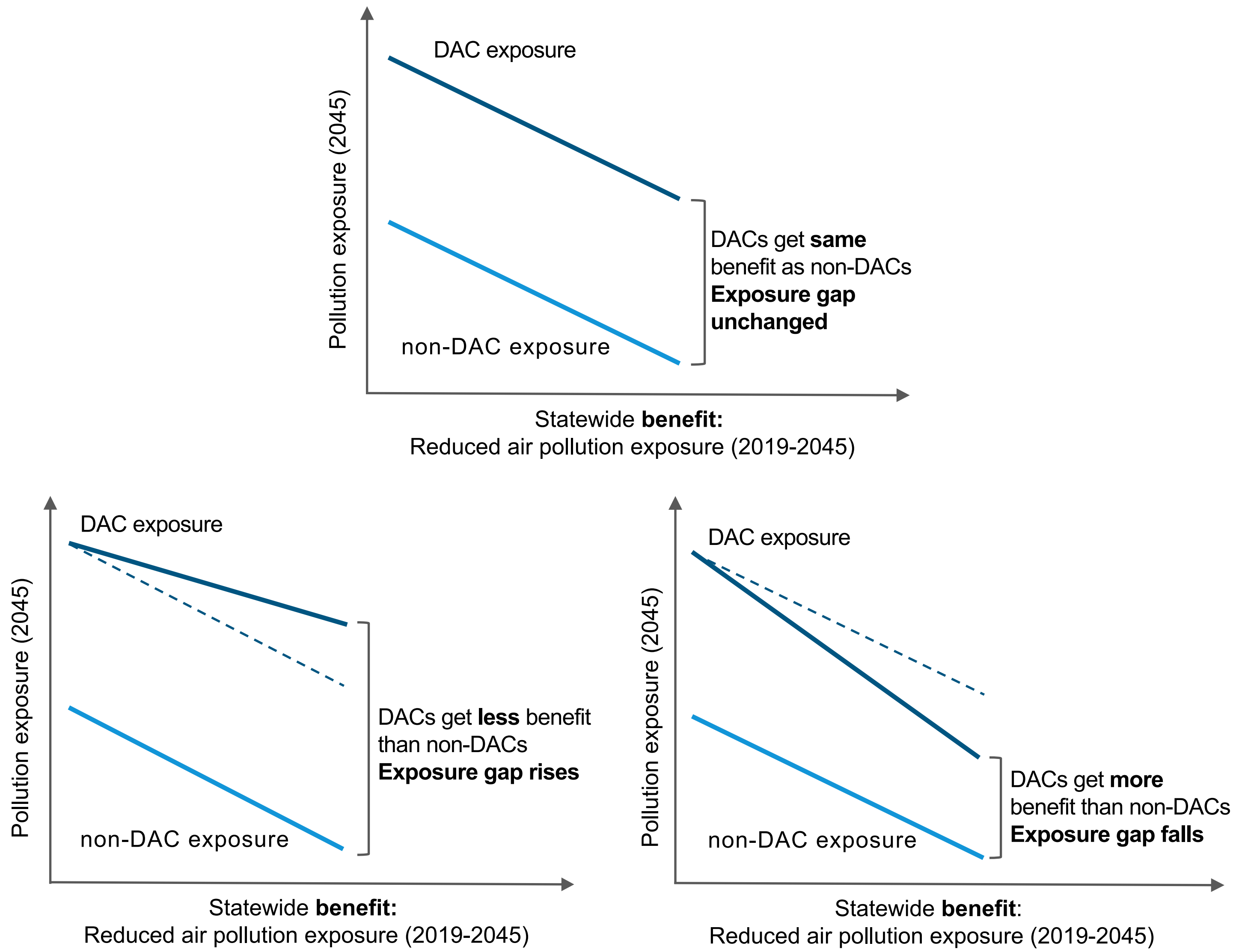


FIGURE III.3. Schematics illustrating how equity consequences are evaluated. The horizontal axis shows statewide total reduction in air pollution exposure between 2019 and 2045. The vertical axis shows air pollution exposure in 2045 by disadvantaged communities (DACs, in dark blue) and non-disadvantaged communities (non-DACs, in light blue).

and then examine the role played by alternative macroeconomic conditions.

Throughout, we present outcomes from individual scenarios from our modeled results with the same structure as that shown illustratively in Figures III.1. and III.2. In these plots, each dot represents a scenario, defined as a particular combination of policy and macroeconomic condition values. We vary the color of these dots to visually distinguish scenarios from each other. In some cases, dots differ in color according to values of a certain policy lever (holding other policy levers and macroeconomic conditions fixed) and in other cases colors indicate different values of a particular macroeconomic condition (holding other macroeconomic conditions and policy levers fixed). Finally, in some cases, we vary the size of these dots according to the percentage GHG reduction between 2019–2045 across the extraction segment.

The aim of this analysis is to discern broad patterns across the scenarios and to facilitate the selection of specific scenarios subject to more detailed analyses in Chapter IV, V and VI. Because of the approximated labor market and air pollution impacts used in these results, we emphasize that the value of projected outcomes in this chapter are more useful for broad comparisons across scenarios but should not be interpreted quantitatively. We leave quantitative answers to key outcomes for our detailed analysis in Chapters IV, V and VI.

B. / EXTRACTION SEGMENT

This section considers outcomes and policies within the extraction segment. Figure III.4. shows the percent change in statewide total employment between 2019 and 2045 (vertical axis) and the percent change in population-weighted statewide total pollution exposure between 2019 and 2045 (horizontal axis) for the no-policy business-as-usual extraction scenario (E-BAU) (orange dot) and across all combinations of production quotas and setbacks under benchmark macroeconomic conditions. Larger dots indicate larger GHG reductions between 2019 and 2045. Consistent with the historical decline in total California crude oil production since 1985, our model projects continued production decline out to 2045 even in the absence of additional decarbonization policies. This results in a projected 44% decline in GHG emissions from crude oil extraction alongside associated declines in total extraction employment and population-weighted total air pollution exposure. As decarbonization intensifies across scenarios, so does the reduction in total employment and air pollution exposure in the extraction segment.

Figure III.5. follows Figure III.4.'s structure but shows only scenarios that only alter production quota levels, which restricts statewide crude oil production in 2045 to 40%, 20%, 10% and 0% of 2019 levels with linear declines between 2019 and 2045. The order in which oil fields exit production is determined by cost of production (as detailed in Chapter II.f.i. and Technical Appendix Section 7.1). That is, more costly oil fields leave production first, followed by less costly fields, as statewide total crude oil production declines. Figure III.5. shows that lower production quota levels increase GHG emissions decline between 2019 and 2045. Lower production quotas also intensify the degree in which reductions in total employment tradeoff with reductions in total pollution exposure.

As an alternative way to present this tradeoff, the

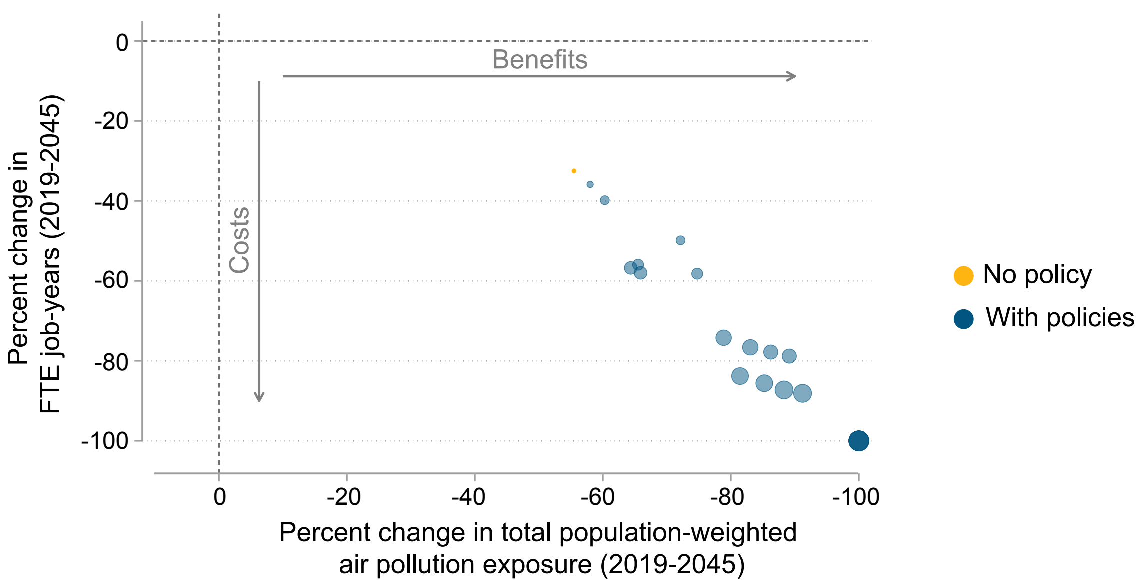


FIGURE III.4. The vertical axis shows the percent change in statewide total FTE job-years between 2019 and 2045. The horizontal axis shows the percent change in statewide total population-weighted air pollution exposure between 2019 and 2045. Each dot represents outcome from a different scenario. The orange dot represents the no-policy, or extraction business-as-usual (E-BAU), scenario. Each blue dot represents a different scenario varying production quotas and setback distance. The size of each dot indicates the magnitude of percent change in GHG emissions between 2019 and 2045. All scenarios assume benchmark values for macroeconomic conditions.

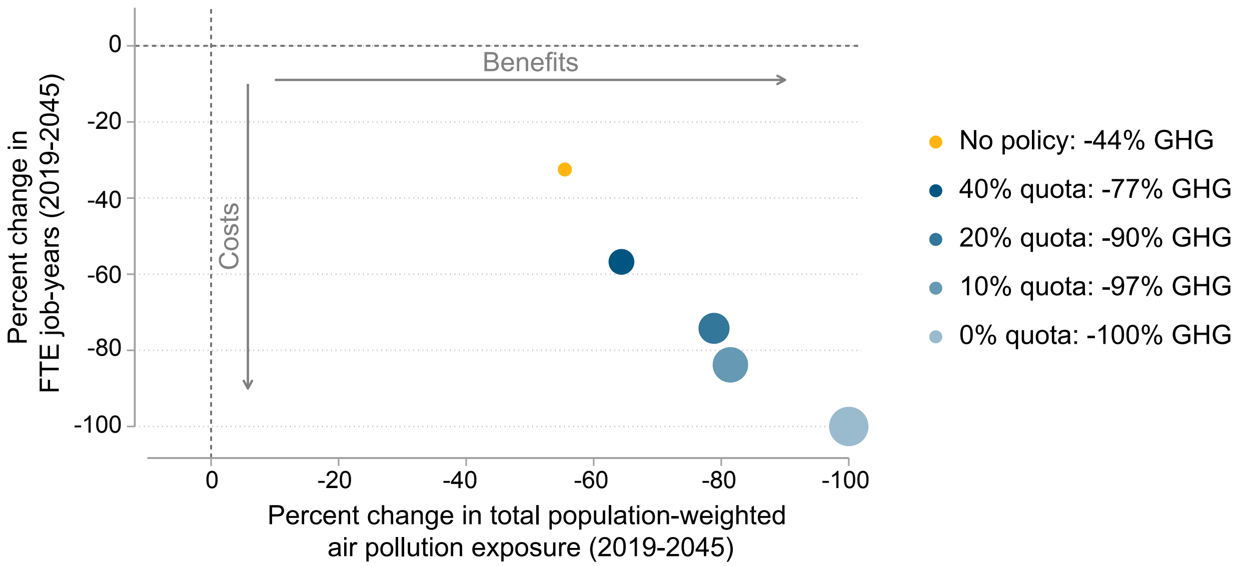


FIGURE III.5. The vertical axis shows the percent change in statewide total FTE job-years between 2019 and 2045. The horizontal axis shows the percent change in statewide total population-weighted air pollution exposure between 2019 and 2045. Each dot represents outcome from a different scenario. The orange dot represents the no-policy, or extraction business-as-usual (E-BAU), scenario. Each blue dot represents a different production quota scenario with GHG emissions in 2045 ranging from 40%, 20%, 10% and 0% of 2019 values (and assuming a linear decline between 2019 and 2045). The size of each dot indicates the magnitude of percent change in GHG emissions between 2019 and 2045 (also indicated in the legend). All scenarios assume benchmark values for macroeconomic conditions.

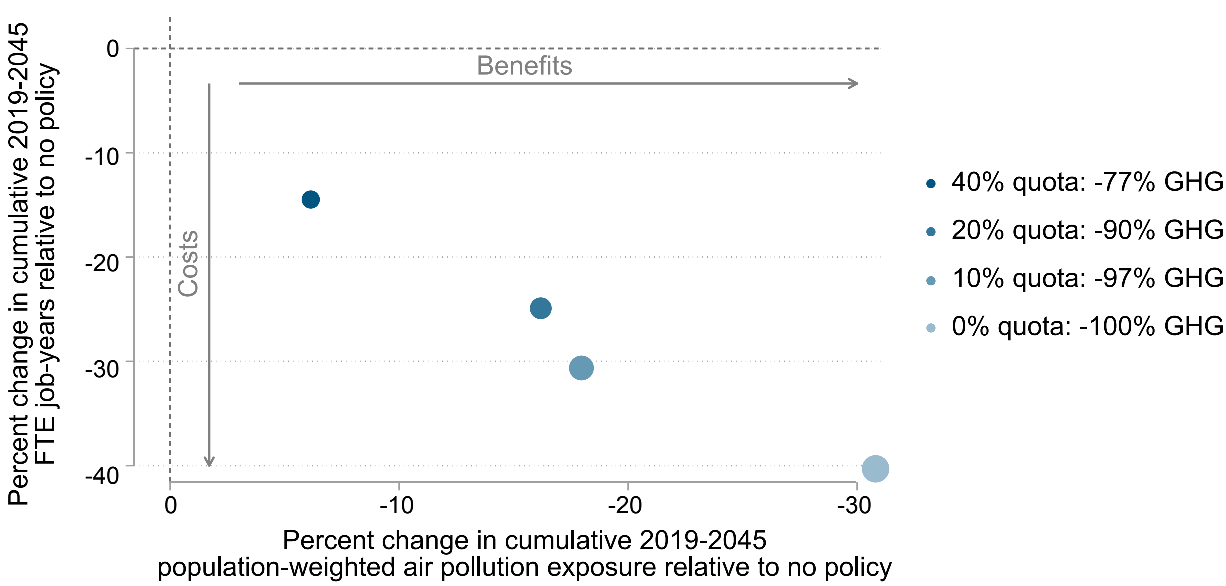


FIGURE III.6. The vertical axis shows the percent change in 2019–2045 cumulative total FTE job-years under production quota scenarios relative to the no-policy scenario. The horizontal axis shows the percent change in 2019–2045 cumulative total population-weighted air pollution exposure under production quota scenarios relative to the no-policy or extraction business-as-usual (E-BAU) scenario. Each blue dot represents a different production quota scenario with GHG emissions in 2045 ranging from 40%, 20%, 10%, and 0% of 2019 values (and assuming a linear decline between 2019 and 2045). The size of each dot indicates the magnitude of percent change in GHG emissions between 2019 and 2045 (also indicated in the legend). All scenarios assume benchmark values for macroeconomic conditions.

vertical axis of Figure III.6. shows the percent change in cumulative employment between 2019 and 2045 for each production quota scenario relative to cumulative employment during the same period under the no-policy E-BAU scenario. Likewise, the horizontal axis of Figure III.6. shows the percent change in cumulative total population-weighted pollution exposure under each production quota scenario relative to that under the no-policy E-BAU scenario.

Figure III.7. presents the same cost-benefit tradeoff, but for changes in setback distances only, ranging from 1,000 feet, 2,500 feet, to 5,280 feet (1 mile). As expected, there is greater decline in GHG emissions with larger setback distances, which is accompanied by larger decreases in employment and total pollution exposure. Figure III.7. suggests that achieving dramatic decarbonization goals by 2045 is not possible with a setback distance of 2,500 feet. Doubling that setback distance to roughly 1 mile also does not achieve greater than 60% decarbonization. Thus, at least for the setback distances considered, setbacks alone cannot achieve dramatic decarbonization, but must be applied together with production quotas. Figure III.8. presents these tradeoffs for cumulative 2019–2045 total FTE job-years and total population-weighted pollution exposure under each setback scenario relative to the no-policy E-BAU scenario.

Thus, we turn next to equity and effectiveness considerations when both policies are considered.

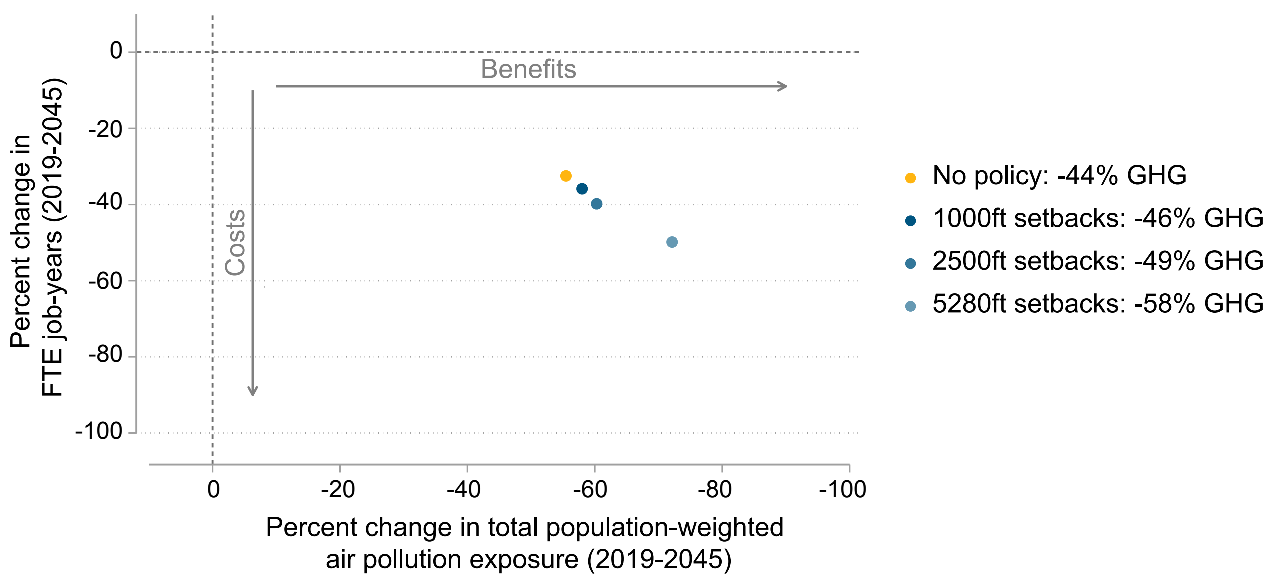


FIGURE III.7. The vertical axis shows the percent change in statewide total FTE job-years between 2019 and 2045. The horizontal axis shows the percent change in statewide total population-weighted air pollution exposure between 2019 and 2045. Each dot represents outcome from a different scenario. The orange dot represents the no-policy, or extraction business-as-usual (E-BAU), scenario. Each blue dot represents a different setback scenario with setback distances ranging from 1,000 feet, 2,500 feet, to 5,280 feet (or 1 mile). The size of each dot indicates the magnitude of percent change in GHG emissions between 2019 and 2045 (also indicated in the legend). All scenarios assume benchmark values for macroeconomic conditions.

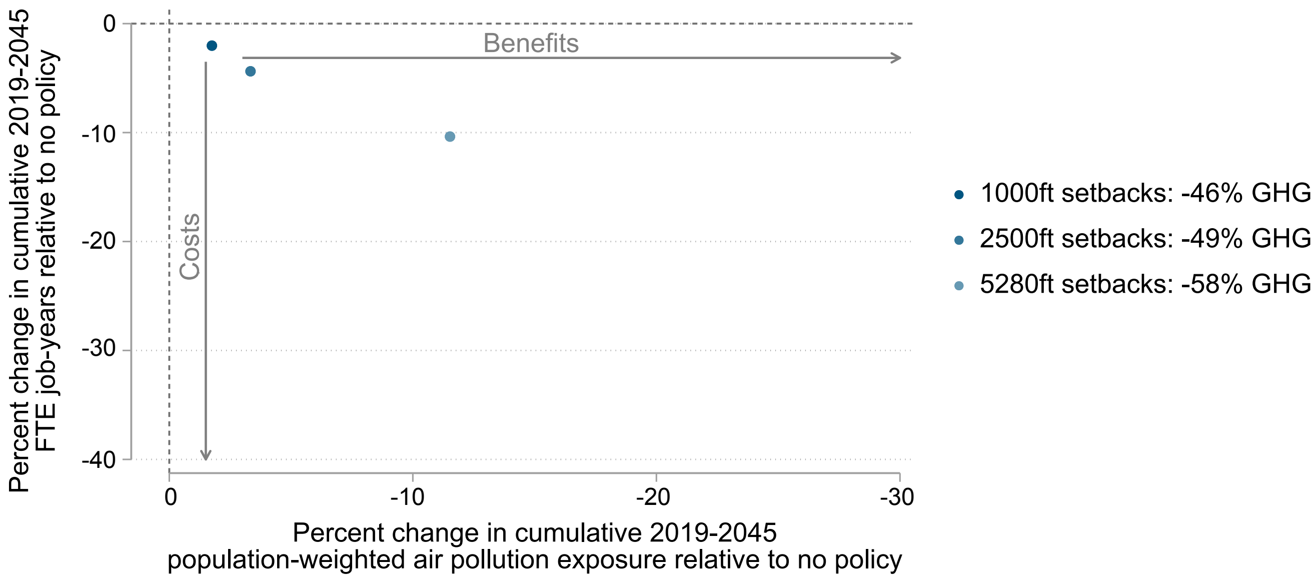


FIGURE III.8. The vertical axis shows the percent change in 2019–2045 cumulative total FTE job-years under setback scenarios relative to the no-policy scenario (E-BAU). The horizontal axis shows the percent change in 2019–2045 cumulative total population-weighted air pollution exposure under setback scenarios relative to the no-policy scenario (E-BAU). Each blue dot represents a different setback scenario with setback distances ranging from 1,000 feet, 2,500 feet, to 5,280 feet (1 mile). The size of each dot indicates the magnitude of percent change in GHG emissions between 2019 and 2045 (also indicated in the legend). All scenarios assume benchmark values for macroeconomic conditions.

i. Equity and efficiency tradeoffs within extraction segment policies

In the beginning of this chapter, we defined the effectiveness of a scenario as the change in employment associated with a given decline in total pollution exposure. A more effective scenario is one in which a given decline in total pollution exposure can be achieved with smaller total labor market impacts.

We consider effectiveness in Figure III.9. by examining how the introduction of setbacks of varying distances alter labor market impacts when introduced together with a production quota. Each line represents a different setback distance. Observe that for a given drop in total air pollution exposure, adding setbacks of increasing distance lead to smaller labor market impacts. Table 8 in the Technical Appendix suggests a possible explanation for this pattern. It shows that across oil fields, fields with a greater share of its area that would exit production under setbacks are also in counties with fewer TFFSS employees in 2019. That is, oil fields more affected by setbacks are also those that employ fewer workers. This negative relationship becomes more pronounced as setback distance increases from 1,000 feet, to 2,500 feet, to 5,280 feet. This is consistent with the pattern shown in Figure III.9. where for a given reduction in total air pollution exposure, we find that setbacks of increasing distance are associated with smaller labor market impacts. However, we highlight that this mechanism is merely suggestive: none of the regression coefficients shown in Table 8 in the Technical Appendix are statistically significant at conventional levels.

We now examine equity along two measures. We first explore how the pollution exposure gap between DACs and non-DACs changes as total population-weighted air pollution exposure from the extraction segment declines (see Section 9.1 of Technical Appendix). Figure III.10. shows how the gap in air pollution exposure in 2045 between DACs and non-DACs across California (vertical axis) relates to the percent change in total air pollution exposure (horizontal axis) across our various policy scenarios under benchmark values for macroeconomic conditions. We detect a systematic relationship: the pollution exposure experienced by DACs falls faster than that of non-DACs as overall pollution exposure drops. That is, as total air pollution exposure from TFFSS falls across the state, the improvement is greater for DACs than for non-DACs. We call this the “equity co-benefit” of lowering total

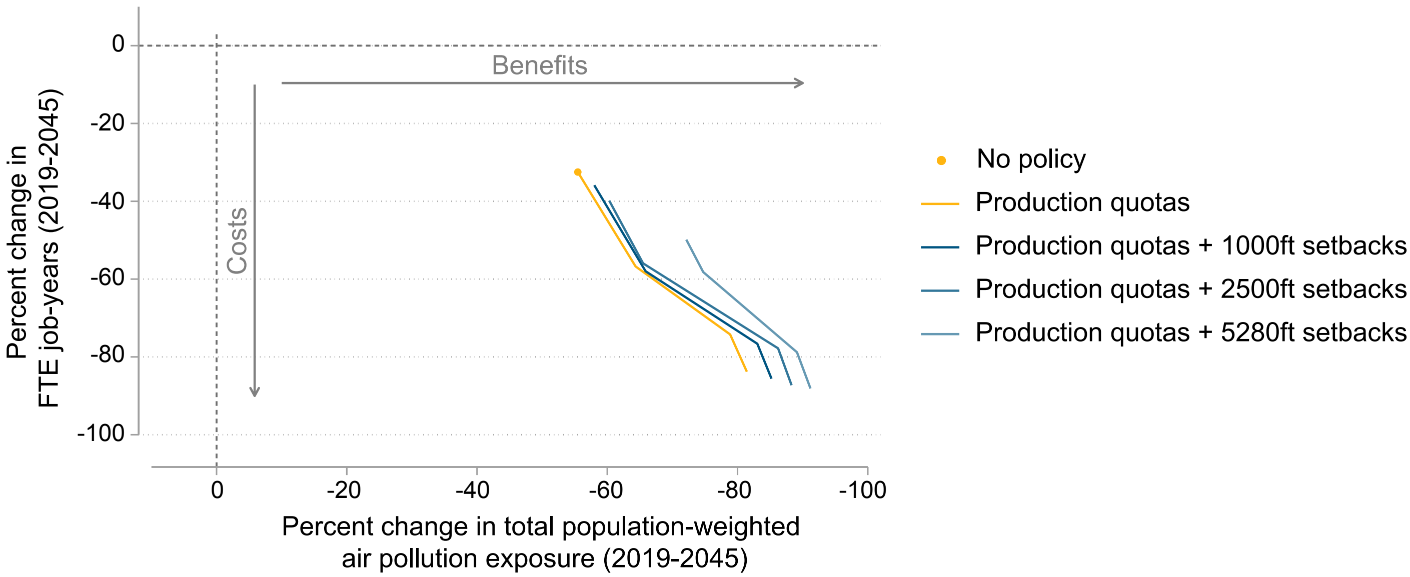


FIGURE III.9. The vertical axis shows the percent change in total FTE job-years between 2019 and 2045. The horizontal axis shows the percent change in total population-weighted air pollution exposure between 2019 and 2045. The orange dot represents the no-policy, or extraction business-as-usual (E-BAU), scenario. Each line represents the cost-benefit tradeoff across production quotas for a given setback distance. All scenarios assume benchmark values for macroeconomic conditions.

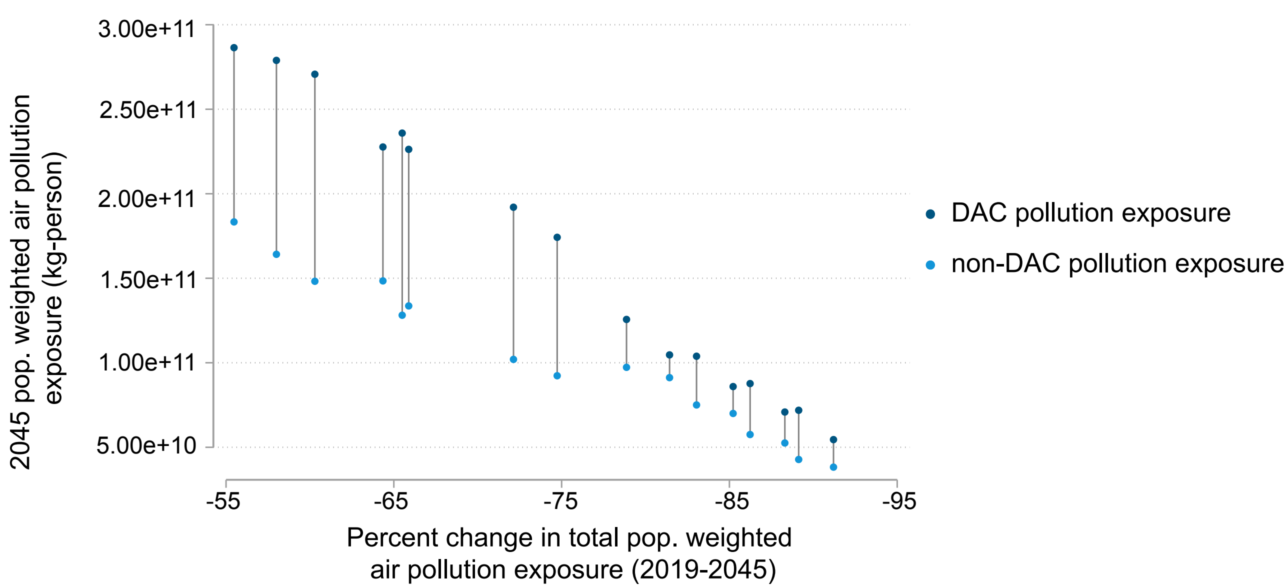


FIGURE III.10. The vertical axis shows the total population-weighted air pollution exposure in 2045 for DACs (in dark blue) and non-DACs (in light blue). The gray lines show the gap in air pollution exposure between DAC and non-DACs. The horizontal axis shows the percent change in total population-weighted air pollution exposure between 2019 and 2045. Each dot pairing represents a scenario with different policy levers. All scenarios assume benchmark values for macroeconomic conditions.

air pollution exposure from the extraction segment.

Figure III.11. visualizes this equity co-benefit using our second equity measure: the share of the change in total population-weighted air pollution exposure between 2019 and 2045 borne by DACs (see Section 9.1 of Technical Appendix). For this measure, a share equal to one implies that all air quality gains between 2019 and 2045 are experienced by DACs. Likewise, a share of one-half indicates that the air quality gains are evenly distributed between DACs and non-DACs. Consistent with Figure III.10., Figure III.11. shows that the share of the change in total air pollution exposure between 2019 and 2045 borne by DACs increases as the drop in total air pollution exposure between 2019 and 2045 becomes larger. That is, the more total air pollution falls, the more the gains in air quality are experienced by DACs.

Figures III.12. and III.13. explore how production quotas and setbacks affect our equity measures. In Figure III.12., each point represents the 2045 pollution exposure gap between DACs and non-DACs, shown above in Figure III.10., across the set of scenarios that jointly vary production quota values and setback distances. Each setback distance is indicated by a different color. Figure III.12. indicates that for a given change in statewide total pollution exposure as indicated by the horizontal axis, the introduction of setbacks leads to a relatively greater pollution exposure gap (or difference) by 2045 between DACs and non-DACs. This increase in the exposure gap is greater as setback distances increase. Thus, for a given reduction in statewide total pollution exposure, the addition of setbacks to a production quota may result in a smaller share of the total statewide air quality benefit to flow to disadvantaged communities. This results in a larger air pollution exposure gap between DACs and non-DACs.

Figure III.13., which has the same axes as Figure III.11., shows a similar pattern when we consider the share of air pollution benefits borne by DACs. In particular, for a given drop in total air pollution exposure, the introduction of setbacks lowers the share of total air benefits borne by DACs. This drop in the share of benefits borne by DACs is greater with increasing setback distances.

Why might the introduction of setbacks to a production quota lead to a lower equity co-benefit? Figures 28 and 29 in the Technical Appendix offer a potential explanation. At the field level, Figure 28 in the Technical Appendix shows a positive correlation between oil extraction cost per barrel and the DAC share of population within a 2 mile buffer of the centroid of the oil field. Under a production quota, oil fields exit from

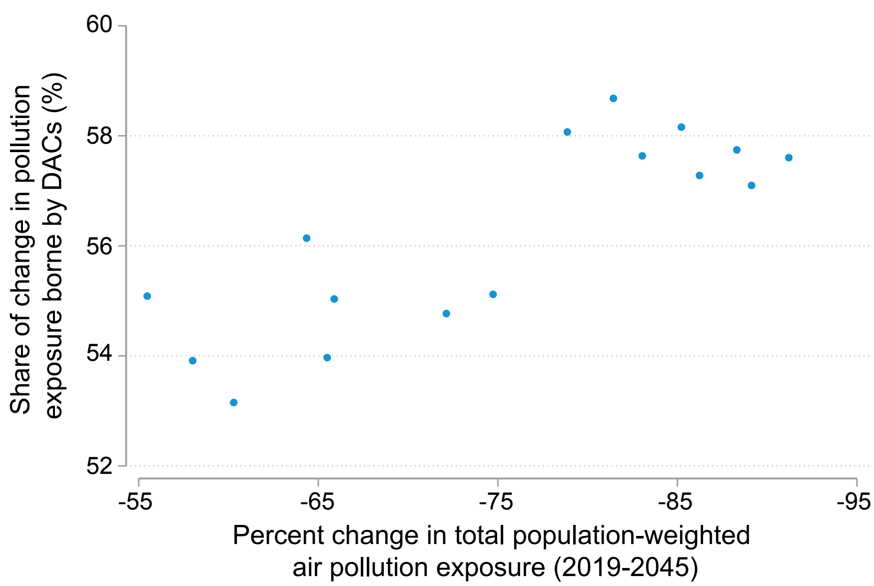


FIGURE III.11. Vertical axis share of the percent change in total population-weighted air pollution exposure between 2019 and 2045 borne by DACs. The horizontal axis shows the percent change in total population-weighted air pollution exposure between 2019 and 2045. Each dot represents a scenario with different policy levers. All scenarios assume benchmark values for macroeconomic conditions.

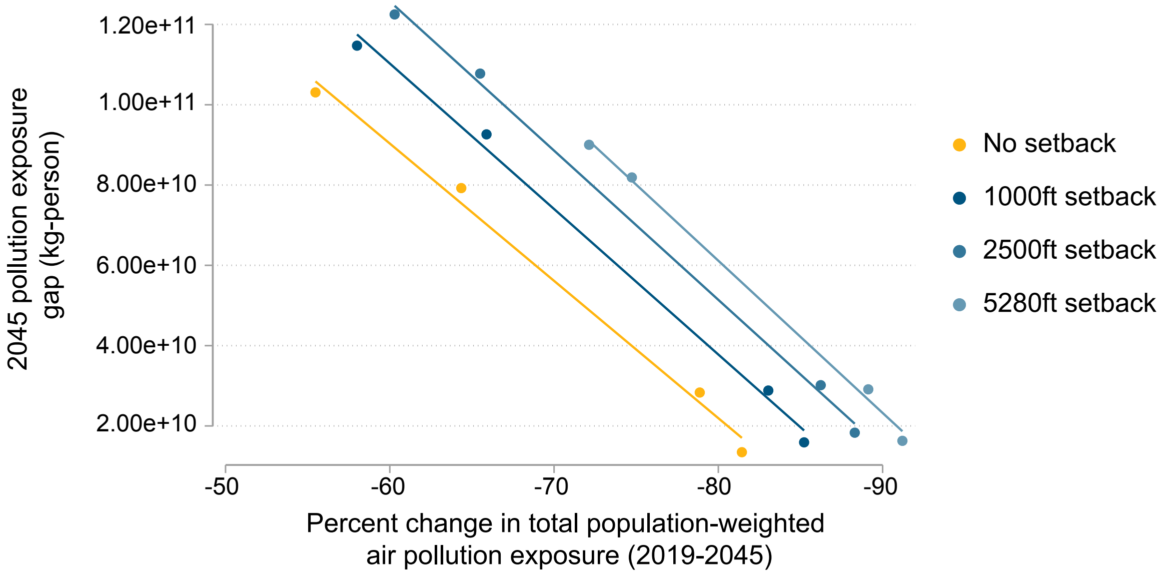


FIGURE III.12. The vertical axis shows the 2045 pollution exposure between DACs and non-DACs. The horizontal axis shows the percent change in total population-weighted air pollution exposure between 2019 and 2045. Each dot represents a scenario with different policy levers. The dots are color coded by setback distance. The lines show a linear fit within a given setback distance. All scenarios assume benchmark macroeconomic conditions.

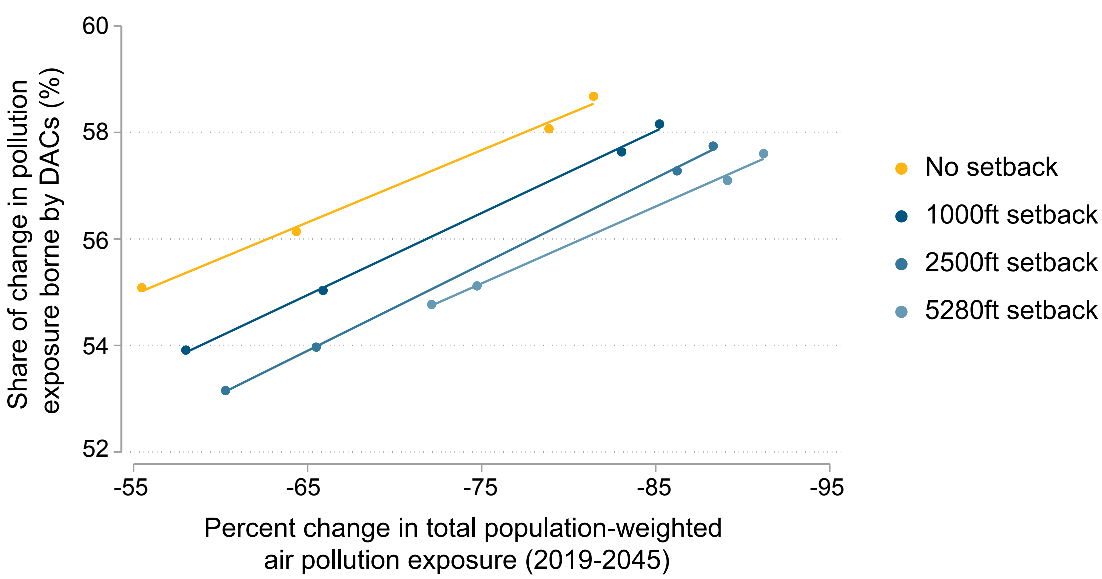


FIGURE III.13. Vertical axis share of the percent change in total population-weighted air pollution exposure from transportation fossil fuel supply sector (TFFSS) between 2019 and 2045 borne by DACs. The horizontal axis shows the percent change in total population-weighted air pollution exposure between 2019 and 2045. Each dot represents a scenario with different policy levers. The dots are color coded by setback distance. The lines show a linear fit within a given setback distance. All scenarios assume benchmark macroeconomic conditions.

from production in the order of high to low extraction costs. This generates an equity co-benefit alongside declines in total air pollution exposure: fields that go off line earlier are also fields with air pollution that disproportionately affect more DACs. Thus, DACs experience more of the air quality benefit as oil extraction declines under a production quota.

The addition of setbacks onto production quotas leads to a reordering of which oil fields go out of production. In particular, oil fields that are more closely located to "sensitive" sites (i.e., residences, schools, playgrounds, daycare centers, elderly care facilities and hospitals) tend to exit production earlier. Figure 29 in the Technical Appendix shows a much weaker relationship between an oil field's area affected by a setback—which captures the field's proximity to "sensitive" infrastructure—and its DAC share of affected population. Thus, the addition of setbacks reallocates production cuts to fields that have fewer nearby DACs. By having these fields go offline rather than fields with a lower cost of oil extraction, setbacks achieve the same reduction in total pollution exposure but with a lower equity co-benefit.

ii. Role of macroeconomic conditions for the extraction segment

We now turn to how different macroeconomic conditions alter the costs and benefits of achieving large GHG reductions between 2019 and 2045. Figures III.14. through III.17. present cost-benefit graphs from independently varying values of each macroeconomic condition while holding all other macroeconomic conditions fixed to benchmark values. Outcomes under the no-policy E-BAU scenario now differ across macroeconomic conditions. In order to understand cost-benefit tradeoffs relative to BAU across macroeconomic conditions, we normalize each axis by taking the percent difference in cumulative 2019–2045 total employment (i.e., vertical axis) and total population-weighted air pollution exposure (i.e., horizontal axis) for each policy scenario relative to its respective no-policy scenario. Each color-coded set of points represent the set of scenarios across policy levers for the same value of a macroeconomic condition of interest. To reduce visual complexity, we focus on scenarios that achieve a 2019–2045 GHG reduction of at least 80%. In general, decarbonization targets require less policy stringency as points move towards the origin of the plot, or in the northwest direction.

Figure III.14. examines cost and benefit tradeoffs under our benchmark projection of post-COVID-19 oil prices,

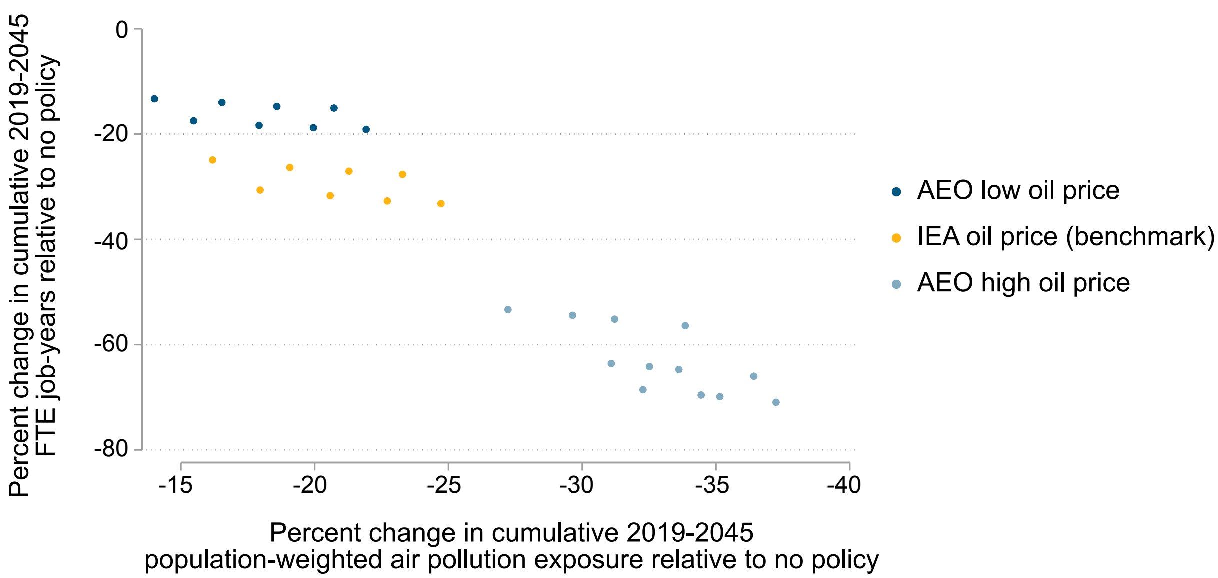


FIGURE III.14. The vertical axis shows the percent change in 2019–2045 cumulative FTE job-years under policy scenarios relative to the no-policy scenario (E-BAU). The horizontal axis shows the percent change in 2019–2045 cumulative total population-weighted air pollution exposure under policy scenarios relative to the no-policy scenario (E-BAU). Each dot represents outcomes from a different scenario that achieves 80% or more GHG reductions between 2019 and 2045. Orange dots show scenarios across policies under the benchmark International Energy Agency (IEA) oil price trajectory obtained from the IEA. Dark blue dots indicate scenarios across policies under the Annual Energy Outlook (AEO) high oil price trajectory. The light blue dots indicate scenarios across policies under the AEO low oil price trajectory. See Technical Appendix Section 8.2 for details.

provided by the IEA as well as pre-COVID-19 high and low oil price trajectories from the AEO. Each of these oil price trajectories between 2020 and 2045 are shown in Figure 20 in the Technical Appendix. In general, the labor market cost and health benefit of achieving more than 80% GHG reductions is lower under a low oil price trajectory and higher under a high oil price trajectory (see Technical Appendix Section 8.2 for more detail). This is expected as lower oil prices reduce the incentive to extract crude oil such that GHG reductions can be achieved with less stringent decarbonization policy interventions.

Figure III.15. examines the role of California's carbon price, which emerges from the state's GHG cap-and-trade (C&T) market, and applies to oil extracting facilities. Higher carbon prices facilitate GHG reductions by making GHG emissions associated with oil extraction more costly (see Technical Appendix Section 8.3 for more detail). As a consequence, a higher carbon price, which we assume to follow the price ceiling under the state's C&T market, allows decarbonization to occur with smaller labor market impacts but also fewer benefits in terms of a reduction in total air pollution exposure.

To examine the role of different carbon capture and storage (CCS) costs, Figure III.16. examines the three different CCS costs detailed in Chapter II.g.iii. (see Technical Appendix Section 8.4 for more detail). Lower CCS costs per metric ton of GHGs facilitate decarbonization by lowering the costs and benefits incurred by TFFSS-specific decarbonization policies. Similarly, Figure III.17. shows that a higher rate of innovation in oil extraction which lower pollution emissions intensity also facilitates decarbonization (see Technical Appendix Section 8.5 for more detail).

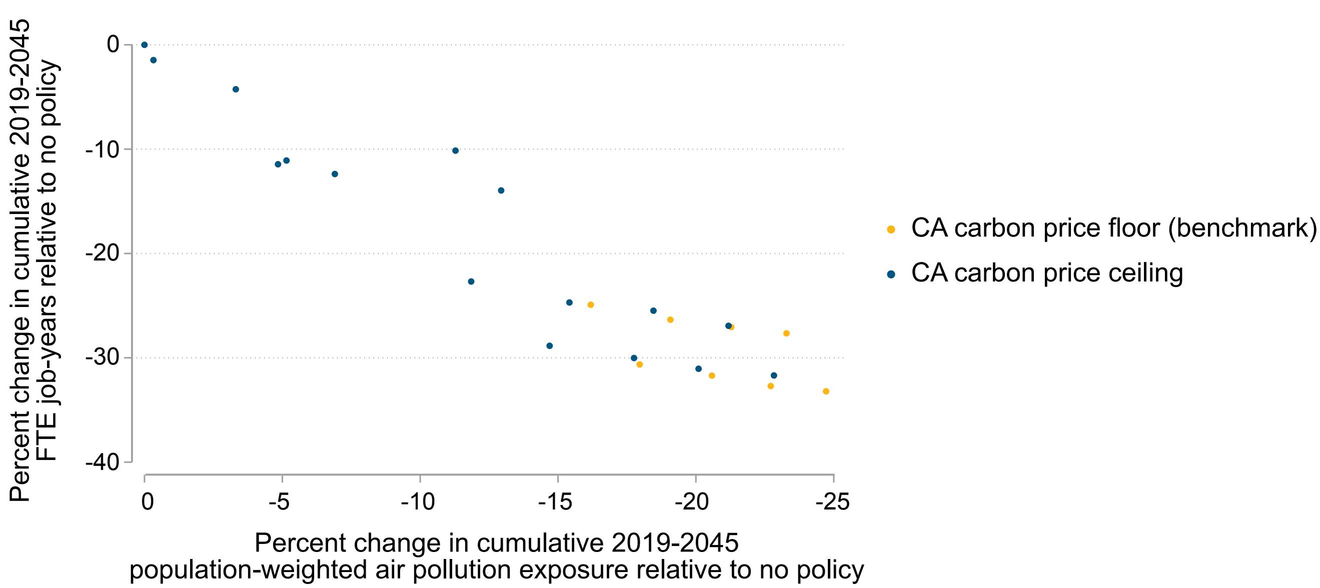


FIGURE III.15. The vertical axis shows the percent change in 2019–2045 cumulative total FTE job-years under policy scenarios relative to the no-policy scenario (E-BAU). The horizontal axis shows the percent change in 2019–2045 cumulative total population-weighted air pollution exposure under policy scenarios relative to the no-policy scenario (E-BAU). Each dot represents outcomes from a different scenario that achieves 80% or more GHG reductions between 2019 and 2045. The orange dots show scenarios across policies under the benchmark carbon price set to the price floor under California's GHG cap-and-trade program. The blue dots show scenarios across policies under a carbon price set to the price ceiling under California's cap-and-trade program. See Technical Appendix Section 8.3 for details.

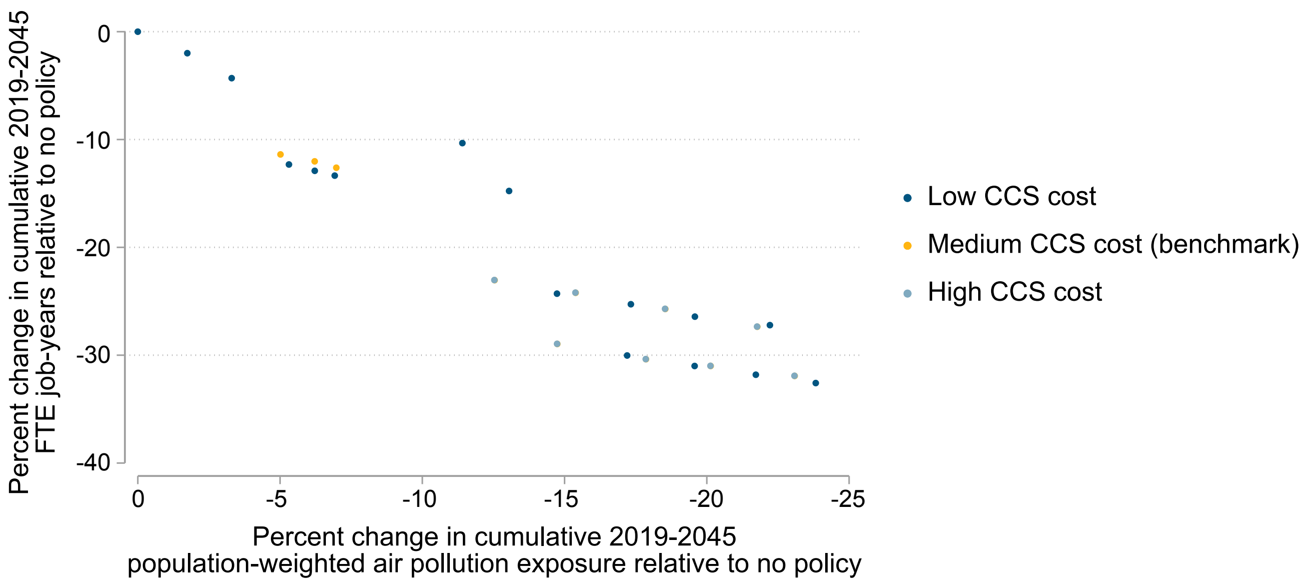


FIGURE III.16. The vertical axis shows the percent change in 2019–2045 cumulative total FTE job-years under policy scenarios relative to the no-policy scenario (E-BAU). The horizontal axis shows the percent change in 2019–2045 cumulative total population-weighted air pollution exposure under policy scenarios relative to the no-policy scenario (E-BAU). Each dot represents outcomes from a different scenario that achieves 80% or more GHG reductions between 2019 and 2045. The orange dots show scenarios across policies under benchmark medium carbon capture and storage (CCS) cost. The dark blue dots indicate scenarios across policies under low CCS cost. The light blue dots indicate scenarios across policies under high CCS cost. See Technical Appendix Section 8.4 for details.

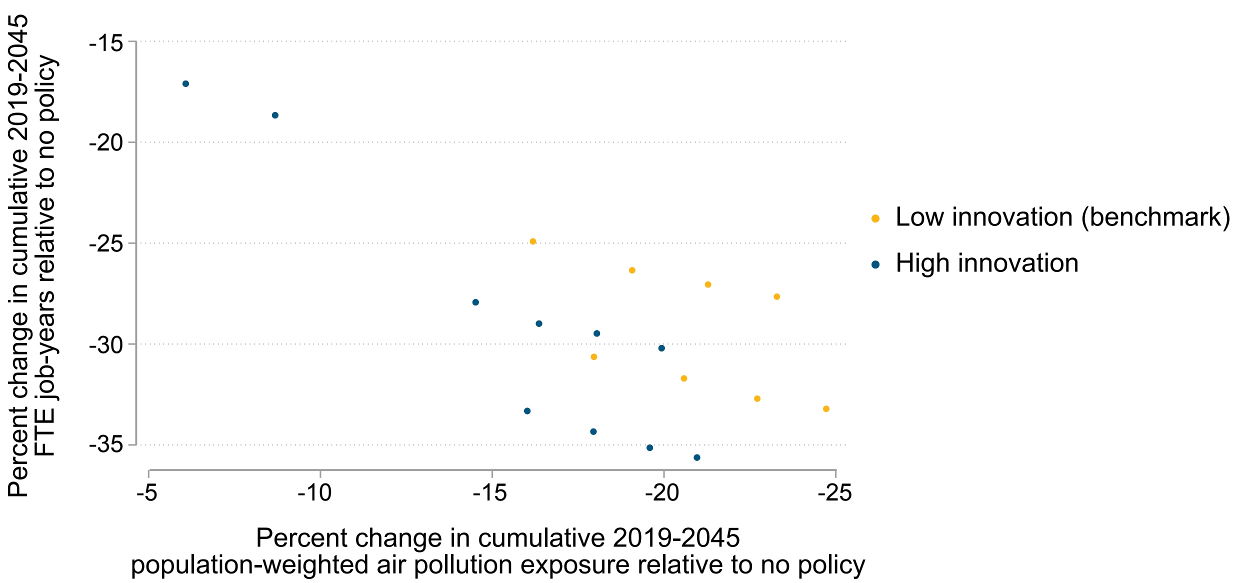


FIGURE III.17. The vertical axis shows the percent change in 2019–2045 cumulative total FTE job-years under policy scenarios relative to the no-policy scenario (E-BAU). The horizontal axis shows the percent change in 2019–2045 cumulative total population-weighted air pollution exposure under policy scenarios relative to the no-policy scenario (E-BAU). Each dot represents outcomes from a different scenario that achieves 80% or more GHG reductions between 2019 and 2045. Orange dots show scenarios across policies using the benchmark low innovation parameter. Blue dots indicate scenarios across policies using the high innovation parameter. See Technical Appendix Section 8.5 for details.

C. / REFINING SEGMENT

This section reviews outcomes and policies within the refining segment. Figure III.18. shows the percent change in statewide total employment between 2019 and 2045 (vertical axis) and the percent change in population-weighted statewide total pollution exposure between 2019 and 2045 (horizontal axis) for the R-BAU scenario (orange dot) and across combinations of in-state demand projections for refined fuels from Study 1 and refined fuel export levels under benchmark macroeconomic conditions. The R-BAU scenario assumes exports remain at historical levels. Larger dots indicate larger GHG reductions between 2019 and 2045.

Because Study 1 projects a decline in in-state demand for refined fuels in the Study 1 BAU scenario, including crude-based and renewable gasoline, diesel, and jet fuel, our model projects a 21% decline in GHG emissions alongside declines in refining employment and population-weighted total air pollution exposure. Increasing decarbonization within refining scenarios through lower demand for refined fuels and lower exports results in further reduction in total employment and air pollution exposure. For scenarios where exports remain high to maintain historical production levels at California refineries, GHG emissions, employment, and air pollution exposure do not change significantly between 2019 and 2045.

Figure III.19. shows the two scenarios that meet the Study 1 BAU and LC1 in-state refined fuels demand and refined fuel exports at historical levels. Lower demand for refined products in the LC1 scenario compared to the Study 1 BAU scenario results in lower revenue for refiners, causing a greater drop in employment. But lower production also leads to less air pollution exposure resulting in greater health benefits.

Figure III.20. shows two scenarios for levels of refined fuel exports, historical level and one that decreases to zero by 2045, where both scenarios meet the Study 1 BAU in-state refined fuels demand. Lower exports compared to historical exports result in lower demand for refined products from California refineries. This effect is similar to the one caused by lower in-state demand for refined fuels, and causes lower revenue and greater drop in employment, but greater health benefits from less air pollution exposure.

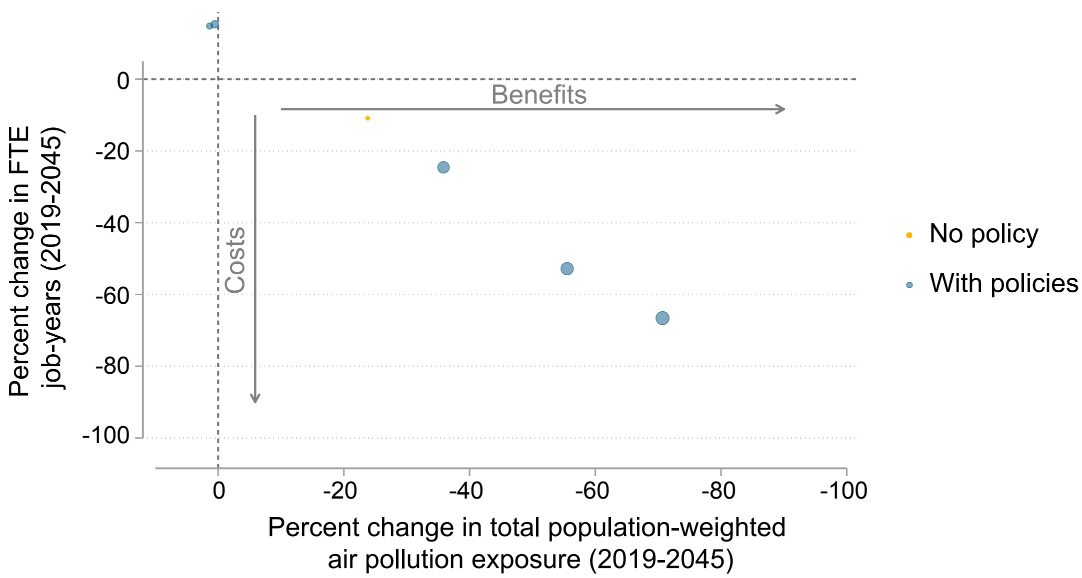


FIGURE III.18. The vertical axis shows the percent change in statewide total FTE job-years between 2019 and 2045. The horizontal axis shows the percent change in statewide total population-weighted air pollution exposure between 2019 and 2045. Each dot represents outcome from a different scenario. The orange dot represents the no-policy, or business-as-usual (R-BAU), scenario. Each blue dot represents a different scenario varying in-state demand projections from Study 1 and export levels of refined fuels. The size of each dot indicates the magnitude of percent change in GHG emissions between 2019 and 2045. All scenarios assume benchmark macroeconomic conditions.

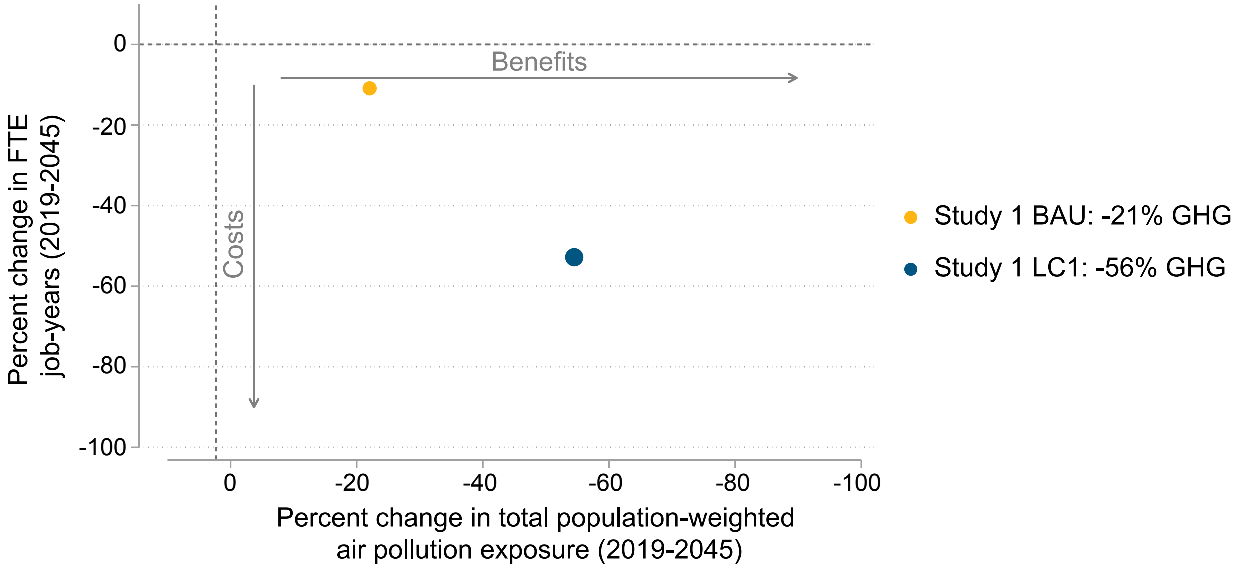


FIGURE III.19. The vertical axis shows the percent change in FTE job-years between 2019 and 2045. The horizontal axis shows the percent change in total population-weighted air pollution exposure between 2019 and 2045. Each dot represents outcome from a different scenario. The orange dot represents Study 1's business-as-usual scenario. The blue dot represents Study 1's central low carbon scenario (LC1) . The size of each dot indicates the magnitude of percent change in GHG emissions between 2019 and 2045 (also indicated in the legend). All scenarios assume benchmark macroeconomic conditions.

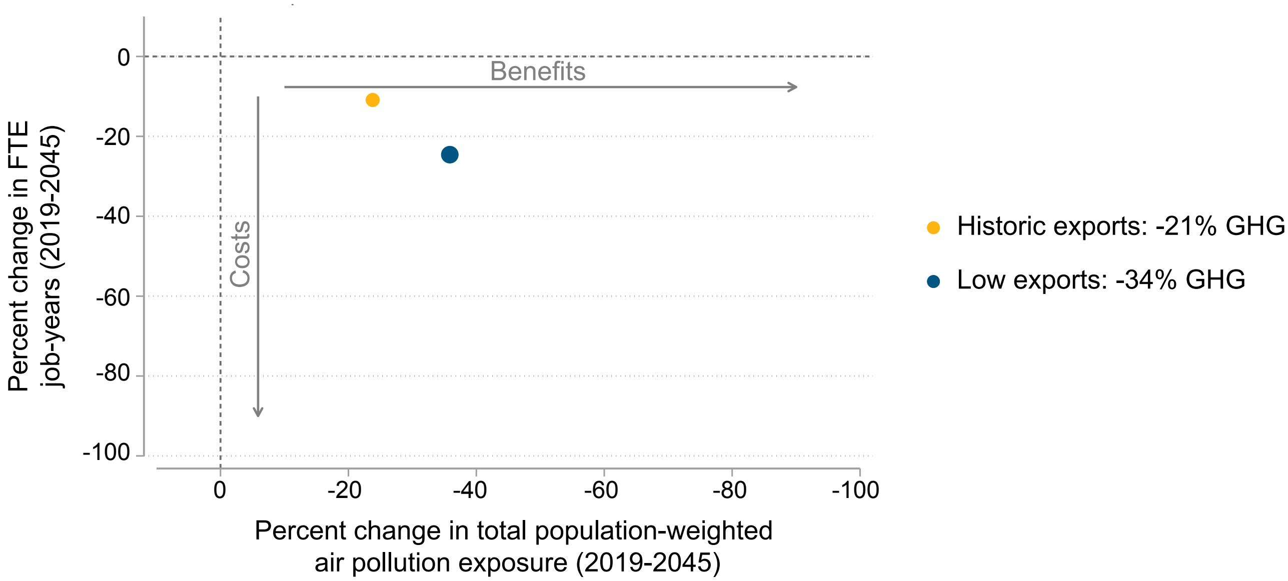


FIGURE III.20. The vertical axis shows the percent change in FTE job-years between 2019 and 2045. The horizontal axis shows the percent change in total population-weighted air pollution exposure between 2019 and 2045. Each dot represents outcome from a different scenario. The orange dot represents the Study 1 no-policy, or business-as-usual scenario. The blue dot represents the low export scenario. The size of each dot indicates the magnitude of percent change in GHG emissions between 2019 and 2045 (also indicated in the legend). All scenarios assume benchmark macroeconomic conditions.

Because the refining data and model resolution is restricted to the two refining clusters in the state—the North and South clusters—we do not present spatially heterogeneous outcomes for DACs and non-DACs for the refining segment.

i. Role of macroeconomic conditions for the refining segment

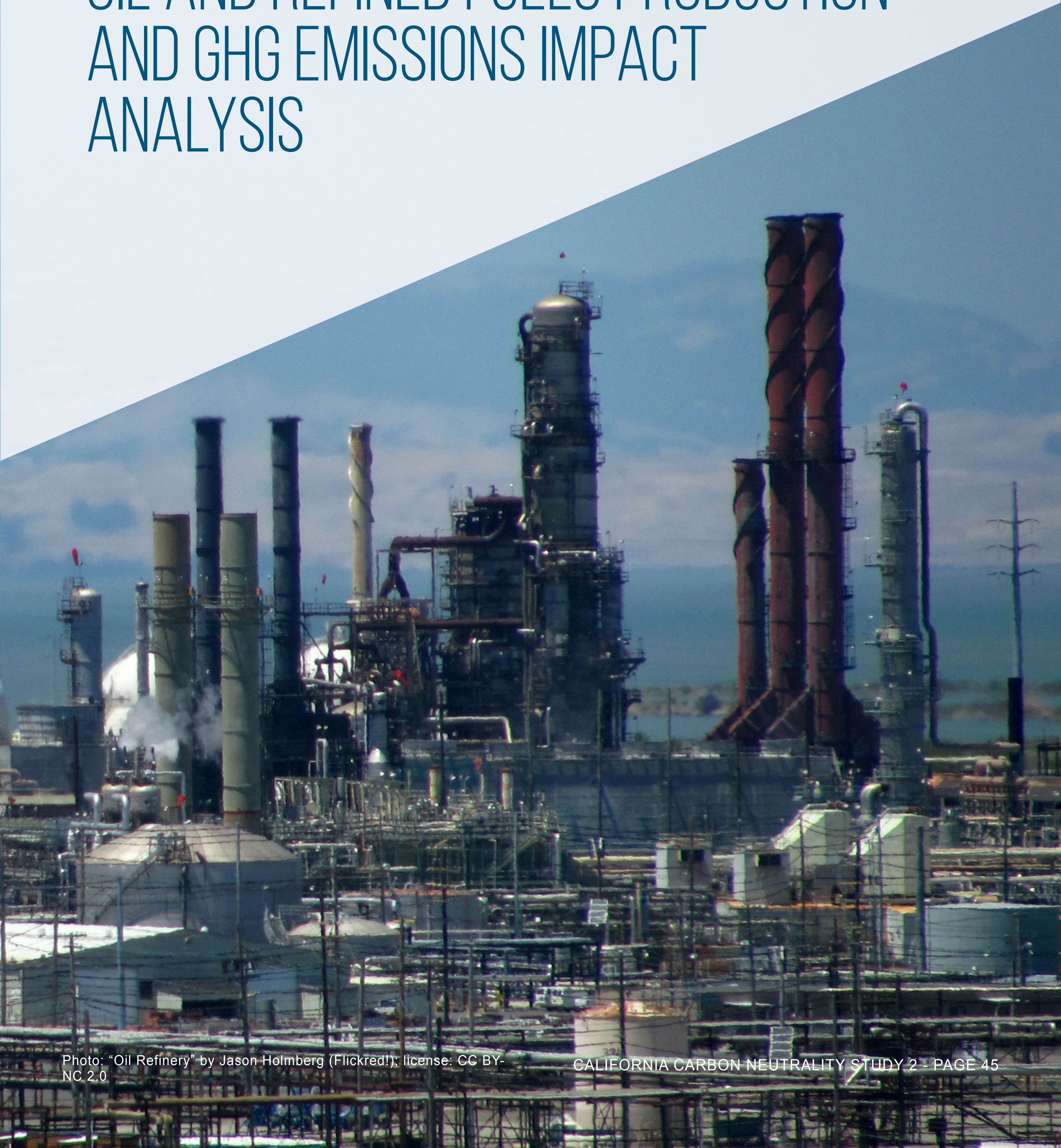
We examine how macroeconomic conditions affect the costs and benefits of achieving GHG reductions in the refining segment. We explore the same four macroeconomic conditions as those for the extraction segment—oil price, innovation, carbon price, and carbon capture and storage (CCS) cost.

Oil prices affect refining revenue, and thus, employment in the refining segment. Similar to the extraction segment, the cost of achieving GHG reductions is lower under a low oil price trajectory and higher under a high oil price trajectory. Because our study does not model the impact of oil prices on fuel demand, fuel production and air pollution remain the same across oil prices.

A higher rate of innovation in refining lowers both GHG emissions and air pollution. However, our model does not capture the impact of innovation on employment.

Both carbon prices and CCS can affect refinery costs, GHG emissions and air pollution. Similar to the extraction segment, lower CCS costs can facilitate decarbonization in the refining segment when a carbon price is imposed. Because we do not explicitly model refinery costs and their impacts on production and demand, additional costs due to a carbon price or adoption of CCS do not affect refinery production or revenue, thus showing no impact on air pollution exposure or employment within each policy scenario. This is a limitation of our model, which is constrained by the scope of this study.

CHAPTER 4
OIL AND REFINED FUELS PRODUCTION AND GHG EMISSIONS IMPACT ANALYSIS



This chapter describes in-state crude oil production from the extraction and refinery segments. For the extraction segment, we enumerate quantities of crude oil extracted and associated greenhouse gas (GHG) emissions generated by a business-as-usual (BAU) scenario and for two selected decarbonization policy scenarios. For the refining segment, we describe in-state refining to meet the demand for fuels prescribed by Study 1, with adjustments of fuel types to account for exports and interstate aviation transport, under a BAU scenario and for two selected decarbonization policy scenarios. We then enumerate quantities of refined fuels and associated GHG emissions generated by the refining segment for these three pathways.

A. / SCENARIOS SELECTED FOR DETAILED ANALYSIS

For the detailed analysis using the full model, we select three scenarios for the extraction segment and three scenarios for the refining segments (see Chapter III for our scenario selection analysis using a simplified version of our model). Although both selected policies and macroeconomic conditions influence our scenarios, we assume the same macroeconomic conditions across all six selected scenarios. These benchmark macroeconomic conditions are defined by the following:

- The International Energy Agency (IEA) crude oil price pathway, in which the future world economy faces delayed recovery from COVID-19
- Low innovation
- California price floor carbon price pathway
- Medium carbon capture and storage (CCS) cost pathway

Table IV.1. describes the three scenarios selected for the extraction and refining segments. The business-as-usual scenario for the extraction segment (E-BAU) assumes no explicit decarbonization policy. The second extraction segment scenario (LCE1) assumes an annual production quota that decreases linearly and results in an 80% reduction in annual production in 2045 compared to 2019. The third, more stringent, extraction segment scenario (LCE2) assumes a 2,500-foot setback policy enacted in 2020 in addition to the annual production quota from LCE1. For both LCE1 and LCE2 scenarios, the 80% reduction in crude oil production between 2019 and 2045 matches the 80% reduction in gallons of gasoline equivalent from the Study 1 central low carbon scenario (LC1) modeled fuel demands spanning this same time period.

The business-as-usual scenario for the refining segment (R-BAU) assumes that California refineries will meet demand for refined products as determined by the Study 1 BAU demand scenario as well as an additional quantity to maintain exports at historical levels. Both the second (LCR1) and third (LCR2) refining segment scenarios assume lower demand of refined products from Study 1's LC1 scenario. However, the LCR1 scenario assumes an additional demand equal to historic exports, whereas the LCR2 scenario assumes that historic exports linearly drop to zero by 2045. The baseline values for crude oil extraction and refining, and GHG emissions used throughout the analysis presented in this chapter are provided in Table IV.2.

In our analysis, the two sets of policy levers for the extraction and refining segments are defined separately because we assume that the trajectories of and impacts within each of the two segments do not affect each other. We assume that any difference between the crude oil demand from the refining segment and the production from in-state extraction will be adjusted by imports or exports of crude oil.

Of all demand for the different end-use fuels from California's transportation sector, we assume that California refineries are limited to producing crude-based and renewable gasoline, diesel and jet fuel (see Figure IV.1.). In our model of the refining segment, we do not include demand for other fuels including electricity, hydrogen, renewable natural gas, ethanol and biodiesel projected by Study 1.

TABLE IV.1. Scenarios selected for the full analysis in this study

Segment	Scenario	Description
Extraction	E-BAU	No decarbonization policy. Benchmark macroeconomic conditions include: IEA crude oil price pathway, low innovation, price floor carbon price and medium CCS cost.
Extraction	LCE1	Annual production quota that decreases linearly and results in an 80% reduction from 2019 historical production in 2045 (2045 quota = 31 million barrels). Benchmark macroeconomic conditions.
Extraction	LCE2	Annual production quota that decreases linearly and results in an 80% reduction from 2019 historical production in 2045 (2045 quota = 31 million barrels). 2,500-foot setback. Benchmark macroeconomic conditions.
Refining	R-BAU	Business-as-usual (BAU) fuel demand trajectory from Study 1. Historic exports. Benchmark macroeconomic conditions include: IEA crude oil price pathway, low innovation, price floor carbon price and medium CCS cost.
Refining	LCR1	Central low-carbon (LC1) fuel demand trajectory from Study 1. Historic exports. Benchmark macroeconomic conditions.
Refining	LCR2	Central low-carbon (LC1) fuel demand trajectory from Study 1. Low exports constrained to linearly drop to zero by 2045. Benchmark macroeconomic conditions.

BAU = business-as-usual, LC = low carbon, E = extraction, R = refining

TABLE IV.2. Baseline values used in Chapter IV

Baseline value description	Year(s)	Value
Crude production	2019	156 million barrels
Crude consumption by refineries	2019	595 million barrels
Total demand for refinery products (excludings exports)	2019	568 million barrels of gasoline equivalent
Historic net exports of refinery products Gasoline Diesel Jet fuel	2015-2019	76.8 million barrels of gasoline equivalent 24.1 million barrels 38.4 million barrels 8.1 million barrels
Extraction GHG emissions	2019	13.1 million metric tons
Refining GHG emissions	2019	29.9 million metric tons

Data sources: Crude production based on DOC extraction data. Refinery crude consumption and demand data from CEC Weekly Fuels Watch. Refined product exports data from the CEC's Finished Products Movement dataset . Extraction GHG emissions are based on emission factors developed using CARB's LCFS and OPGEE. Refining GHG emissions based on emission factors developed using CARB's MRR dataset.

In addition to the demand for end-use fuels from Study 1, we assume that California refineries produce additional jet fuel for interstate aviation transport (see Figure IV.1.). Lastly, we also assume that refineries produce additional quantities of refined products for export, which are not shown in Figure IV.1. Note that we estimate export quantities based on historical net exports to simplify California's fuels market that has historically both imported and exported refined fuels.

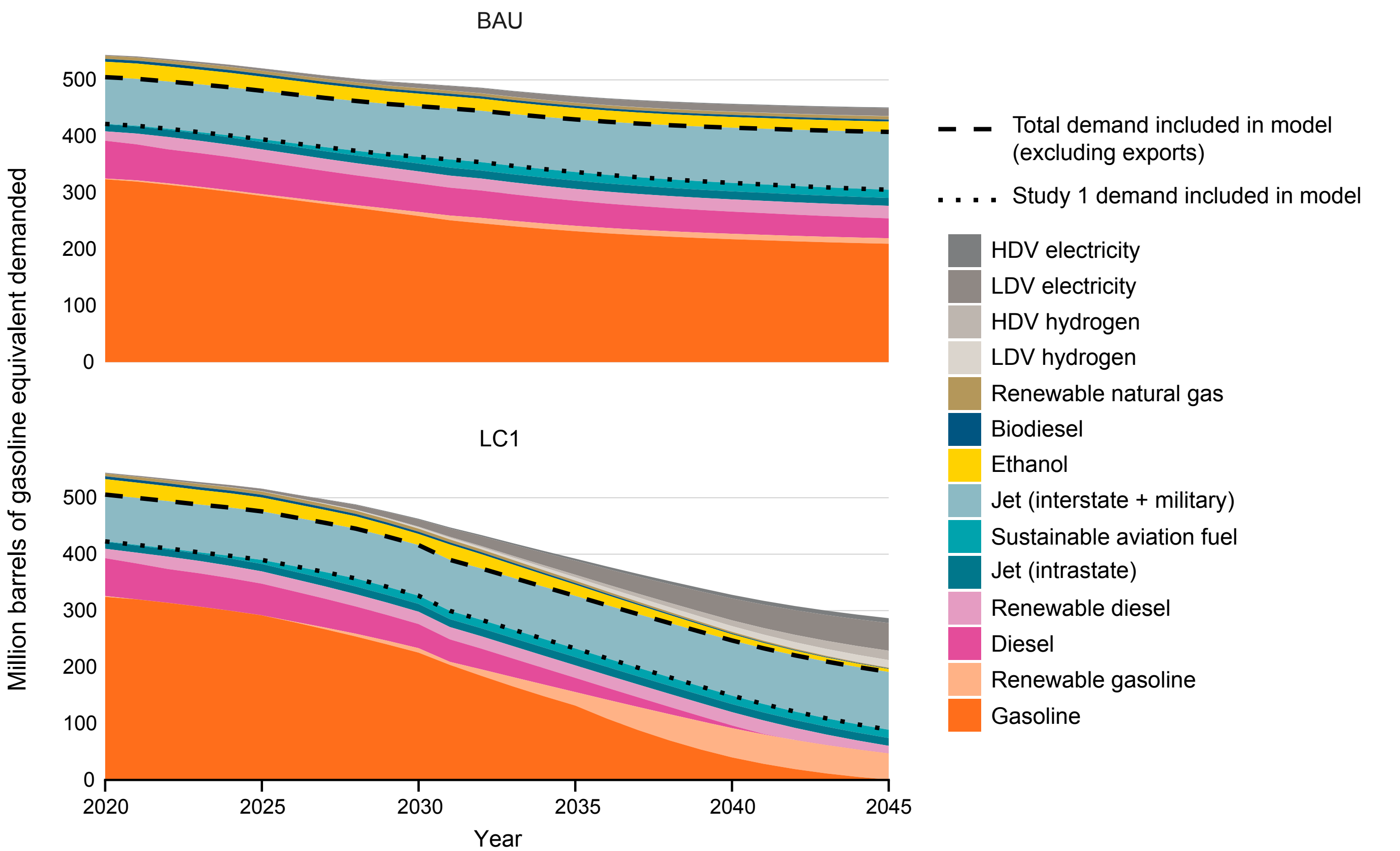


FIGURE IV.1. Projections of end-use fuels demanded by California's transportation sector. Demand projections for all fuels except jet fuel demand from military and interstate travel were provided by Study 1. Study 2 includes only demand for fuels below the dashed line, excluding ethanol, hydrogen and electricity as out of scope, but including jet fuel demand from military and interstate travel. Sustainable aviation fuel is referred to as renewable jet fuel in this study.

B. / PRODUCTION OF CRUDE OIL AND REFINED PRODUCTS

In-state crude oil production from the extraction segment

In all three extraction segment scenarios examined (E-BAU, LCE1 and LCE2), in-state crude oil production is projected to decline. Figure IV.2. shows the crude oil production trajectories under each scenario. Under the E-BAU scenario, crude oil production declines by 38%, from 156 million barrels in 2019 to 97 million barrels in 2045. Both the LCE1 and LCE2 scenarios have production quotas that limit production in a linearly decreasing fashion such that production in 2045 cannot exceed 20% of 2019 levels. The production trajectories of these scenarios start to follow the quota's path between 2028 and 2032. Crude oil production in 2045 under the two extraction low carbon scenarios is about 30 million barrels, reflecting an 80% decrease from 2019 levels. Under LCE1, because our model projects a lower crude oil production compared to the linearly decreasing production quota until 2028, crude oil production is constrained by the quota only from 2028 onwards. This is the year when LCE1's crude oil production trajectory first falls below that of the E-BAU scenario. Similarly, under LCE2, crude oil production is constrained by the quota from 2032 onwards, when the crude oil production trajectory begins to coincide with LCE1's trajectory. Before 2032, crude oil production in LCE2 is lower than in LCE1 because of the additional setback policy under LCE2.

In all three extraction segment scenarios (E-BAU, LCE1 and LCE2), our model projects a significant fall in production of crude oil from 2019 to 2020. This decrease in production is partly due to the drop in global oil price caused by COVID-19's impact on the global economy. The much lower oil price in 2020 compared to prices in the previous few years leads to far fewer new well entries within that year in our model. A second reason for the drop in crude oil production is that our decline curve model that projects the rate of depletion from oil

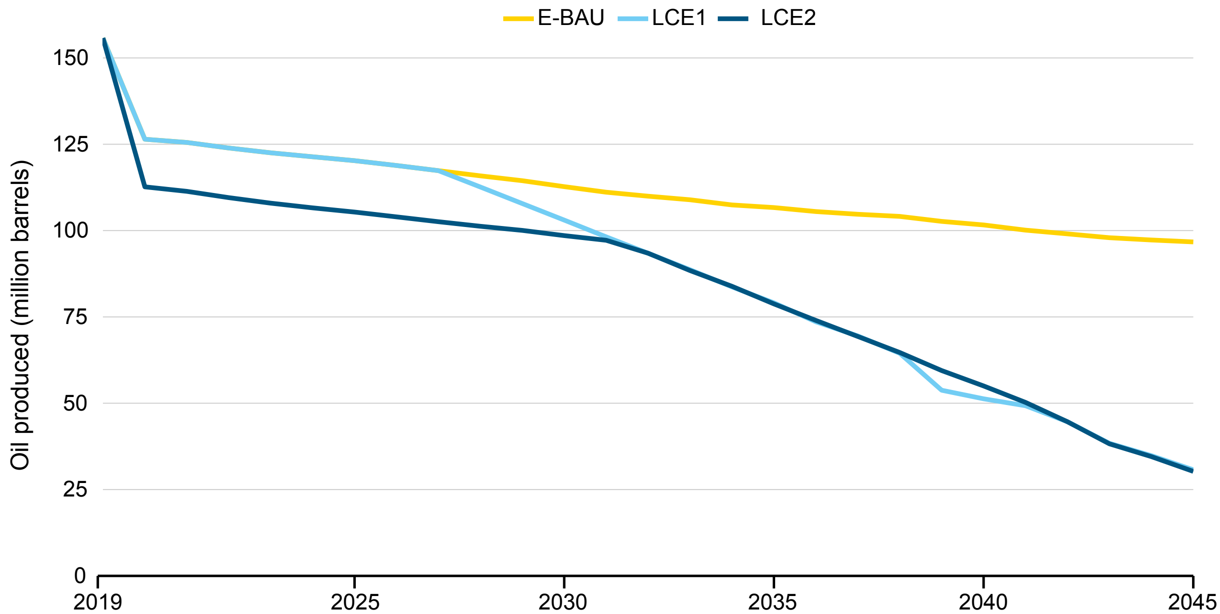


FIGURE IV.2. Projected crude oil extracted under E-BAU, LCE1 and LCE2 scenarios. The marked decrease in production from 2019 to 2020 is partly due to the drop in global oil price caused by COVID-19, which leads to far fewer modeled new well entries in 2020.

fields slightly underestimates the crude oil production in 2020 from wells that entered in previous years due to the presence of statistical error in our model. Because we model the crude oil production decline curves as smooth functions, we do not not capture short-term fluctuations that lead to deviations from the curve.

Figure IV.3. shows the modeled in-state crude oil production under the three extraction scenarios (E-BAU, LCE1, LCE2) separated by production from existing wells (i.e., wells drilled before 2020) and new wells (i.e., wells drilled in and after 2020). In the E-BAU scenario, production from existing wells declines by 76%—from 155.7 million barrels in 2019 to 37.7 million barrels in 2045. Total projected crude oil production from new wells in the E-BAU scenario reaches 59.1 million barrels by 2045. Production quotas and the setback policy affects production from both existing and new wells. Because crude oil production is not constrained by production quotas until 2028 for LCE1 and 2032 for LCE2, our model projects new well entry before these years. Production from these wells is constrained once production quotas bind.

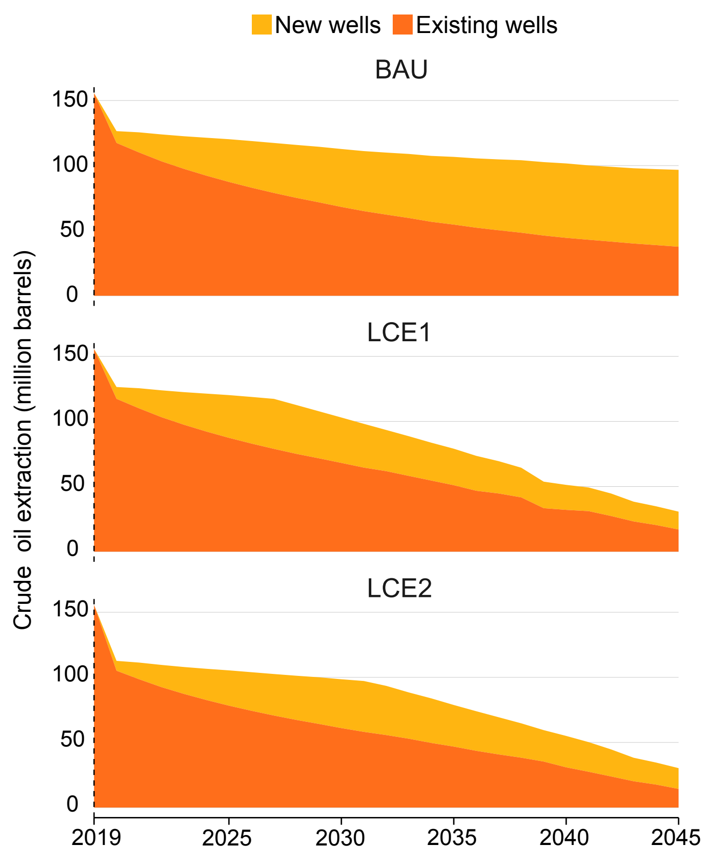


FIGURE IV.3. Projected crude oil extracted under E-BAU, LCE1 and LCE2 scenarios, as modeled from 2019 to 2045. The modeled data separates crude oil extraction from new and existing wells according to the well entry model.

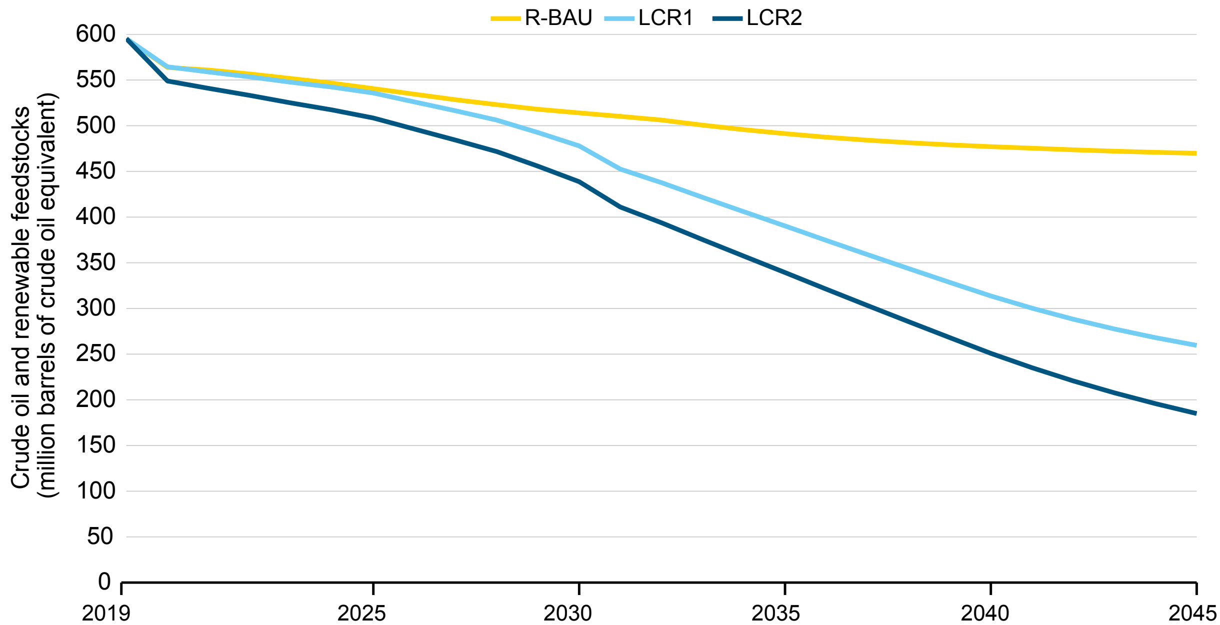


FIGURE IV.4. Projected crude oil and renewable feedstocks (summed together) in units of million barrels of crude oil equivalent consumed by in-state refineries under R-BAU, LCR1 and LCR2 scenarios.

Refined fuels production and crude oil consumption in the refining segment

The total quantity of crude equivalent—which includes crude oil and renewable feedstocks—consumed by in-state refineries declines across all three scenarios for the refining segment (R-BAU, LCE1 and LCE2). Under R-BAU, crude consumed by refineries declines by 21% from 595 million barrels in 2019 to 470 million barrels in 2045 (Figure IV.4.). Refineries consume less crude oil under LCR1 than under R-BAU. Refinery consumption in the LCR1 scenario declines to 260 million barrels in 2045, a 56% decrease from 2019 levels. Of the three refining segment scenarios, refineries consume the least amount of crude oil under LCR2, which minimizes exports of refined products. Under LCR2, refinery consumption of crude oil decreases to 185 million barrels, which is a 69% decline from 2019 levels. These values in turn can be thought of as the remaining refining capacity California will need in 2045 relative to 2019: 79% for R-BAU, 44% for LCR1, and 31% for LCR2.

Refined fuels demand drives crude oil consumption in the refining segment (Figure IV.5.). Under R-BAU, gasoline and jet fuel remain the dominant fuels refined in-state, together making up 80% of in-state demand and 67% of total demand (including exports) in 2045. Projected in-state demand for crude-based gasoline and diesel decreases to zero under LCR1 and LCR2

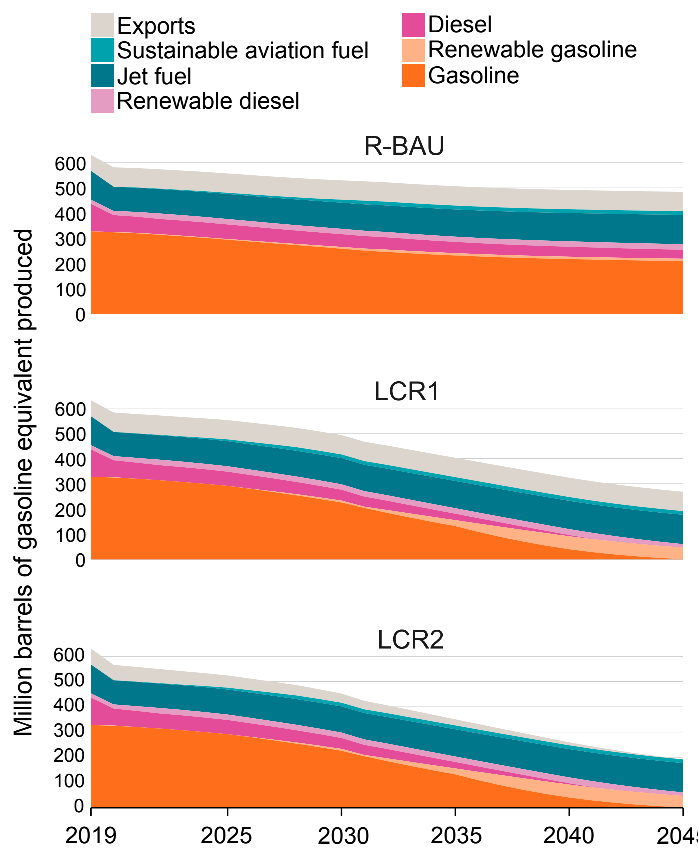


FIGURE IV.5. Modeled refined fuel production by in-state refineries from 2019 to 2045, separated by fuel type and exports, under R-BAU, LCR1 and LCR2 scenarios. Exports include a mix of gasoline, diesel and jet fuel based on historical shares.

based on the projected demand from the Study 1 LC1 scenario. Under LCR1 and LCR2, jet fuel is the dominant fuel refined in-state, mainly due to demand from interstate aviation transport. As a result of the rising jet fuel demand across all scenarios, crude oil consumption—and consequently, GHG emissions—from the refining sector does not drop to near-zero levels under any of the scenarios. Refined fuel demand from interstate aviation transport could be met by sustainable aviation fuel (or renewable jet fuel) depending on federal policies, technological progress and future costs; but processing this fuel will also have associated GHG emissions. Under R-BAU, total exports of gasoline, diesel and jet fuel make up 16% of total refined fuel demand in 2045. Exports are a larger share (29%) of total refined fuel demand under the LCR1 scenario due to the lower total in-state fuel demand from the Study 1 LC1 scenario. In the LCR2 scenario, there are no projected exports of refined fuels in 2045.

The share of crude oil imports in California's refinery inputs will depend on in-state crude oil production (extraction scenarios) and demand for both crude oil and renewable feedstock to produce renewable fuels (refining scenarios) (Figure IV.6.). In the R-BAU

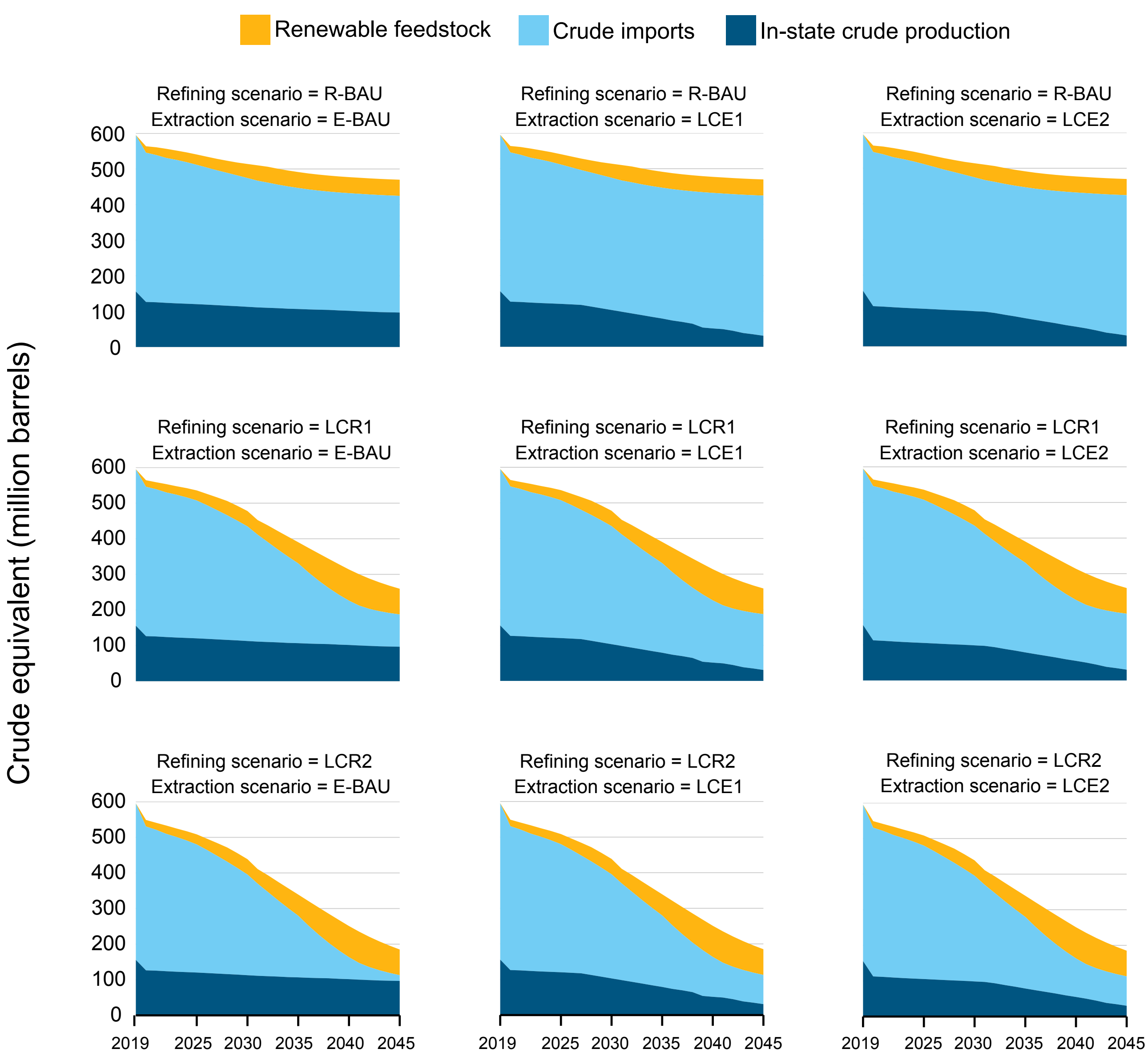


FIGURE IV.6. Modeled crude oil and renewable feedstocks (million barrels) consumed by in-state refineries from 2019 to 2045, separated by crude oil source, under all combinations of extraction (E-BAU, LCE1 and LCE2) and refining (R-BAU, LCR1 and LCR2) scenarios.

scenario, crude oil imports are the dominant feedstock to refineries across all extraction scenarios. For LCR1 and LCR2, overall quantities of crude oil imports decrease significantly compared to 2019, but the proportion of feedstocks varies widely, depending on extraction scenarios. In the E-BAU scenario (i.e., when in-state extraction is not constrained by policies), crude oil imports fall faster compared to LCE1 and LCE2 because they limit in-state extraction through policies, and imports fill the larger gap between in-state supply and refinery demand. None of the scenarios result in export of in-state produced crude oil.

C. / GREENHOUSE GAS EMISSIONS

GHG emissions from the extraction segment

Under the E-BAU scenario, we project California's GHG emissions associated with extraction in 2045 to be 7.4 $MtCO_2e$, 44% less than modeled GHG emissions in 2019 (13.1 $MtCO_2e$) (Figure IV.7.).

In the LCE1 scenario, which assumes a linearly decreasing annual production quota that reaches 20% of 2019 crude oil production in 2045, California's oil extraction GHG emissions in 2045 are projected to be 1.3 $MtCO_2e$. These GHG emissions are 90% less than modeled emissions in 2019, and 82.4% less than GHG emissions projected under E-BAU in 2045. The greater drop in GHG emissions from 2019 to 2045 compared to the decrease in crude oil production is a result of lower GHG emission factors associated with wells remaining in 2045 after imposing the production quota.

In the LCE2 scenario, which assumes a setback policy of 2,500 feet is introduced in 2020 together with the annual production quota assumed in LCE1, California's oil extraction GHG emissions in 2045 are projected to be 1.4 $MtCO_2e$. These GHG emissions are 89% less than modeled emissions in 2019, and 81.9% less than projected GHG emissions under E-BAU in 2045.

Under the benchmark macroeconomic conditions used in LCE1 and LCE2 (i.e., price floor carbon price), CCS is not adopted by oil fields at any point over 2019–2045, so GHG emissions from the extraction segment are not impacted by CCS. Figure 26a in the Technical Appendix shows the macroeconomic conditions under which oil fields adopt CCS, and the resulting impacts on GHG emissions from the extraction segment. In particular, CCS is adopted and provides emissions reductions under central and high carbon prices.

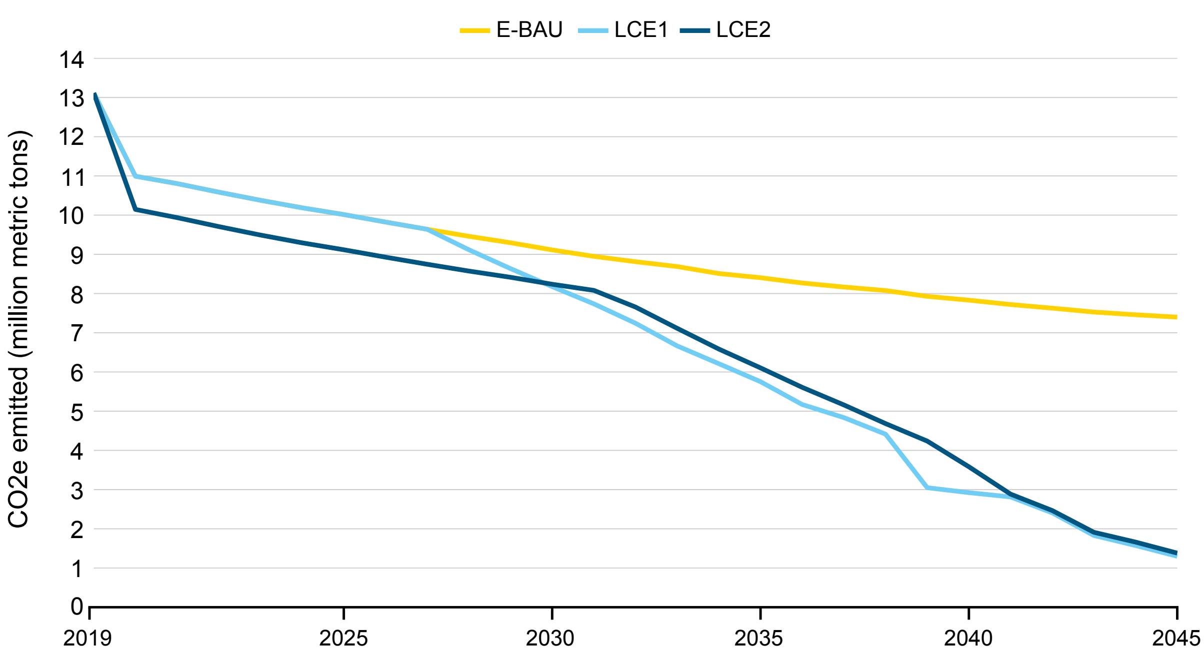


FIGURE IV.7. Modeled GHG emissions ($MtCO_2e$) emitted from oil extraction in California from 2019 to 2045, under the E-BAU, LCE1 and LCE2 scenarios.

Because of differences in methodologies, our modeled historical emissions are lower than those reported in the California Air Resources Board (CARB) GHG Inventory; e.g., total greenhouse gas emissions for the extraction segment in 2017 estimated using our method (the last year for which emissions data are available in the GHG Inventory) are 18% lower than those reported by the GHG Inventory tool after accounting for emissions associated with natural gas and Combined Heat and Power (CHP) (see the Synthesis Report, pages 55–56). Further, our model does not capture the potential increase in emission factors over time as seen in historical data (see the Synthesis Report, Figure 37). Because of these limitations in our methodology, our projections of GHG emissions for the extraction segment are likely underestimated.

GHG emissions from the refining segment

Under the R-BAU scenario, which assumes the Study 1 BAU refined fuels demand trajectory and fuel exports at historic levels, we project that California's GHG emissions from the refining segment in 2045 will be 23.5 $MtCO_2e$, 21.3% less than modeled emissions in 2019 (29.9 $MtCO_2e$) (Figure IV.8.).

In the LCR1 scenario, which assumes the Study 1 LC1 in-state fuel demand trajectory and fuel exports at historic levels, California's refining GHG emissions in 2045 are projected to be 13.0 $MtCO_2e$, 56.4% less than modeled emissions in 2019, and 44.7% less than projected under R-BAU in 2045.

In the LCR2 scenario, which assumes in-state fuel demand from the Study 1 LC1 scenario and fuel exports that decrease to zero in 2045, California's refining GHG emissions in 2045 are projected to be 9.3 $MtCO_2e$, 69% less than modeled emissions in 2019, and 60.5% less than projected under R-BAU in 2045.

Modeled GHG emissions for the refining and extraction segments of the Transportation Fossil Fuel Supply Sector (TFFSS) (Figure IV.9.) reveal how projected changes associated with each segment contribute to the total decline in sector emissions. Annual reductions in GHG emissions from the entire TFFSS in 2045 relative to 2019 vary from -12.1 $MtCO_2e$ (-28%) for R-BAU + E-BAU to -32.4 $MtCO_2e$ (-75%) for both LCR2 + LCE1 and LCR2 + LCE2. Note that in this analysis, we do not include extraction emissions associated with imported crude oil (Figure IV.6.) as well as refining or other emissions associated with renewable fuels not included in our model (e.g., ethanol, biodiesel) (Figure IV.1.).

The refining segment contributes 70% of modeled TFFSS GHG emissions in 2019. In the nine scenario combinations considered, the contribution of refining

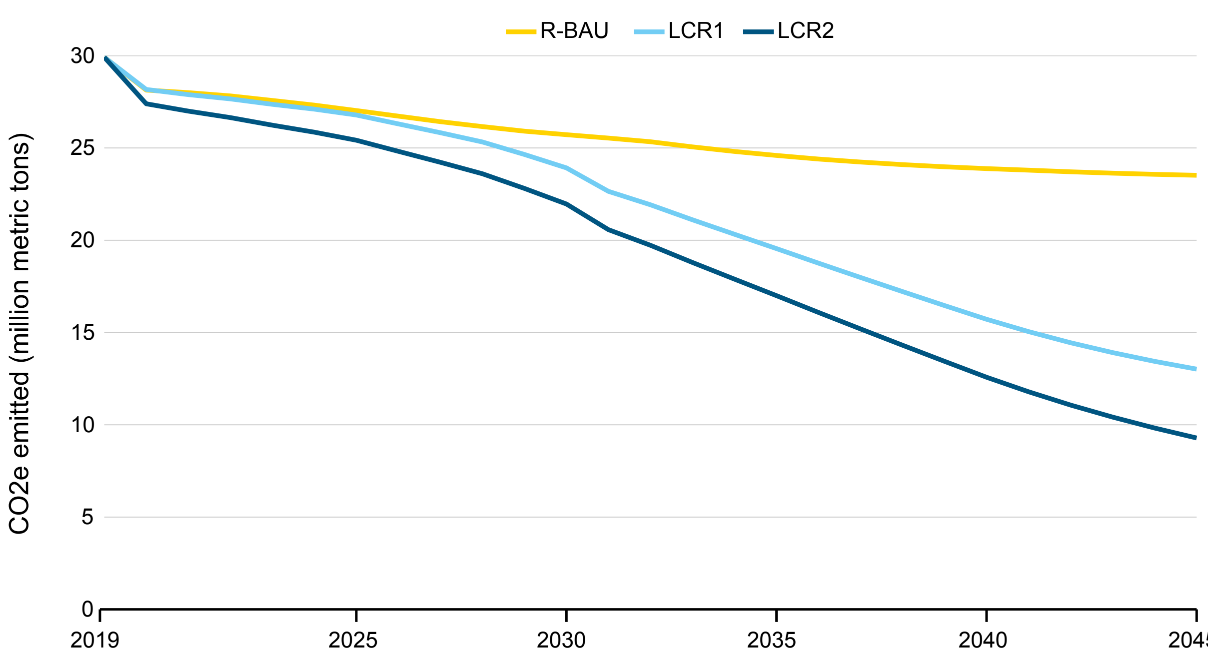


FIGURE IV.8. Modeled GHG emissions (MtCO2e) emitted from crude refining in California from 2019 to 2045, under the R-BAU, LCR1 and LCR2 scenarios.

emissions to the TFFSS sector in 2045 varies from a low of 56% (LCR2 + E-BAU) to a high of 95% (R-BAU + LCE2). This variation in the proportion of GHG emissions attributed by the refining segment is a result of varying stringencies of combined refining and extraction scenarios: the combination of more restrictive refining policies with less restrictive extraction policies, raises the contribution of extraction emissions relative to refining, whereas the combination of less restrictive refining policies with more restrictive extraction policies has the opposite effect. Regardless, refinery emissions persist as more than half of total TFFSS GHG emissions in all years and in all scenario combinations. These persistent refinery emissions are driven by the processing of renewable liquid fuels (assumed to be processed by existing in-state refineries), processing of jet fuel for interstate aviation transport, and potential exports of refined fuels.

Under the benchmark macroeconomic conditions used in LCR1 and LCR2 (i.e., price floor carbon price), CCS is not adopted by refineries at any point over 2019–2045, so GHG emissions from the refining segment are not impacted by CCS. Figure 26b in the Technical Appendix shows the macroeconomic conditions under which refineries adopt CCS, and the resulting impacts to GHG emissions from the refining segment. In particular, CCS is adopted and provides emissions reductions under central and high carbon prices.

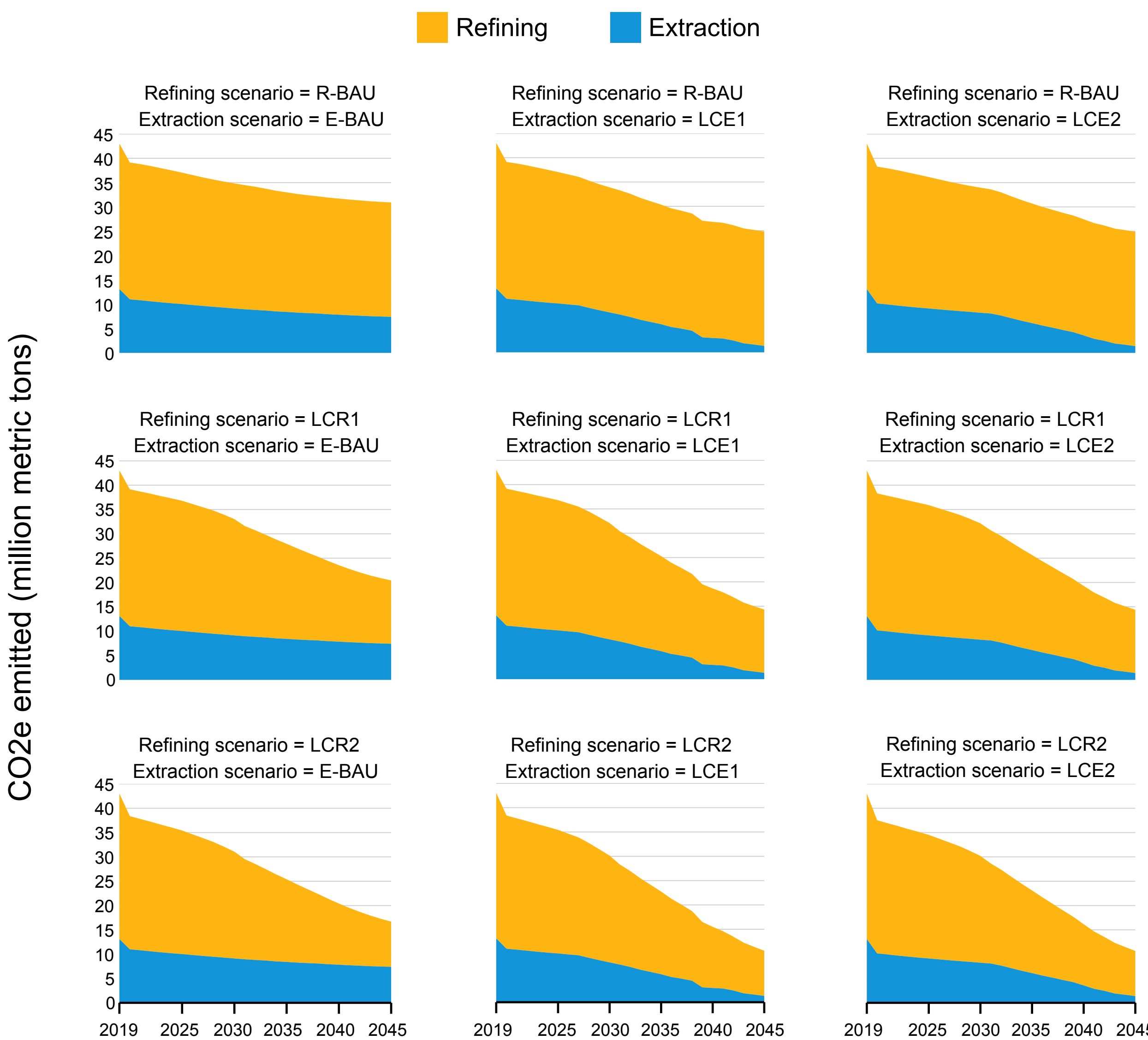


FIGURE IV.9. Modeled GHG emissions ($MtCO_2e$) for the transportation fossil fuel supply sector (TFFSS) from 2019 to 2045, under all combinations of extraction (E-BAU, LCE1 and LCE2) and refining (R-BAU, LCR1 and LCR2) scenarios.

D. / TAX REVENUE POTENTIAL FROM THE EXTRACTION SEGMENT

Excise tax and production quota

As discussed earlier, the model implements a crude oil production quota in LCE1 and LCE2 scenarios in a least-cost framework. The most costly oil fields are taken offline sequentially until the quota is satisfied. The Technical Appendix Section 7.1 reviews the correspondence between such a policy and an excise tax. In particular, for each quota level, there exists a tax level that would achieve an equivalent reduction in production. Based on the tax levels estimated to correspond with the production quotas, we estimate that in 2045, an excise tax that would achieve the production quota in LCE1 and LCE2 would provide $3.08 billion and $3.04 billion ($2045) in annual revenue, respectively.

County-level property taxes

California currently does not levy a statewide excise tax on oil and gas production, but counties in the state collect ad-valorem taxes, taxes based on assessed values, such as property taxes on land, oil and gas resources, and equipment owned in their jurisdictions. In addition to the 1% property tax rate on all real estate parcels established by Proposition 13 in 1978, most counties in the state also levy voter-approved bond taxes on parcels that go as high as 0.25%, bringing the total effective tax rate to 1.25%. There are a few key features about property tax in California that have implications on each county's budget:

- ► Property tax revenue remains within the county in which it is collected and is used exclusively by local governments. The 1% property tax revenue goes to the county's general fund and the remaining voter-approved tax revenue usually goes to infrastructure projects, public services, and maintenance of local school facilities and programs.
- ► Property tax revenues from oil and gas properties are volatile, as they are assessed based on the price of the subsurface resources and vary with the price of specific grades of crude oil and natural gas. For example, the Kern General Fund lost nearly $45 million (-31%) in property tax revenue in FY 2016–2017 compared to FY 2015–2016 due to the drop in price of oil.
- ► The property tax is typically based on the property's acquisition value, adjusted for inflation (capped at 2% via Proposition 13); however, as this variant of tax structure does not apply to oil and gas properties Rule 468 of California's property tax rule for petroleum producing properties was designed to take into account annual "physical and economic conditions," which are interpreted as annual depletions prices, and other regulatory change limitations.

Calculating oil and gas property taxes is a complex process in California that varies over counties and assessors, in some cases, taking into account projected oil prices, new reserves, firm level capitalization rates and infrastructure improvements. For that reason, we only show here the loss in tax revenues from extraction sites (i.e., oil and gas properties) compared to the E-BAU scenario due to the loss in discounted cash flow of production in 2020 to 2045 from each scenario's policy levers. This is in line with the State of California Tax Code Rule 8 wherein value is defined as derived from the "present worth of a future income stream."

To simplify our analysis, our property tax implication calculations make the following assumptions: 1) there are no new reserves nor improvements in land and infrastructure as defined in Property Tax Rule 468, 2) that the effective ad-valorem tax rate remains constant over 2020–2045, 3) the assessor has information on when and how the quota will be administered across counties over 2020–2045, 4) there are reevaluations of oil and gas producing properties every year (61). As oil and gas properties are not reevaluated every year and valuations change moderately from year to year, these assumptions result in conservative (larger) estimates of losses in tax revenues. Section 10 of the Technical Appendix provides more detail on how property tax implications are calculated.

Figure IV.10. shows that Kern, Monterey, Fresno, Los Angeles and Ventura Counties will experience the largest total tax revenue loss under the LCE1 and LCE2 scenarios relative to the BAU-E scenario. Kern County will see the biggest impact with an annual average fall in property tax revenue from extraction sites of $24 million (LCE2) to $27 million (LCE1), followed by Monterey County at $2.5 million (LCE2) to $2.6 (LCE1), and Los Angeles County at $0.65 million (LCE1) and $2.9 million (LCE2) over 2020–2045. The impact on Los Angeles County's tax base is quite different based on the scenarios compared to Fresno County, for example, with an average loss in tax revenue of around $1.4 million regardless of scenario.

Table IV.3. lists the average loss for all affected counties. Some extraction counties, including Orange County (no impact for LCE1 and $470,000 for LCE2), Tulare County ($20,000 for LCE1 and -$30,000 for LCE2), and Santa Barbara County (no impact for LCE1 and -$90,000 for LCE2), will see moderate changes in their tax revenue from oil and gas property due to the decreased oil production under the LCE1 and LCE2 policy scenarios relative to the E-BAU scenario over 2020–2045.

Due to the nature of the implementation of the quota wherein 1) production from individual fields is removed until aggregate production is less than the annual quota limit, 2) production is removed in order of the most expensive to the least expensive, and 3) the quota decreases linearly until 2045, county's loss in tax revenue will vary over the years 2020–2045. Examining the time-profile of property tax revenues, Figure IV.11. shows that oil and gas property tax revenue losses decline gradually each year before increasing again. The only notable exception is Kern County, which will experience more dramatic changes in tax revenues over time.

Many counties with crude oil production are already experiencing a declining share of their property tax revenues coming from oil and gas operations. This is in part because of declining crude oil production in these counties, as well as increasing value of residential, commercial and agricultural properties. For example, Kern County's share of assessed property value in commercial and agricultural properties increased by 5% ($4.1 billion), whereas its share of assessed value for oil and gas property declined by 7.7% from FY 2019–2020 (63).

TABLE IV.3. Average loss in annual county tax revenue over 2020–2045 for all impacted counties under the LCE1 and LCE2 scenarios compared to E-BAU.

County	Tax revenue loss (million $2020)	
	LCE1	LCE2
Fresno	-1.42	-1.34
Kern	-26.97	-24.40
Kings	-0.04	-0.03
Los Angeles	-0.65	-2.90
Monterey	-2.64	-2.46
Orange	0.00	-0.47
San Luis Obispo	-0.02	-0.02
Santa Barbara	0.00	-0.09
Tulare	-0.02	-0.03
Ventura	-0.48	-0.95

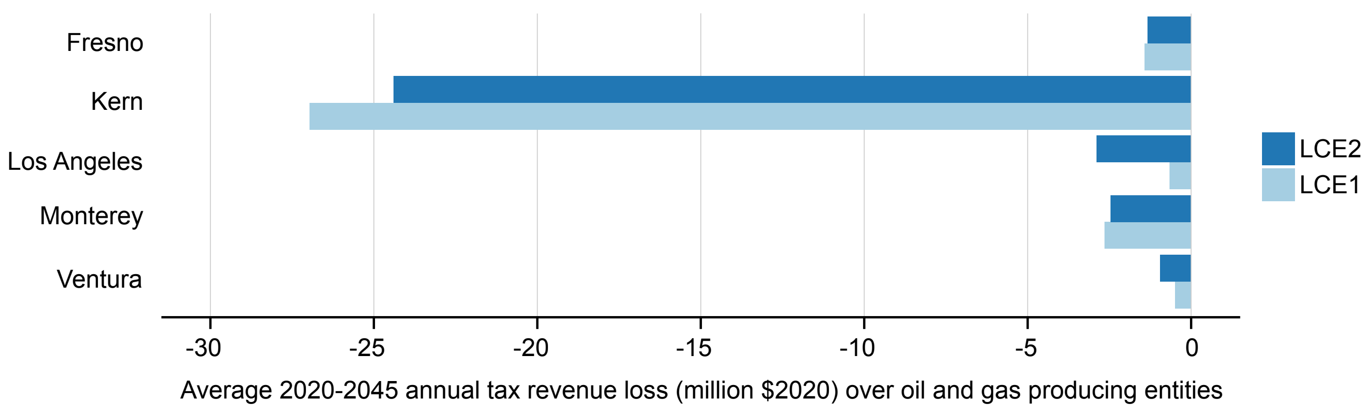


FIGURE IV.10. Average loss in annual county tax revenue (millions $2020) over 2020–2045 for the top five impacted counties under the LCE1 and LCE2 scenarios compared to E-BAU.

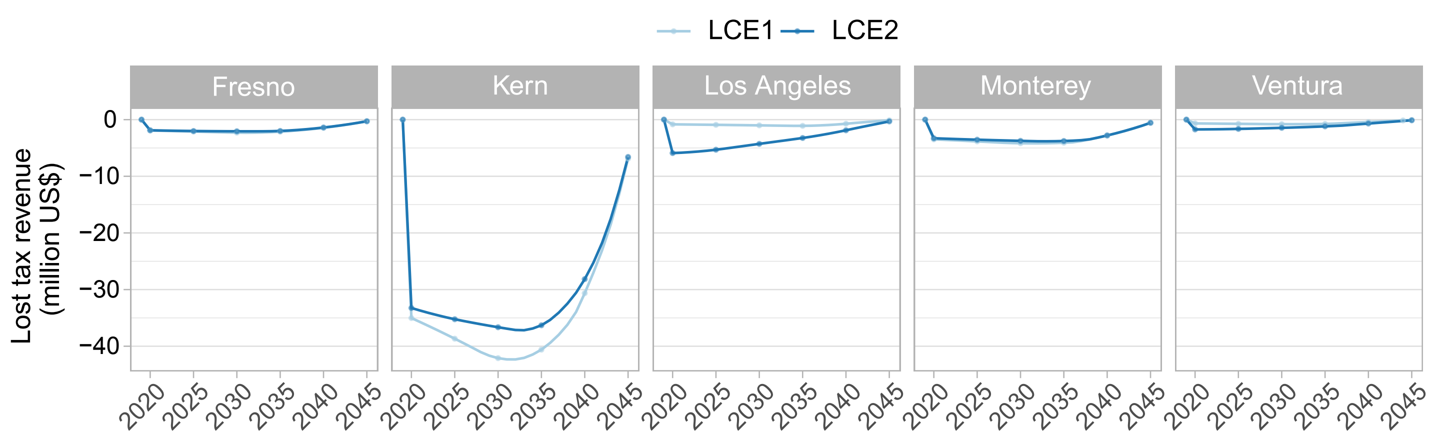


FIGURE IV.11. Loss in annual county tax revenue (in million $) from 2020 to 2045 under the LCE1 and LCE2 scenarios compared to E-BAU.

CHAPTER 5

LABOR IMPACT ANALYSIS

“Collection of Construction Safety Helmet” by Skitterphoto; license: CC0

In this chapter, we present the estimated results for the full-time equivalent (FTE) job-years employment and total compensation under the business-as-usual (BAU) and low carbon scenarios for the transportation fossil fuel supply sector (TFFSS). The results are shown for each trajectory between the baseline year of 2019 and to the end period of 2045, and also for net impact of a low carbon scenario relative to BAU.

The results are derived from the IMPLAN model and estimated for the following years: 2019 (baseline), 2020, 2025, 2030, 2035, 2040 and 2045, and then linearly interpolated between the five-year increments to produce an annual series. The year 2019 is the baseline so that the data inputs are observed and not projected by the TFFSS extraction and refining models. The estimates for the years 2020, 2025, 2030, 2035, 2040 and 2045 are derived from the TFFSS extraction and refining model projections for revenues, given by quantity produced times the price (see Chapter II for an overview of modeling methods) that are then used as inputs in IMPLAN.

A. / IMPLAN BASELINE LABOR ANALYSIS FOR 2019

Tables V.1. and V.2. report the direct, indirect, induced, and total FTE employment and total worker compensation supported by the TFFSS in 2019, the baseline year in our analysis. In 2019, the extraction segment of the TFFSS directly supported close to 12,000 FTE job-years, an additional 11,405 FTE job years through indirect effects (including employment in non-contracted construction industry), and 9,618 through induced effects. In total, the extraction segment supported 31,320 FTE job-years in 2019. Thus, directly supported FTE employment in the extraction segment accounts for close to 40% of the total FTE employment supported by the extraction segment.

Regionally, we focus on the seven leading counties where extraction employment is located: Kern, Los Angeles, Fresno, Monterey, Orange, Ventura and Santa Barbara. These seven counties account for 99% of direct FTE employment supported by the extraction segment in 2019. Total FTE employment supported by California's extraction segment is most concentrated

TABLE V.1. FTE employment supported by extraction and refining segments of the transportation fossil fuel supply sector in 2019 (job-years)

	FTE employment (job-years)			
	Direct	Indirect	Induced	Total
Extraction, statewide				
	11,885	11,405	9,618	31,320
7 extraction counties				
Kern	6,458	1,346	1,642	9,446
Los Angeles	2,777	3,393	1,901	8,071
Fresno	732	1,242	696	2,670
Monterey	663	255	215	1,134
Orange	510	1,623	1,981	4,114
Ventura	399	427	360	1,186
Santa Barbara	177	264	222	663
Refining, statewide				
	5,571	12,694	7,181	25,446
4 refining counties				
Los Angeles	3,148	11,308	6,567	21,022
Contra Costa	1,895	797	353	3,045
Solano	402	309	137	848
Kern	127	280	124	531

TABLE V.2. Total worker compensation supported by extraction and refining segments of the transportation fossil fuel supply sector in 2019 (in millions of $2019)

	Total worker compensation ($2019, millions)			
	Direct	Indirect	Induced	Total
Extraction, statewide				
	1,388	948	470	2,479
7 extraction counties				
Kern	1,103	87	74	1,264
Los Angeles	66	287	107	460
Fresno	51	99	84	234
Monterey	73	18	9	99
Orange	3	101	38	142
Ventura	62	35	17	113
Santa Barbara	29	21	10	60
Refining, statewide				
	1,604	1,843	838	2,799
4 refining counties				
Los Angeles	904	737	363	2,004
Contra Costa	547	39	15	600
Solano	126	13	5	144
Kern	27	18	6	51

in Kern and Los Angeles Counties. Moreover, directly supported FTE employment is largest in Kern County, whereas indirect and induced FTE employment supported by the extraction segment is larger than the directly supported FTE employment in Los Angeles County.

The refining segment of the TFFSS directly supported 5,571 FTE job-years in 2019, with a markedly larger additional 12,694 FTE job years through indirect effects (including, to a large extent, employment in the distribution segment), and 7,181 through induced effects. In total, the refining segment supported 25,446 FTE job-years. Los Angeles County accounted for 21,022 FTE jobs in total employment supported by refining (including 3,148 directly supported FTE jobs), whereas Contra Costa County had 1,895 FTE jobs directly supported by refining.

In 2019, the extraction segment of the TFFSS directly generated $1.4 billion in total worker compensation, with $948 million and $470 million through indirect and induced effects, respectively, for a total of $2.5 billion in total worker compensation stemming from the extraction segment. More than half of this total worker compensation accrues to workers in Kern County ($1.3 billion).

In 2019, the refining segment accounted for $1.6 billion in directly supported worker compensation, with an additional $1.8 billion from indirectly supported activities and $838 million from induced economic activities. In total, $2.8 billion in total worker compensation statewide was associated with the TFFSS refining segment. Over 70% of this total accrues from activities in Los Angeles County; Contra Costa County accounts for most of the remainder.

B. / ANALYSIS OF STATEWIDE DIRECT IMPACTS

Figure V.I. shows the projected trajectory of statewide FTE employment in jobs-years from 2019 to 2045 that is directly supported by the TFFSS. We then report similar figures for all outcomes and segments.

The estimates indicate that in 2019 the TFFSS extraction segment directly supported close to 12,000 job-years. In 2020, under all scenarios, this number is reduced significantly, in part due to the large drop in global oil prices and demand for oil products caused by the COVID-19 pandemic, and to the extraction model idiosyncrasies (see Chapter IV.b. for further details). The labor market outcomes are the same for the BAU and decarbonization scenarios in the baseline year of 2019 since the TFFSS model begins its prediction in the year 2020. As a result, the estimates for 2019 will not contribute to the scenario impact analysis that compares labor market outcomes under a low carbon scenario relative to a BAU scenario. Thus, the 2020–2019 drop in quantity extracted and refined will not affect our ranking and interpretation of scenario impacts relative to BAU.

From 2020 to 2025, FTE employment in the extraction segment is projected to increase across the E-BAU, LCE1 and LCE2 scenarios, after which FTE employment trajectories diverge. Under the E-BAU scenario, FTE employment in extraction directly supported by California's TFFSS sector is projected to remain relatively constant at about 8,200 job-years from 2026 to 2045. This is noteworthy as production is projected to decline in the segment, but in spite of this, revenues are expected to grow under the projected price path of crude oil from the US Energy Information Administration (see Figure 20 in the Technical Appendix).

Under the LCE1 and LCE2 scenarios, direct FTE employment in the extraction segment trends down, from roughly 8,200 (LCE1) and 6,700 (LCE2) in 2025 to 3,100 (LCE1) and 2,700 (LCE2) in 2045 (all in job-years). Notably, the FTE employment trajectories in extraction are similar for the LCE1 (20% production quota) and LCE2 scenarios which adds a mandated 2,500-foot setback to LCE1.

Figure V.2. reports the projected trajectory of statewide FTE employment in jobs-years directly supported by the refining segment from 2019 to 2045. Following a drop in FTE employment between the baseline year of 2019 and the model-output year of 2020, directly supported FTE employment in refining is projected to grow from 2020 to 2025 across the R-BAU, LCR1, and LCR2 scenarios.

Under the R-BAU scenario, from 2026 to 2045, direct FTE employment in the refining segment is projected to experience a small increase, from 4,810 jobs-years in 2026 to 5,075 jobs-years in 2045. For both the LCR1 and LCR2 scenarios directly-supported FTE employment is expected to decline.

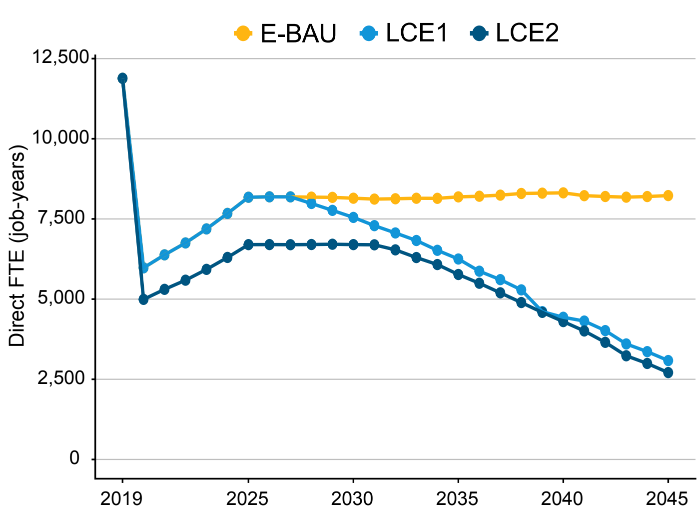


FIGURE V.1. Projected directly supported FTE employment trajectories in the transportation fossil fuel supply sector extraction segment, 2019–2045 (Job-Years). The yellow line corresponds with the E-BAU scenario, the light blue line corresponds with the LCE1 scenario, and the dark blue line corresponds with the LCE2 scenario (the scenario that is projected to produce the largest reduction in GHGs). By construction, the E-BAU, LCE1 and LCE2 numbers are the same in the baseline (pre-model) year of 2019.

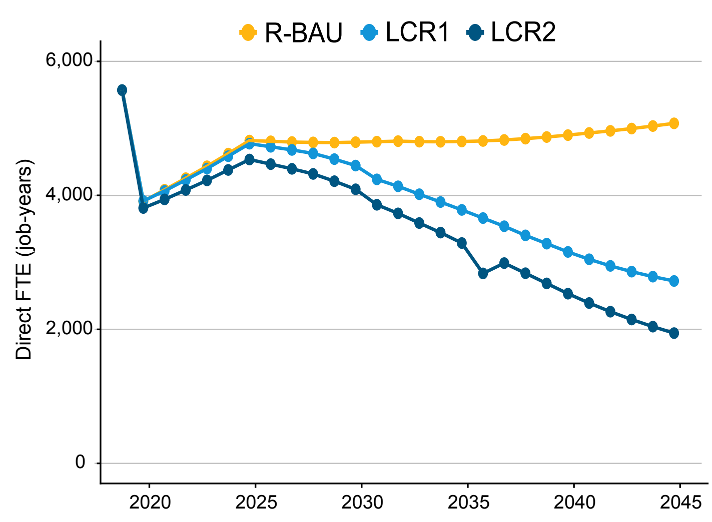


FIGURE V.2. Projected directly supported FTE employment trajectories in the transportation fossil fuel supply sector refining segment, 2019–2045 (Job-Years). The yellow line corresponds with the R-BAU scenario, the light blue line corresponds with the LCR1 scenario, and the dark blue line corresponds with the LCR2 scenario (the scenario that is projected to produce the largest reduction in GHGs). By construction, the R-BAU, LCR1 and LCR2 numbers are the same in the baseline (pre-model) year of 2019.

Figures V.3. and V.4. summarize the estimates contained in Figures V.1. and V.2. by summing the direct FTE employment trajectory for every year from 2019 to 2045 under each scenario. Figure V.3. reports the results for directly supported employment in the extraction segment. In the E-BAU scenario, FTE employment is projected to grow by 218,025 job-years between 2019 and 2045, or by approximately 8,075 job-years per year on an annualized basis. In the low carbon scenarios for the extraction segment, FTE employment grows by 171,850 job-years (LCE1) and by 152,643 job-years (LCE2). The net impact of each low carbon scenario relative to the E-BAU estimate is -46,174 job-years (LCE1) and -65,382 job-years (LCE2). Over the 27-year period from 2019 to 2045, these net employment impacts correspond to 21% and 30% reductions in FTE employment in job-years in the extraction segment, relative to the E-BAU scenario. These estimates also allow us to isolate the impact of the 2,500-foot setback policy in LCE2 relative to the 20% production quota policy in LCE1. The net impact of the 2,500-foot setback policy for directly supported employment in extraction is -19,208 FTE job-years over 2019–2045.

Figure V.4. presents directly supported FTE employment in the refining segment. Direct employment impacts for refining are smaller than for extraction due to the smaller size of segment. The R-BAU scenario results in a projected growth of directly supported FTE employment of 128,953 job-years from 2019 to 2045. Projected directly supported FTE employment growth over the same period is smaller under the low carbon scenarios for the refining segment: 106,039 job-years (LCR1) and 94,611 (LCR2). The net impacts of each low carbon scenario on direct FTE employment, relative to the R-BAU scenario are -22,914 (LCR1) and -34,341 (LCR2), corresponding to -18% and -27% impacts relative to the R-BAU scenario, respectively.

Figures V.5. and V.6. report total worker compensation directly supported by the extraction (Figure V.5.) and refining (Figure V.6.) segments of California's TFFSS as projected under each scenario trajectory. The values are in millions of 2019 dollars and future dollar values are discounted to 2019 using a 3% discount rate.

For the extraction segment, Figure V.5. shows that in the E-BAU scenario, direct total worker compensation is projected to grow by $19 billion between 2019 and 2045, or by approximately $0.7 billion per year on an annualized basis. For the LCE1 and LCE2 scenarios, the corresponding estimate is approximately $15 billion. Both scenarios project an impact on extraction

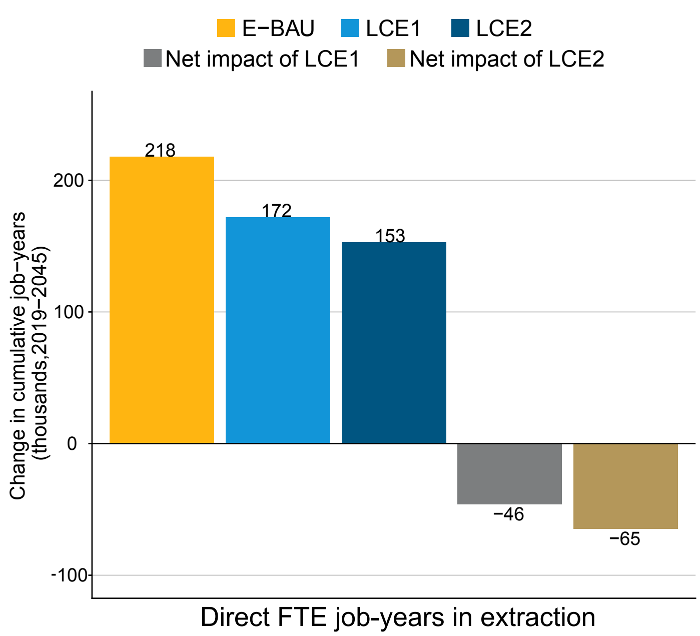


FIGURE V.3. Projected cumulative impact of E-BAU, LCE1 and LCE2 scenarios on directly supported FTE employment in the transportation fossil fuel supply sector extraction segment, 2019–2045 (thousands of job-years).

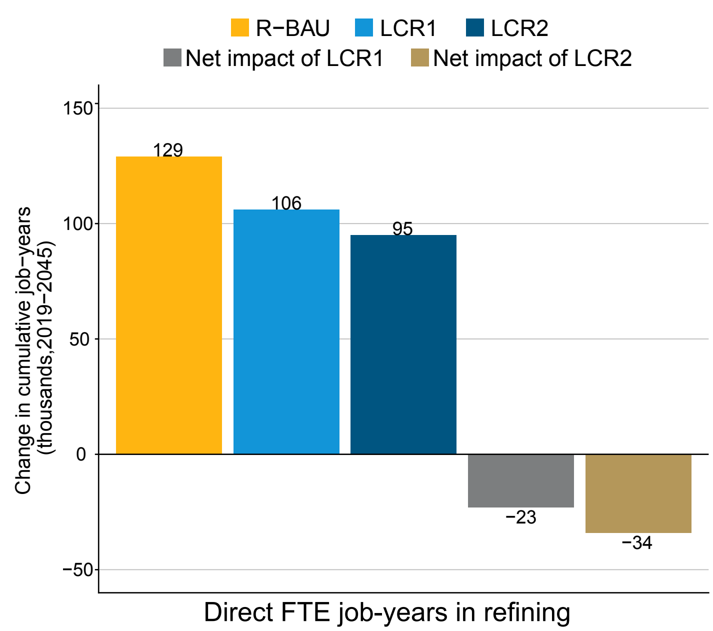


FIGURE V.4. Projected cumulative impact of R-BAU, LCR1 and LCR2 scenarios on directly supported FTE employment in the transportation fossil fuel supply sector refining segment, 2019–2045 (thousands of job-years).

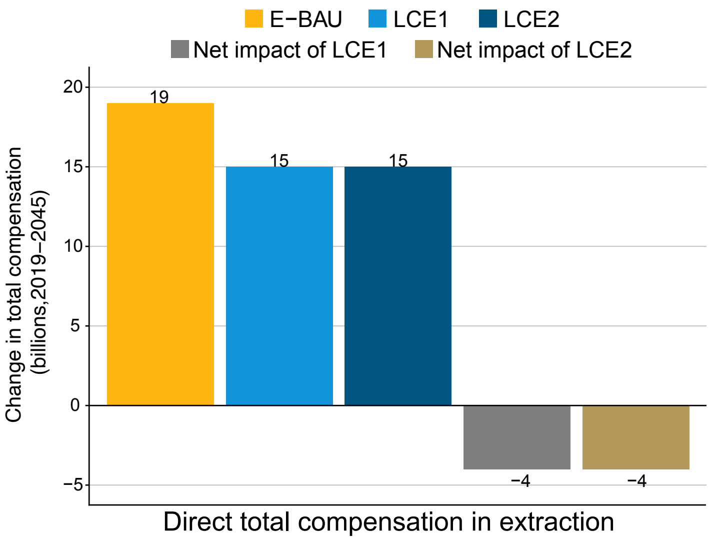


FIGURE V.5. Present discounted value of projected cumulative impact of E-BAU, LCE1 and LCE2 scenarios on directly supported total worker compensation in the transportation fossil fuel supply sector extraction segment, 2019–2045 ($2019 billions). The discount rate used in the calculations is 3%.

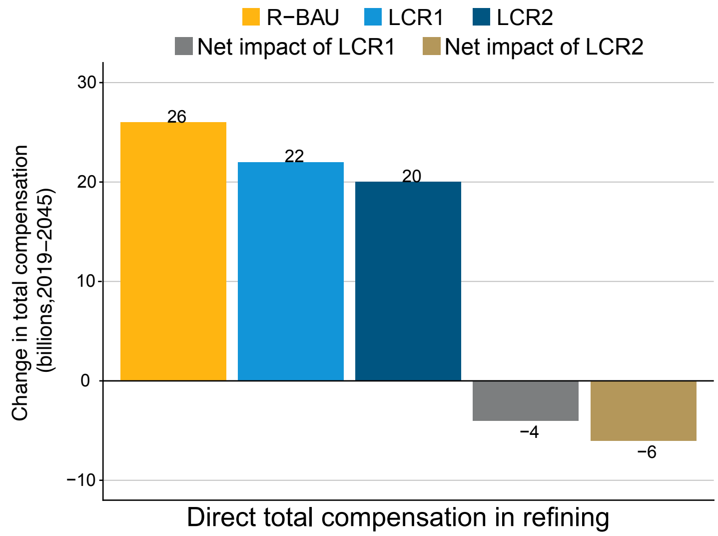


FIGURE V.6. Present discounted value of projected cumulative impact of R-BAU, LCR1 and LCR2 scenarios on directly supported total worker compensation in the refining segment, 2019–2045 ($2019 billions). The discount rate used in the calculations is 3%.

direct total worker compensation of roughly -$4 billion, or -20%, between 2019 and 2045, relative to the E-BAU scenario.

The corresponding estimates for the refining segment are shown in Figure V.6. For the R-BAU scenario, direct total worker compensation is projected to grow by $26 billion between 2019 and 2045. Under the LCR1 scenario, the projected cumulative increase in refining total worker compensation is $22 billion, whereas it is $20 billion under LCR2. Relative to the projected growth under the R-BAU scenario, the low carbon scenarios in the refining segment project impacts of -$4 billion, or -15%, (LCR1) and -$6 billion, or -23%, (LCR2) for directly supported worker compensation.

C. / REGIONAL ANALYSIS OF DIRECT IMPACTS

We now turn to a regional, county-level analysis of the FTE employment and total worker compensation directly supported in the extraction and refining segments of California's TFFSS.

Figure V.7 reports the projected cumulative directly supported FTE employment in extraction under the E-BAU, LCE1 and LCE2 scenarios. We focus on the seven leading counties where extraction employment is located: Kern, Los Angeles, Fresno, Monterey, Orange, Ventura and Santa Barbara. These seven counties account for 99% of TFFSS extraction employment under the E-BAU scenario from 2019 to 2045.

In absolute terms, Kern and Los Angeles Counties are the most impacted by the low carbon scenarios. For Kern County, both LCE1 and LCE2 are projected to reduce cumulative FTE employment in extraction by 32,000 to 33,000 job-years between 2019 and 2045, relative to the baseline projection. In percentage terms, these correspond to impacts of -24% and -25%. The LCE2 scenario has a notably larger impact on projected FTE employment in Los Angeles County compared to LCE1, with a net impact of -20,000 job-years relative to

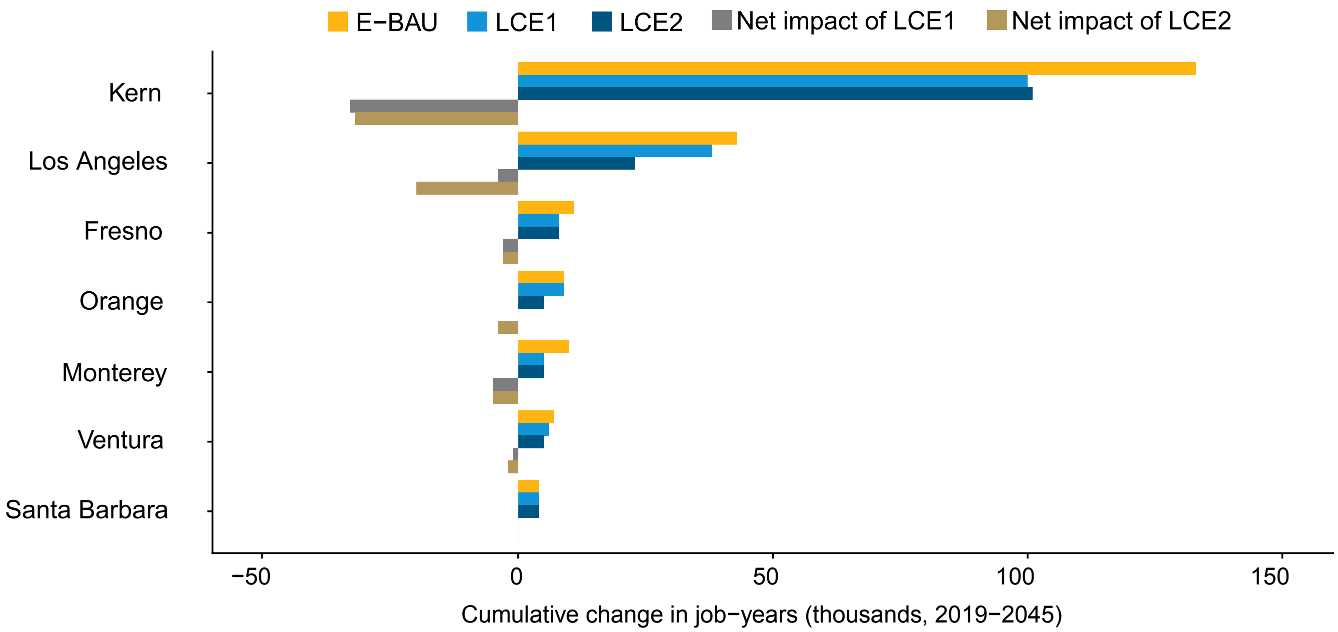


FIGURE V.7. Projected cumulative impact of E-BAU, LCE1 and LCE2 scenarios on directly supported FTE employment in the transportation fossil fuel supply sector extraction segment from 2019 to 2045 in the seven largest extraction counties in California. The yellow, light blue and dark blue bars on the positive side of the figure correspond to the cumulative change in FTE employment directly supported by the extraction segment (in thousands of job-years between 2019 and 2045) in the E-BAU, LCE1 and LCE2 scenarios, respectively. The gray and brown bars represent the net impact of the LCE1 and LCE2 scenarios, relative to the E-BAU scenario, again in terms of cumulative change in FTE employment directly supported by the extraction segment.

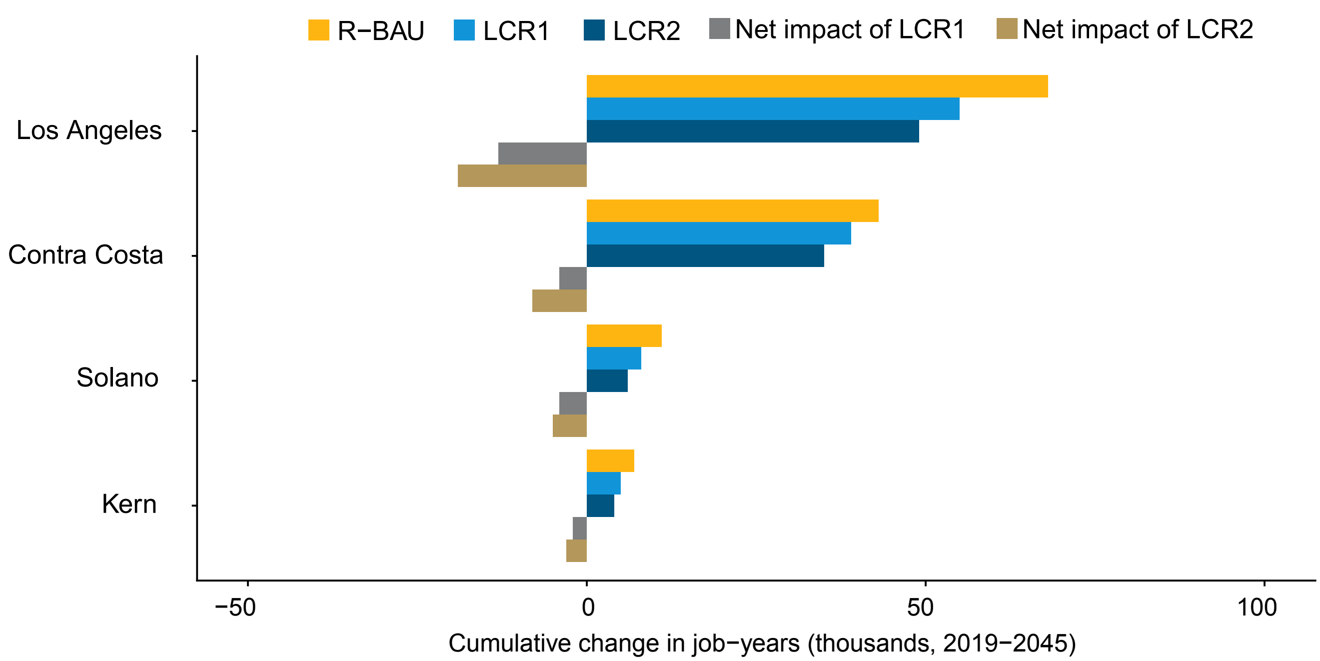


FIGURE V.8. Projected cumulative impact of R-BAU, LCR1 and LCR2 scenarios on directly supported FTE employment in the transportation fossil fuel supply sector refining segment from 2019 to 2045 in the four refining counties in California. The yellow, light blue and dark blue bars on the positive side of the figure correspond to the cumulative change in FTE employment directly supported by the refining segment (in thousands of job-years between 2019 and 2045) in the R-BAU, LCR1 and LCR2 scenarios, respectively. The gray and brown bars represent the net impact of the LCR1 and LCR2 scenarios, relative to the R-BAU scenario, again in terms of cumulative change in FTE employment directly supported by the refining segment.

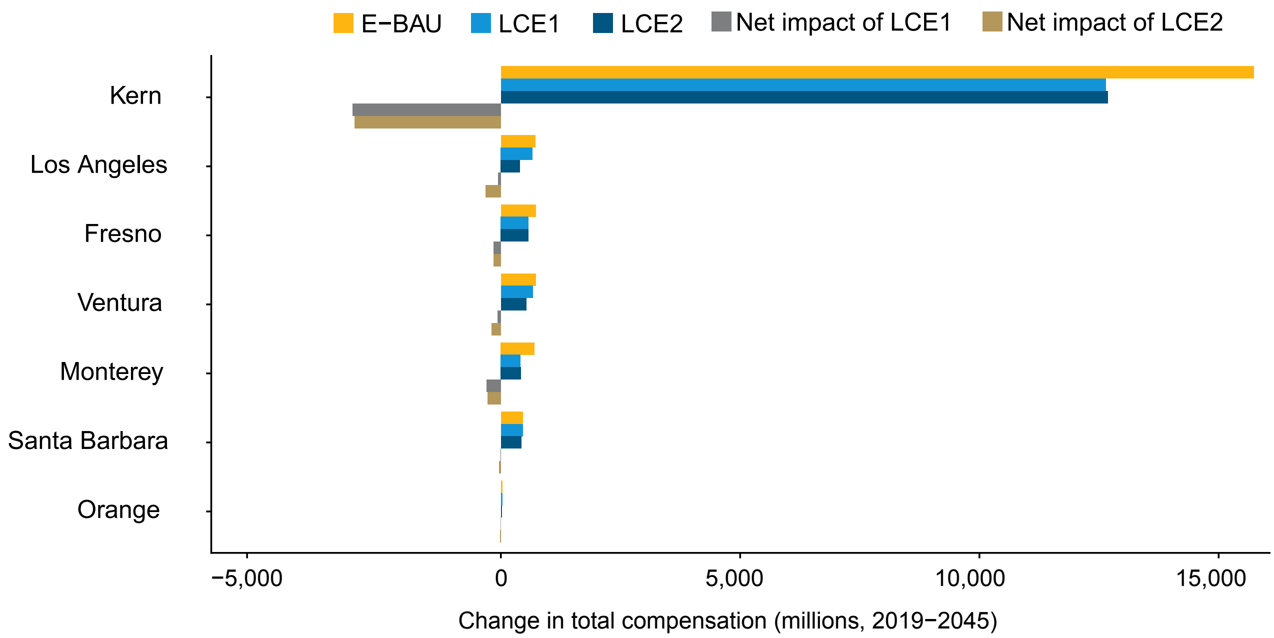


FIGURE V.9. Present discounted value of projected cumulative impact of E-BAU, LCE1 and LCE2 scenarios on directly supported total worker compensation in the transportation fossil fuel supply sector extraction segment from 2019 to 2045 in the largest extraction counties in California in terms of employment. The yellow, light blue and dark blue bars on the positive side of the figure correspond to the cumulative change in total worker compensation directly supported by the extraction segment (in $2019 millions between 2019 and 2045) in the E-BAU, LCE1 and LCE2 scenarios, respectively. The gray and brown bars represent the net impact of the LCE1 and LCE2 scenarios, relative to the E-BAU scenario, again in terms of cumulative change in total worker compensation directly supported by the extraction segment. The discount rate used in the calculations is 3%.

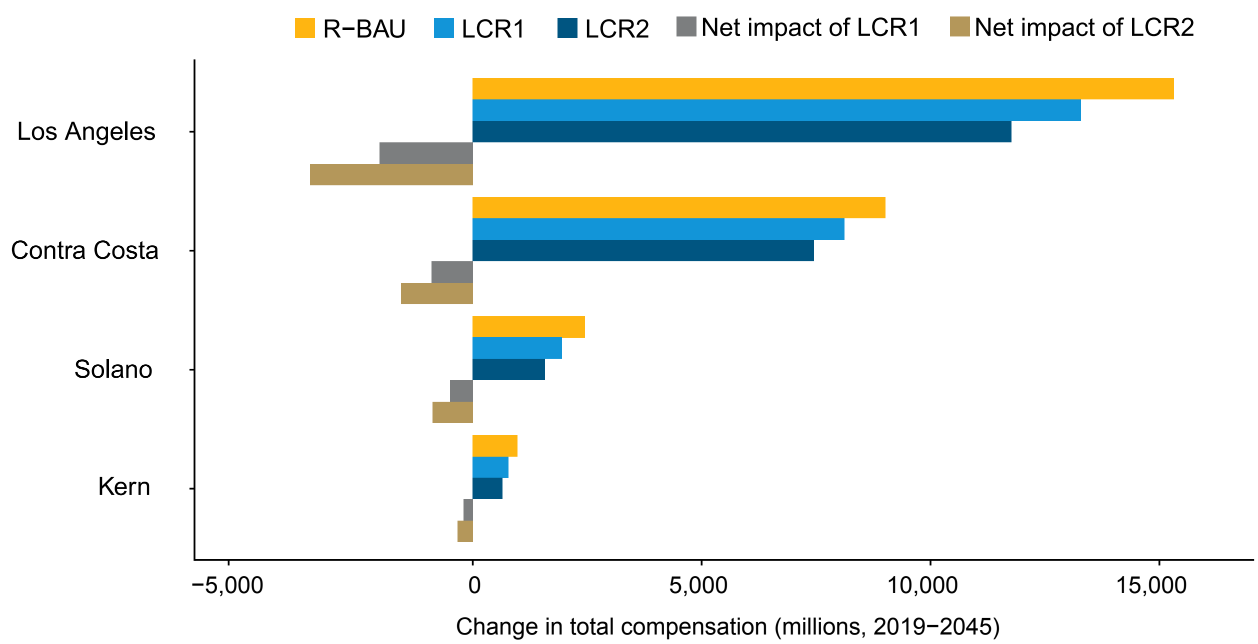


FIGURE V.10. Present discounted value of projected cumulative impact of R-BAU, LCR1 and LCR2 scenarios on directly supported total worker compensation in the transportation fossil fuel supply sector refining segment from 2019 to 2045 in the four refining counties in California. The yellow, light blue and dark blue bars on the positive side of the figure correspond to the cumulative change in total worker compensation directly supported by the refining segment (in $2019 millions between 2019 and 2045) in the R-BAU, LCR1 and LCR2 scenarios, respectively. The gray and brown bars represent the net impact of the LCR1 and LCR2 scenarios, relative to the R-BAU scenario, again in terms of cumulative change in total worker compensation directly supported by the refining segment. The discount rate used in the calculations is 3%.

the E-BAU scenario, amounting to a -46% impact over 2019–2045.

Figure V.8. shows the projected cumulative directly supported FTE employment in refining under the R-BAU, LCR1 and LCR2 scenarios. This analysis pertains to the four counties with refining activity in California: Los Angeles, Contra Costa, Solano and Kern.

The two largest refining counties in California in terms of production, Los Angeles and Contra Costa, are also the two most impacted counties by the low carbon scenarios in terms of direct FTE employment. LCR2 leads to larger reductions in directly supported FTE employment than LCR1. Across the four refining counties, the projected change in directly supported FTE employment under the low carbon scenarios between 2019 and 2045 ranges from -10% to -46%, relative to the R-BAU FTE employment trajectory.

Figures V.9. and V.10. report projected impacts of the low carbon scenarios on directly supported total worker compensation between 2019 and 2045. As in Figures V.5. and V.6., the cumulative projected impacts are discounted in present value terms to the year 2019 using a 3% discount rate, and dollars are adjusted for inflation to 2019 levels. Otherwise, Figures V.9. (extraction) and V.10. (refining) are organized in the same manner as Figures V.7. and V.8.

Figure V.9. shows that the largest projected impacts of the low carbon scenarios on the extraction segment total worker compensation are concentrated in Kern County. Specifically, the model projects that the discounted cumulative directly supported total worker compensation will decline by $3 billion, or -20%, between 2019 and 2045 for the LCE1 and LCE2 scenarios, relative to the E-BAU scenario.

In the case of projected impacts for total worker compensation directly supported by the refining segment, Los Angeles County is the most impacted. The present discounted value of cumulative total worker compensation under LCR1 and LCR2 over 2019–2045 and relative to the R-BAU scenario is -$0.23 billion to -$3.1 billion.

In the case of projected impacts for total worker compensation directly supported by the refining segment, Los Angeles County is the most impacted. The present discounted value of cumulative total worker compensation under LCR1 and LCR2 over 2019–2045 and relative to the R-BAU scenario is -$0.23 billion to -$3.1 billion.

D. / ANALYSIS OF TOTAL IMPACTS

We conclude this chapter by presenting the results for the total impacts on FTE employment in job-years and total worker compensation. The total impacts are defined as the sum of the direct, indirect, and induced effects of changes in activity in the extraction and refining segments of the TFFSS. Thus, in the case of total effects, the employment and compensation impacts are not limited to workers in the extraction and refining segment industries; these impacts can occur in any industry that is economically linked to the extraction and refining segments. The figures and tables are structured using the same convention as earlier in the chapter.

Figure V.11. shows that under the E-BAU scenario, the projected total cumulative FTE employment (inclusive of direct, indirect, and induced effects) supported by the extraction segment of California's TFFSS amounts to 673,000 jobs-years over 2019–2045. By comparison, projected total cumulative FTE employment in job-years associated with activity in the extraction segment under the LCE1 and LCE2 scenarios is 549,000 and 480,000, respectively. This amounts to an estimated net impact of -123,000 FTE job-years over 2019–2045 under LCE1 and -193,000 FTE job-years under LCE2.

Figure V.12. presents total FTE employment supported by activity in the TFFSS refining segment under the BAU and low-carbon scenarios. An important difference between total FTE employment impact across extraction and refining segments is that total FTE employment impacts are significantly larger in the refining segment. This reflects the larger indirect and induced effects of activity in the refining segment (relative to the extraction segment), as shown in Tables V.1., V.2., and V.3. Compared to R-BAU, the net cumulative impact of LCR1 over 2019–2045 is a reduction in total FTE employment of 275,000 job-years (or -20% of R-BAU scenario job-years), while net cumulative impact of LCR2 over 2019–2045 is a reduction in total FTE employment of 474,000 job-years (or -37% of R-BAU scenario job-years).

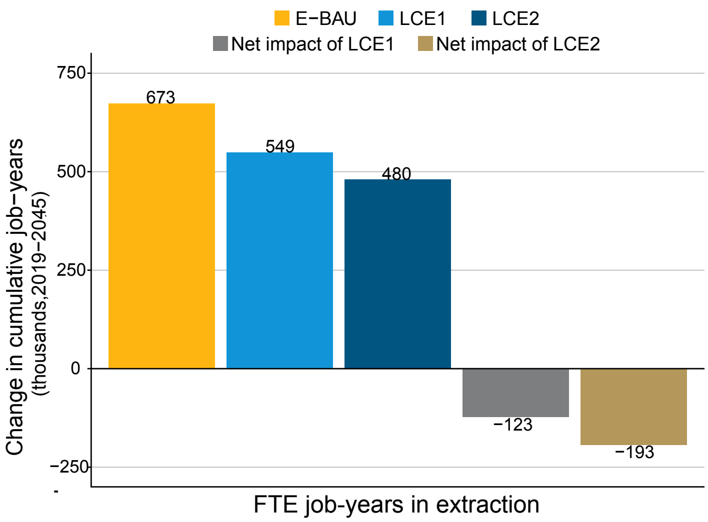


FIGURE V.11. Projected cumulative impact of E-BAU, LCE1 and LCE2 scenarios on total supported FTE employment by the transportation fossil fuel supply sector extraction segment from 2019 to 2045 (thousands of job-years).

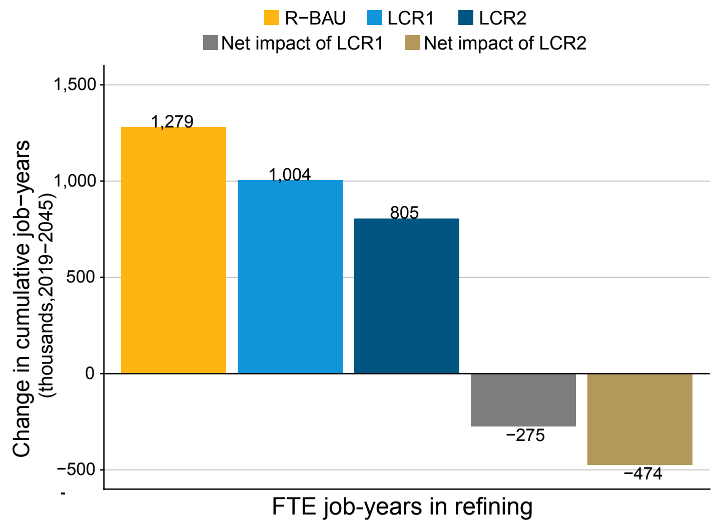


FIGURE V.12. Projected cumulative impact of R-BAU, LCR1 and LCR2 scenarios on total supported FTE employment by the transportation fossil fuel supply sector refining segment from 2019 to 2045 (thousands of job-years).

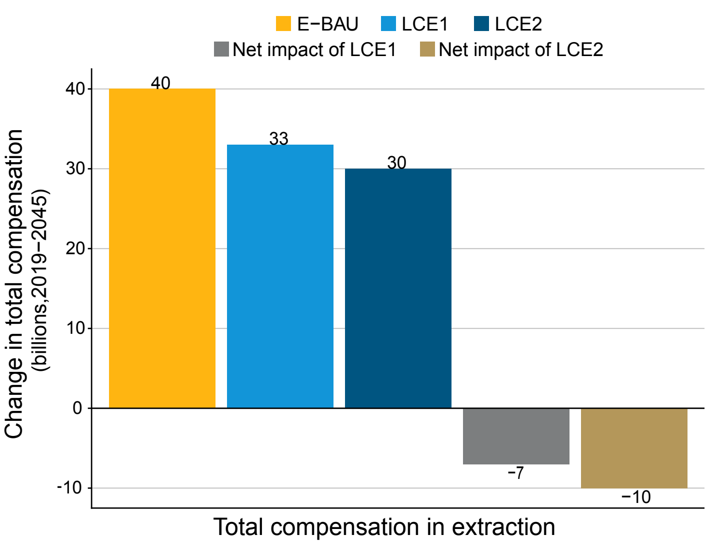


FIGURE V.13. Present discounted value of projected cumulative impact of E-BAU, LCE1 and LCE2 scenarios on total supported total worker compensation in the transportation fossil fuel supply sector extraction segment from 2019 to 2045 ($2019 billions). The discount rate used in the calculations is 3%.

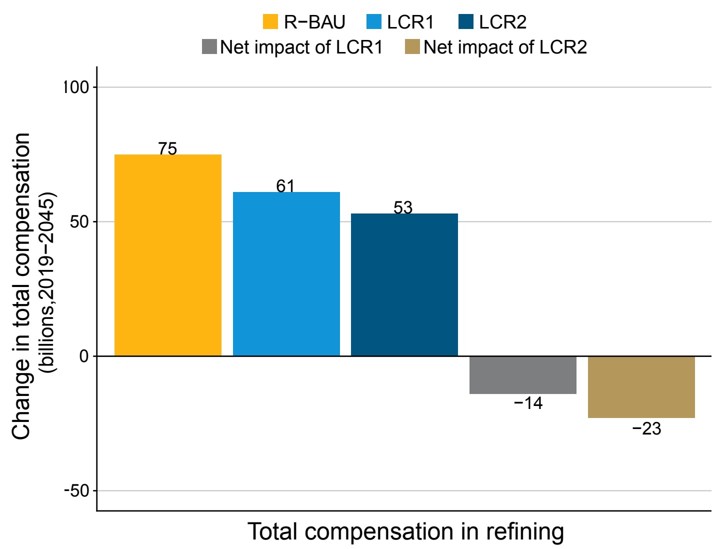


FIGURE V.14. Present discounted value of projected cumulative impact of R-BAU, LCR1 and LCR2 scenarios on total supported total worker compensation in the transportation fossil fuel supply sector refining segment from 2019 to 2045 ($2019 billions). The discount rate used in the calculations is 3%.

Figures V.13. and V.14. show the estimates for total worker compensation that reflect the direct, indirect and induced effects associated with the extraction and refining segments of the TFFSS. The projected discounted cumulative total worker compensation under the E-BAU scenario from 2019 to 2045 associated with the total economic activity generated by the extraction segment is $40 billion ($2019). By comparison, the same figures for the LCE1 and LCE2 scenarios are $33 billion and $30 billion, respectively. Relative to the E-BAU, the net impacts of the low carbon scenarios on total worker compensation are -$7 billion (LCE 1) and -$10 billion (LCE2).

The total impacts on worker compensation associated with the refining segment reported in Figure V.14. again highlight the importance of the indirect and induced channels associated with refining. The projected discounted cumulative total worker compensation under the R-BAU scenario from 2019 to 2045 associated with the total economic activity generated by the refining segment is $75 billion ($2019). This is almost twice the amount generated by the extraction segment. The cumulative total worker compensation under the LCR1 and LCR2 scenarios are $61 billion and $53 billion, respectively. In percentage terms, relative to the R-BAU scenario, the reduction in total worker compensation is -19% under LCR1 and -31% under LCR2.

Tables V.3. and V.4. report estimates at the county level. To ease interpretation and contextualization, the tables also report the statewide estimates of the direct and total supported FTE employment. These estimates are also reported in Figures V.3., V.4., V.11. and V.12. It is important to note that indirect and induced effects reported are not limited to the seven extraction counties or four refining counties listed in the table. Indirect and induced effects that occur outside of the key extraction and refining counties are included in the calculation of the statewide impacts.

When considering the total FTE employment impacts that account for direct, indirect and induced effects, the regional analysis leads to a similar conclusion as for the direct impacts. For the extraction segment, the total FTE employment effects are concentrated in Kern, Los Angeles and Fresno Counties. These three counties account for approximately two-thirds of the total impact on cumulative FTE employment in job-years.

The difference between direct and total impacts is especially relevant for the refining segment, which generates much larger indirect and induced FTE employment effects compared to extraction. In particular, the total impact on FTE employment statewide between 2019 and 2045 in the R-BAU scenario amounts to 1.3 million FTE job-years, 630,000 of which occur in the four refining counties, with the rest occurring in other counties. Across the LCR1 and LCR2 scenarios, Los Angeles County is predicted to be the most impacted in terms of total FTE employment, with projected cumulative FTE employment impacts of

TABLE V.3. Total FTE employment supported by extraction and refining segments of the transportation fossil fuel supply sector from 2019 to 2045 (job-years)

	FTE employment (job-years)				
	E-BAU	LCE1	LCE2	LCE1 - E-BAU	LCE2 - E-BAU
Extraction, statewide					
Direct impact	218,025	171,850	152,643	-46,175	-65,382
Total impact	672,553	549,205	479,622	-123,348	-192,931
7 extraction counties					
Kern	203,873	158,871	158,110	-45,001	-45,762
Los Angeles	143,325	127,482	82,592	-15,843	-60,733
Fresno	96,032	79,205	76,291	-16,827	-19,742
Monterey	18,718	12,339	12,180	-6,379	-6,538
Orange	45,652	41,388	26,487	-4,264	-19,165
Ventura	21,994	18,781	16,877	-3,214	-5,117
Santa Barbara	13,590	12,058	11,345	-1,532	-2,245
	R-BAU	LCR1	LCR2	LCR1 - R-BAU	LCR2 - R-BAU
Refining, statewide					
Direct impact	128,953	106,039	94,611	-22,914	-34,342
Total impact	1,278,972	1,003,620	805,012	-275,352	-473,960
4 refining counties					
Los Angeles	504,419	401,661	332,903	-102,758	-171,515
Contra Costa	73,546	64,384	59,171	-9,161	-14,375
Solano	23,173	15,212	11,919	-7,961	-11,254
Kern	26,441	15,109	10,405	-11,332	-16,036

TABLE V.4. Present discounted value of total worker compensation supported by extraction and refining segments of the transportation fossil fuel supply sector from 2019 to 2045 ($2019, millions)

	Total worker compensation ($2019, millions)				
	E-BAU	LCE1	LCE2	LCE1 - E-BAU	LCE2 - E-BAU
Extraction, statewide					
Direct impact	19,105	15,445	15,061	-3,660	-4,044
Total impact	40,084	33,052	30,275	-7,032	-9,809
7 extraction counties					
Kern	18,327	14,879	14,830	-3,449	-3,498
Los Angeles	1,418	1,262	1,087	-156	-331
Fresno	3,679	3,132	3,020	-548	-659
Monterey	5,861	5,351	3,566	-510	-2,295
Orange	1,056	714	705	-341	-350
Ventura	867	812	755	-55	-112
Santa Barbara	1,846	1,684	1,134	-161	-712
	R-BAU	LCR1	LCR2	LCR1 - R-BAU	LCR2 - R-BAU
Refining, statewide					
Direct impact	25,627	21,989	19,965	-3,638	-5,662
Total impact	75,082	61,428	52,554	-13,655	-22,528
4 refining counties					
Los Angeles	32,048	27,019	23,694	-5,029	-8,354
Contra Costa	9,610	8,663	8,023	-946	-1,587
Solano	2,740	2,014	1,686	-726	-1,054
Kern	1,746	936	229	-811	-1,517

-102,758 (LCR1) and -171,515 (LCR2).

Impact estimates for total compensation that account for indirect and induced effects are markedly larger than the direct impacts alone, in general by a factor of 2 or 3 for both the extraction and refining scenarios. The impacts of the low carbon scenarios on total worker compensation in the extraction segment (LCE1 and LCE2) are concentrated in Kern County. The impacts of the low carbon scenarios on the refining segment (LCR1 and LCR2) are concentrated in Los Angeles County.

CHAPTER 6
HEALTH AND AIR POLLUTION ANALYSIS

Photo: “Conoco Phillips refinery sunset” by Nick Fullerton; license: CC BY 2.0

A. / PROJECTED CONTRIBUTION OF THE TRANSPORTATION FOSSIL FUEL SUPPLY SECTOR TO AMBIENT $PM_{2.5}$ AND TAC RELEASES

Figure VI.1. plots the projected contribution of the extraction and refining segments to ambient $PM_{2.5}$ under the business-as-usual (BAU) and low carbon scenarios, over the period 2019–2045. See Table IV.1. for details regarding the scenarios used in this study. We report averages across all census tracts in California. We derive ambient $PM_{2.5}$ contributions by applying a pollution transport model (InMAP model) to the projected trajectory of direct emissions of $PM_{2.5}$ and its precursors (NO_x, SO_x, VOCs, NH_3) from transportation fossil fuel supply sector (TFFSS) extraction and refining sites. We focus on contributions of the TFFSS to ambient concentrations of $PM_{2.5}$ (as opposed to direct releases of $PM_{2.5}$) because ambient concentrations of $PM_{2.5}$ are an input into the calculation of the health benefits. Moreover, we use the atmospheric transport feature of InMAP to better represent the exposure to $PM_{2.5}$ that originates from TFFSS sites. To ease interpretation and comparisons with the toxic air contaminants (TACs) analysis below, the series are normalized to take a value of one in the baseline year of 2019.

In the left panel (extraction), we can observe a sizable drop in $PM_{2.5}$ contribution between 2019 and 2020, even in the E-BAU scenario. This drop reflects the reduction in extraction driven by the reduction in global oil prices and demand for oil products caused by the COVID-19 pandemic and to the extraction model idiosyncrasies. Refer to Chapter IV.b. for a discussion of the 2019–2020 drop in crude oil production as a consequence of these impacts. The additional drop observed for scenario LCE2 relative to LCE1 can be interpreted as driven by the added stringency in LCE2.

Turning to the trends, under the E-BAU scenario, the contribution of the extraction segment of TFFSS to ambient $PM_{2.5}$ is projected to fall by more than 40% by 2045, whereas the contribution of the refining segment is projected to fall by 20%. In absolute levels, the extraction segment contributes on average 0.01 micrograms per cubic meter to statewide average ambient $PM_{2.5}$ of 10.5 micrograms per cubic meter at the baseline. The refining segment's contribution in level at the baseline is 0.19 micrograms per cubic meter.

For both refining and extraction, the contribution of each segment to ambient $PM_{2.5}$ concentration is projected to fall under the low carbon scenarios, with the more stringent scenarios LCE2 and LCR2 leading to larger declines. Relative to 2019 ambient $PM_{2.5}$

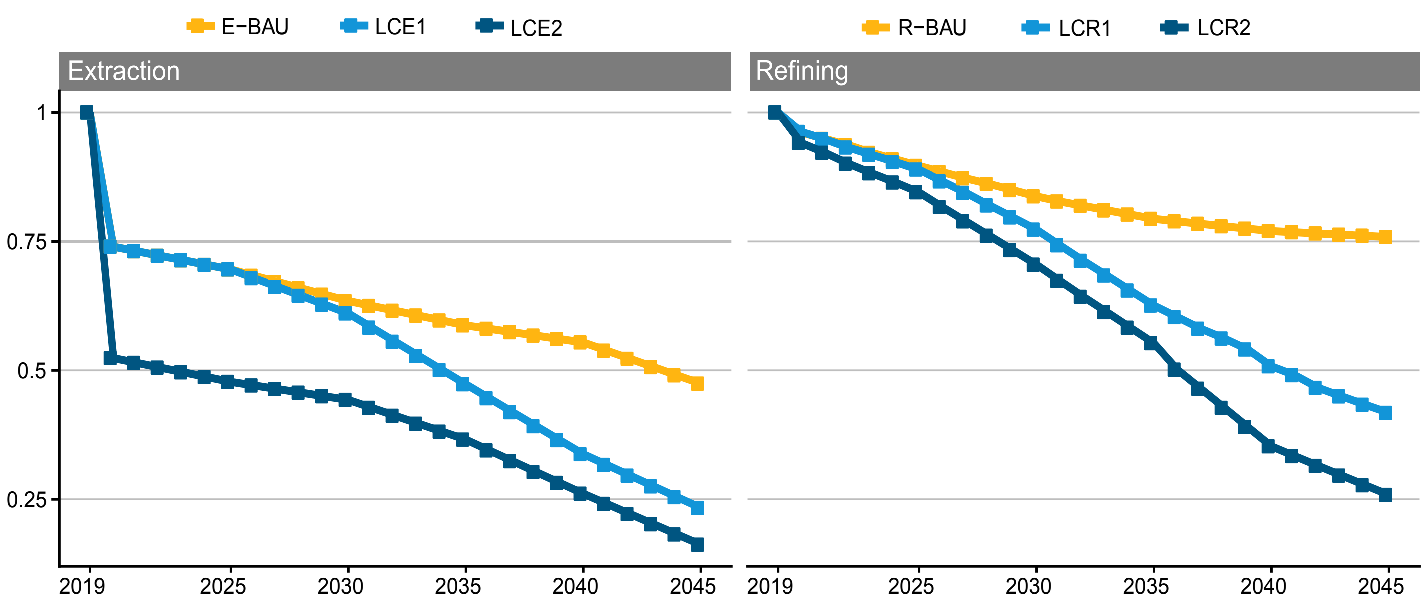


FIGURE VI.1. Estimated contribution of extraction and refining segments to ambient $PM_{2.5}$ for average census tract, under E-BAU, LCE1, LCE2, and R-BAU, LCR1 and LCR2 scenarios from 2019 to 2045. Each series is normalized by its value in 2019 so the entries are relative to 2019 values (2019 = 1).

contributions, LCE1 and LCE2 lead to the extraction segment contributing 77% and 84% less ambient $PM_{2.5}$, respectively, whereas LCR1 and LCR2 result in the refining segment contribution declines of 58% and 76%, respectively (Figure VI.1.).

Figure VI.2 plots the projected contribution of the extraction and refining segments to TAC releases under the BAU and low carbon scenarios from 2019 to 2045. We estimate TAC releases using the emissions factors for TACs and extraction and refining production quantities projected by the model. Throughout this chapter, we refer to the nine highest toxicity-weighted releases as "TACs". The toxicity weights, defined by the U.S. EPA, account for the cancer and non-cancer risks associated with exposure to the chemical compounds that make up TACs. These nine TACs are formaldehyde, benzene, nickel, arsenic, cadmium, chromium, acrolein, PAH and 1,3-butadiene. Data limitations prevented us from considering additional TACs and so the exposure estimates we report should be interpreted as underestimates.

In Figure VI.2., the left panel shows the projected trends in TAC releases for the extraction segment and the right panel shows projected TAC releases for the refining segment. Under the E-BAU scenario, releases of TACs are estimated to drop by 38% by 2045 compared to 2019, while releases from the refining segment under the R-BAU scenario are expected to fall by 21% relative to 2019.

The trajectory for total TACs emitted by the TFFSS trends downwards for all low carbon scenarios. Relative to 2019, TAC releases from the extraction segment decline (by 2045) by about 80% under both LCE1 and LCE2, whereas TAC releases from the refining segment decline by 56% (LCR1) and 69% (LCR2).

Figure VI.3. shows the changes in ambient $PM_{2.5}$ concentrations originating from the TFFSS extraction segment under the LCE2 scenario, reporting the difference in the cumulative projected concentration from 2045 to 2019. Ambient $PM_{2.5}$ originating from extraction sites is composed of direct emissions of $PM_{2.5}$ or its precursors, distributed through an atmospheric transport model. Negative values indicate a reduction in the contribution, and a darker shade indicates a larger reduction.

Figure VI.3. shows that the reduction in ambient $PM_{2.5}$ in the LCE2 scenario (relative to E-BAU in 2019) are concentrated around Kern County and adjacent counties, even after accounting for the atmospheric transport of emitted $PM_{2.5}$. Figure VI.4. presents the same information, but centers on Kern County. The first-order impact of the low carbon scenarios for extraction on ambient $PM_{2.5}$ concentrations in Kern County will

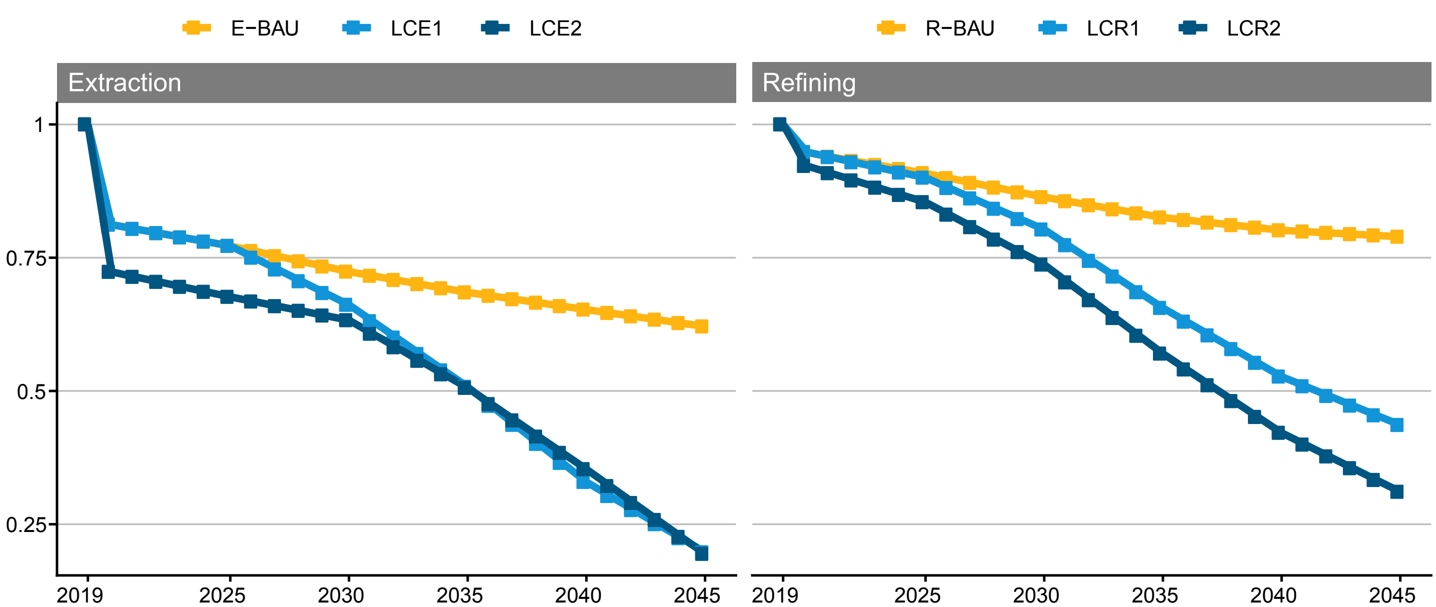


FIGURE VI.2. Estimated total releases of TACs from extraction and refining segments under E-BAU, LCE1, LCE2, R-BAU, LCR1, and LCR2 scenarios from 2019 to 2045. Each series is normalized by its value in 2019 so the entries are relative to 2019 values (2019 = 1).

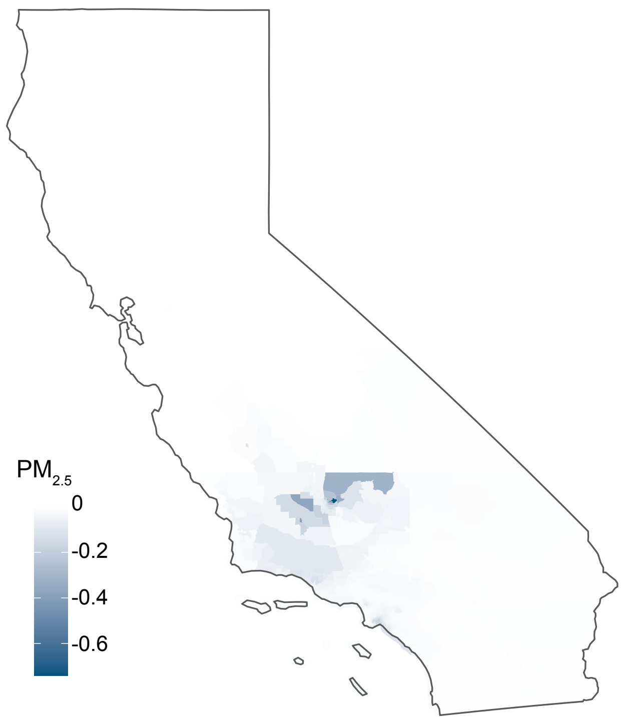


FIGURE VI.3. Projected change in ambient concentrations of $PM_{2.5}$ (in μg/m³) originating from emissions in the extraction segment in the LCE2 scenario from 2045 to 2019.

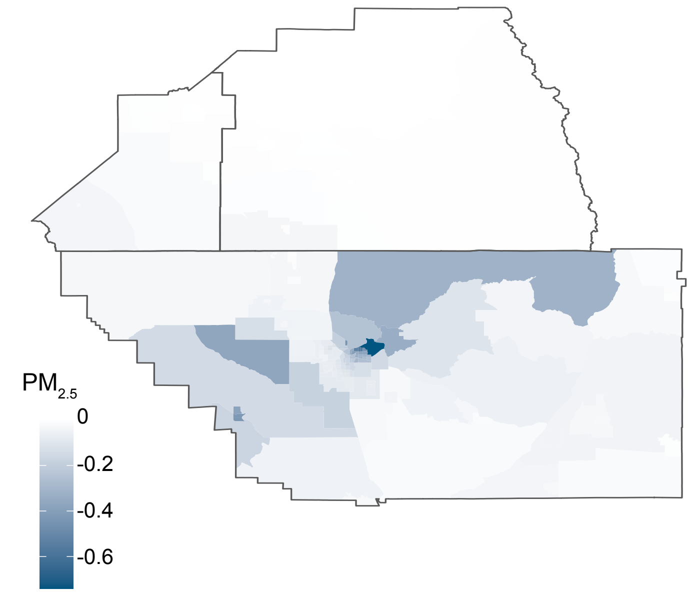


FIGURE VI.4. Projected change in ambient concentrations of $PM_{2.5}$ (in μg/m³) originating from emissions in the extraction segment in the LCE2 scenario from 2045 to 2019 in Kern County and vicinity.

also be evident in the census tract- and zip code-level analysis of the health impacts.

This focused analysis shows that the changes in the contribution of extraction to ambient $PM_{2.5}$ vary at a fine spatial scale. We project that most areas will experience a reduction in $PM_{2.5}$ contribution, but a few areas could experience an increase.

Figures VI.5., VI.6. and VI.7. report the projected changes in ambient $PM_{2.5}$ concentrations originating from emissions in the TFFSS refining segment under the LCR2 scenario from 2045 to 2019. Negative values indicate a reduction in the contribution, and a darker shade indicates a larger reduction.

Figure VI.5. shows that the impact of the LCR2 scenario on ambient $PM_{2.5}$ from the refining segment (relative to the R-BAU in 2019) are concentrated around Contra Costa and Los Angeles Counties in addition to adjacent counties. Figures VI.6. (Contra Costa County) and VI.7. (Los Angeles County) display the same information but centers on each county.

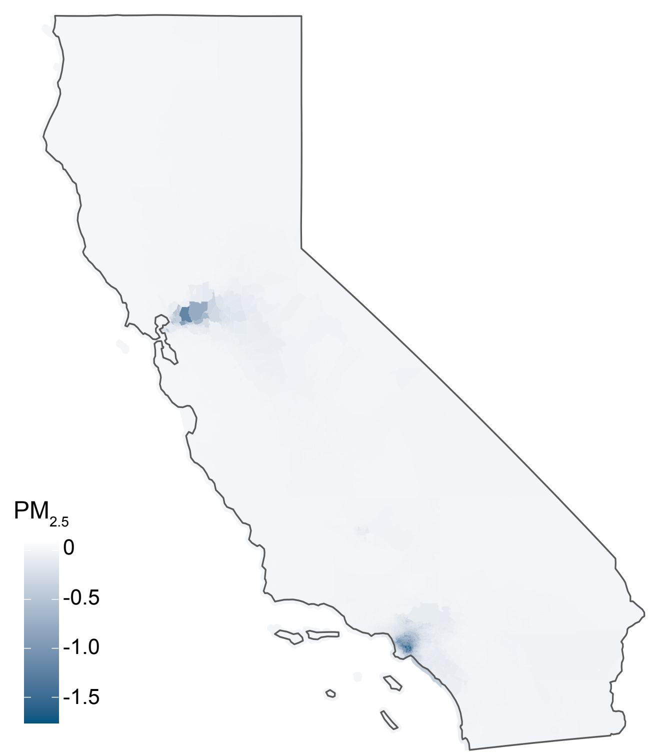


FIGURE VI.5. Projected change in ambient concentrations of $PM_{2.5}$ (in μg/m³) originating from emissions in the refining segment from the LCR2 scenario between 2045 and 2019.

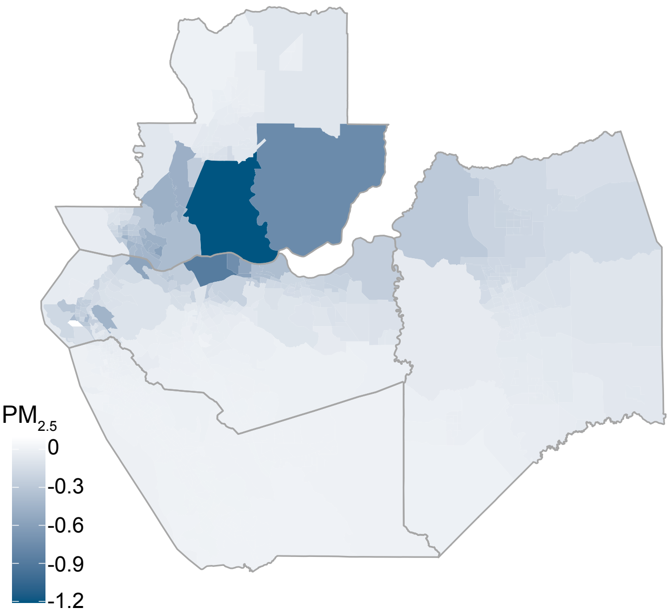


FIGURE VI.6. Projected change in ambient concentrations of $PM_{2.5}$ (in μg/m^3) originating from emissions in the refining segment from the LCR2 scenario between 2045 and 2019 in Contra Costa County and its vicinity.

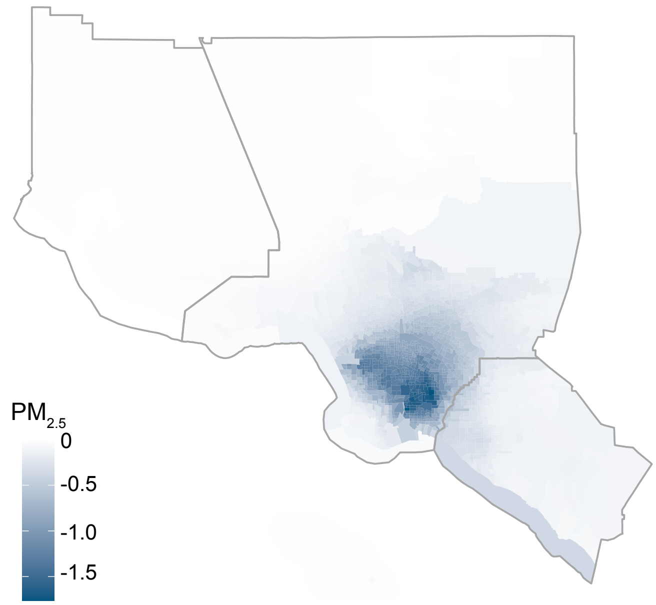


FIGURE VI.7. Projected change in ambient concentrations of $PM_{2.5}$ (in μg/m^3) originating from emissions in the refining segment from the LCR2 scenario between 2045 and 2019 in Los Angeles County and its vicinity.

Figures VI.6. and VI.7. highlight the importance of conducting the health impact analysis at a fine spatial scale, as the model predicts different changes in ambient $PM_{2.5}$ concentration across different census tracts of Contra Costa and Los Angeles Counties. In the analysis below, we evaluate the health impacts at the census tract level.

B. / PROJECTED IMPACTS ON PREMATURE MORTALITY

We analyze the projected impact of the low carbon scenarios on premature mortality— which we define as deaths of infants (age less than one) and of individuals aged 29 years old or more associated with exposure to ambient $PM_{2.5}$ generated by the activities in the TFFSS—using the method presented in Chapter II.d. Figure VI.8. reports the trajectory of statewide projected annual premature mortality from 2019 to 2045 associated with ambient $PM_{2.5}$ arising from the extraction segment under E-BAU, LCE1 and LCE2 scenarios.

In 2019, 32 deaths were associated with ambient $PM_{2.5}$ originating from the extraction segment. In 2020, these estimates dropped to 25 deaths for E-BAU and LCE1, and to 18 deaths for LCE2. This large drop is primarily due to the COVID-19-related drop in global crude oil prices and the consequent projected decrease in the quantity of crude oil extracted (see Chapter IV.b. for a detailed explanation). Under E-BAU, the projected statewide premature mortality associated with ambient $PM_{2.5}$ originating from the extraction segment stays roughly constant at about 25 deaths per year. For both the LCE1 and LCE2, projected annual premature mortality stays at the 2020 level until 2027, after which it begins to decline. In total, projected annual premature mortality declines by more than half between 2020 and 2045. Notably, the reduction in projected annual premature mortality is larger under LCE2 than LCE1.

Figure VI.9. reports the trajectory of statewide projected annual mortality from 2019 to 2045 associated with the emissions of primary $PM_{2.5}$ and its precursors (NO_x, SO_x, VOCs, NH_3) released by the refining segment under the R-BAU, LCR1 and LCR2 scenarios.

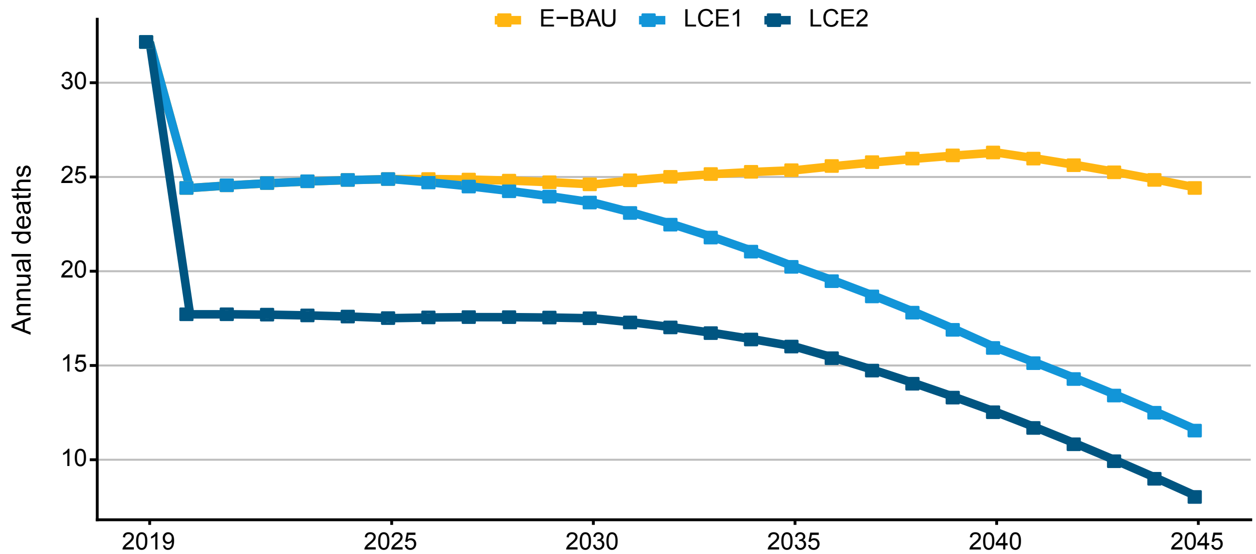


FIGURE VI.8. Projected annual premature mortality associated with the change in ambient concentrations of $PM_{2.5}$ (in μg/m³) originating from emissions in the extraction segment under E-BAU, LCE1 and LCE2 from 2019 to 2045.

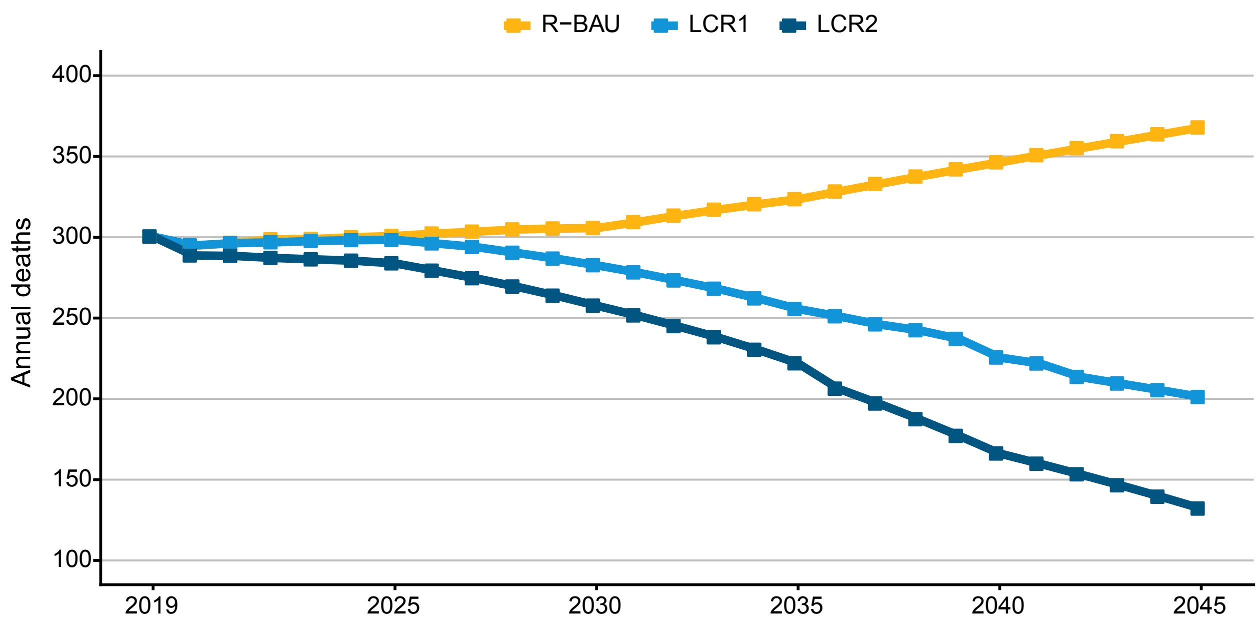


FIGURE VI.9. Projected annual premature mortality associated with the change in ambient concentrations of $PM_{2.5}$ (in μg/m³) originating from emissions in the refining segment under R-BAU, LCR1 and LCR2 from 2019 to 2045.

The estimates for refining segment related premature mortality show markedly different patterns than those for extraction. First, ambient $PM_{2.5}$ from the refining segment is associated with a larger number of premature deaths in 2019 (approximately 300 premature deaths in 2019) relative to the extraction segment (32 premature deaths in 2019). Second, under the R-BAU scenario, projected premature mortality associated with ambient $PM_{2.5}$ originating from the refining segment increases from 300 in 2019 to 367 in 2045. Third, under both LCR1 and LCR2, projected mortality declines between 2019 and 2045, including a more than 50% decline under scenario LCR2.

Figures VI.10. and VI.11. show the cumulative projected premature mortality estimated to be driven by ambient $PM_{2.5}$ originating from the extraction segment (Figure VI.10) and refining segment (Figure VI.11.). The entries in the figure correspond to the sum of all premature deaths under a given scenario from 2019 to 2045. In other words, the bars in Figures VI.10. and VI.11. correspond to the areas under the lines in Figures VI.8. and VI.9. The figures also report the impact of each low carbon scenario relative to the E-BAU and R-BAU scenarios. Net impacts can be interpreted as an estimate of the benefit of the low carbon scenarios, denominated in avoided premature deaths.

Under the E-BAU scenario, the extraction segment generates ambient $PM_{2.5}$ emissions that cause a cumulative projected premature mortality of 686 premature deaths statewide between 2019 and 2045. We project that LCE1 and LCE2 scenarios will cause 566 and 429 premature deaths, respectively. Therefore, the net cumulative impact of LCE1 relative to E-BAU is a reduction in projected premature mortality of 120 deaths, whereas for scenario LCE2, it is a reduction of 257 deaths.

Turning to impacts of ambient $PM_{2.5}$ generated by activities in the refining segment of the TFFSS, Figure VI.11. shows significantly larger predicted cumulative premature mortality compared to extraction. Under the R-BAU scenario, the cumulative projected premature mortality statewide between 2019 and 2045 is 8,679 deaths. The projected premature mortality under LCR1 and LCR2 are 7,123 and 6,217, respectively, between 2019 and 2045. Compared to the R-BAU scenario, this amounts to net cumulative impacts of 1,555 and 2,462 avoided deaths under LCR1 and LCR2.

The impact analysis in Figures VI.10. and VI.11. leads to the following observations. First, under R-BAU, ambient $PM_{2.5}$ emanating from activity in the refining segment is projected to lead to more than 10 times the number of premature deaths in the state compared to those caused by ambient $PM_{2.5}$ from the extraction segment. Second, LCE2 and LCR2 are associated with larger benefits, in the form of larger reductions in premature mortality associated with $PM_{2.5}$ emissions (primary and secondary) attributable to activities in extraction and refining.

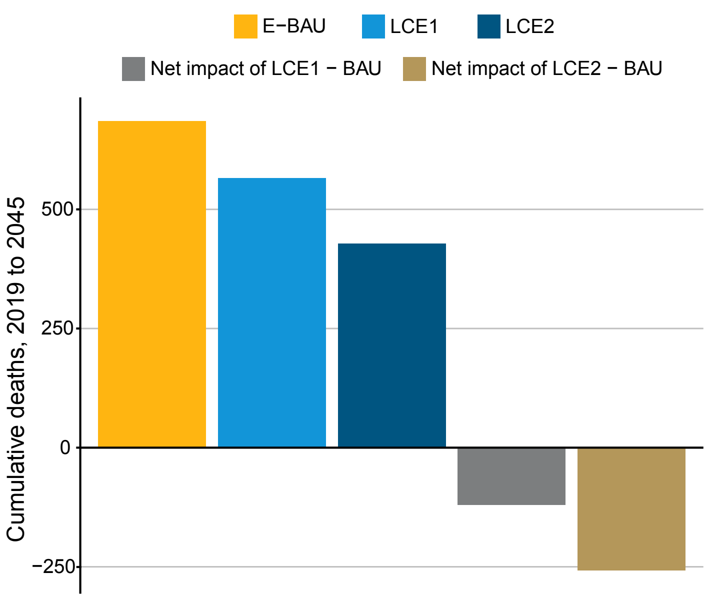


FIGURE VI.10. Cumulative projected premature mortality associated with the change in ambient concentrations of $PM_{2.5}$ (in µg/m^3) originating from emissions in the extraction segment under E-BAU, LCE1 and LCE2 from 2019 to 2045.

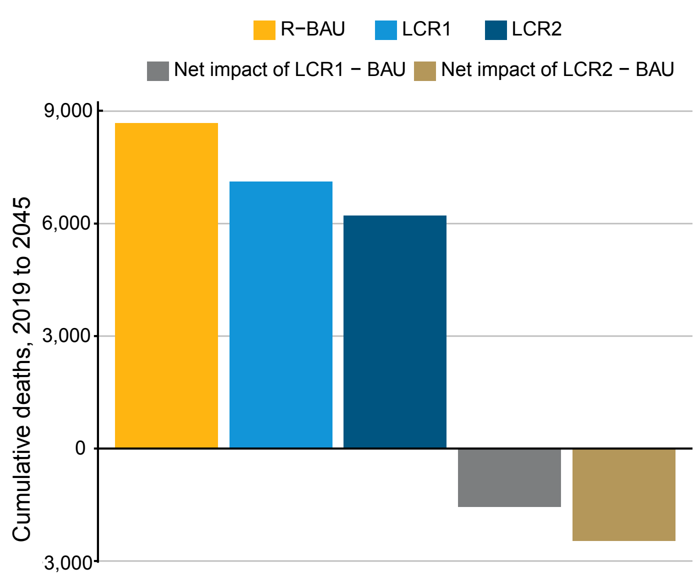


FIGURE VI.11. Cumulative projected premature mortality associated with the change in ambient concentrations of $PM_{2.5}$ (in µg/m^3) originating from emissions in the refining segment under R-BAU, LCR1 and LCR2 from 2019 to 2045.

C. / PROJECTED IMPACTS ON MORBIDITY OUTCOMES

Figure VI.12. and Figure VI.13. continue to document the projected health impacts associated with ambient $PM_{2.5}$ originating from the extraction segment and refining segment, and report morbidity outcomes (i.e., non-fatal adverse health outcomes). Following the health impact evaluation literature for $PM_{2.5}$, we focus on three outcomes: a. the number of hospitalizations due to cardiovascular disease (CVD) and respiratory disease (RD), b. the number of emergency room (ER) visits for asthma-related conditions, and c. the number of non-fatal heart attacks. In each figure, the entries correspond to the total sum of morbidity outcomes under a given scenario from 2019 to 2045. The figures also report the impact of each low carbon scenario, net of the BAU scenarios (E-BAU and R-BAU). The net impact can also be interpreted as an estimate of the public health benefit of a low carbon scenario, denominated in change in morbidity outcomes, or in the number of adverse health conditions.

Figure VI.12. reports the projected impacts on morbidity outcomes stemming from $PM_{2.5}$ and its precursors emitted from the extraction segment in California. Under E-BAU, the cumulative projected cumulative change in the number of hospital visits for CVD and RD between 2019 and 2045 is 468. The same estimates for the LCE1 and LCE2 scenarios are 385 and 284 hospital visits for CVD and RD, respectively. Therefore, the net cumulative impact of LCE1, relative to E-BAU, is a reduction in projected CVD and RD adverse health outcomes of 88 hospital visits, whereas LCE2 produces 181 fewer hospital visits. Panels b. and c. in Figure VI.12. show the patterns for ER visits for asthma conditions and for non-fatal heart attacks

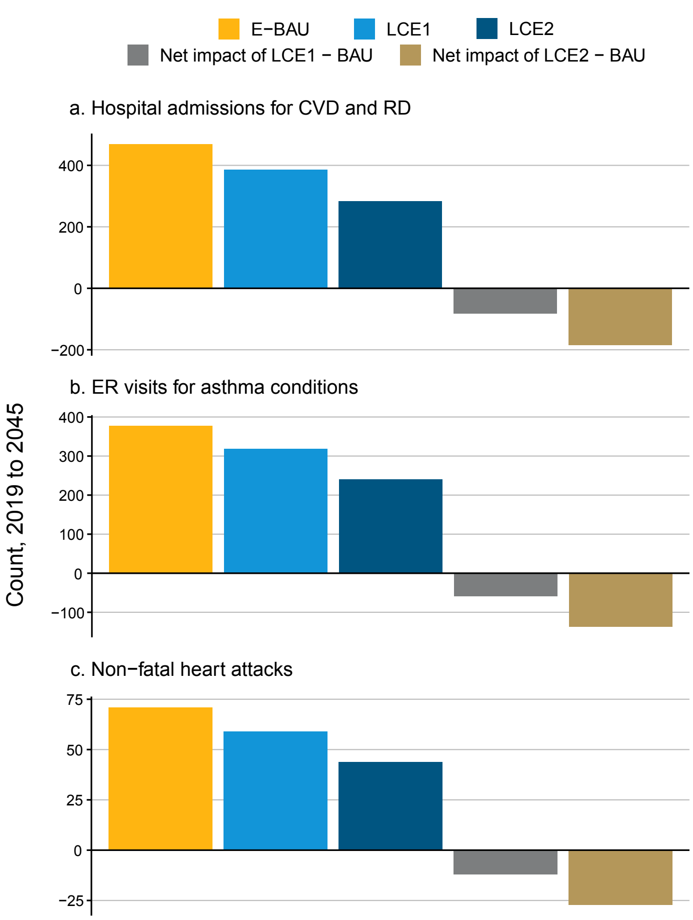


FIGURE VI.12. Cumulative projected morbidity associated with the change in ambient concentrations of $PM_{2.5}$ (in μg/m³) originating from emissions in the extraction segment under E-BAU, LCE1 and LCE2 scenarios from 2019 to 2045.

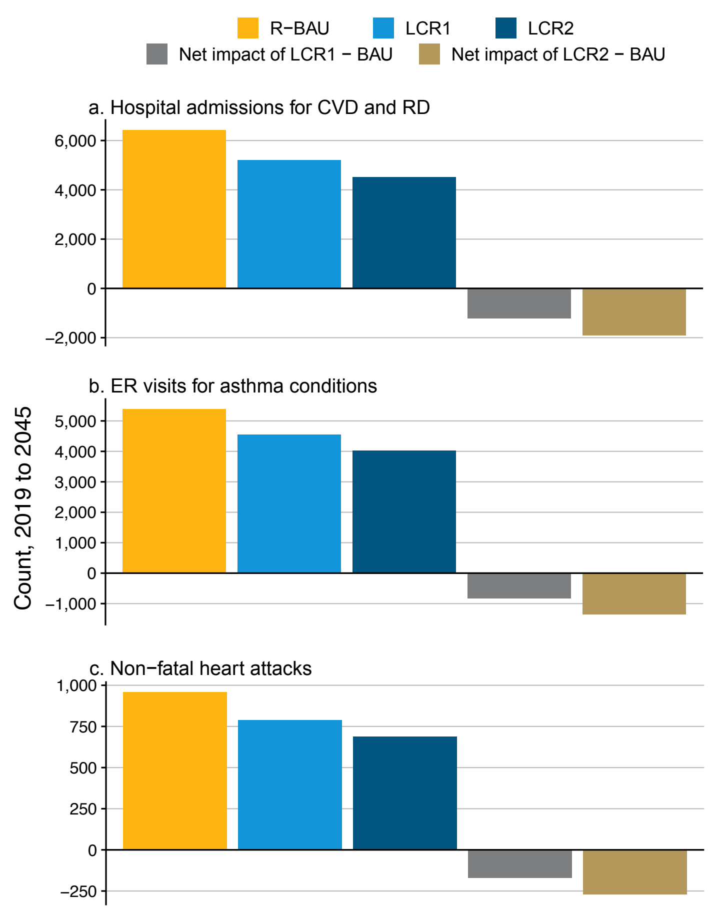


FIGURE VI.13. Cumulative projected morbidity associated with the change in ambient concentrations of $PM_{2.5}$ (in μg/m³) originating from emissions in the refining segment under R-BAU, LCR1 and LCR2 scenarios from 2019 to 2045.

are similar as those for hospital visits. Across the three morbidity outcomes, the LCE1 and LCE2 scenarios are projected to provide reduced morbidity benefits of -16% to -39%, respectively, relative to E-BAU over the period 2019–2045.

Figure VI.13. reports the projected impacts on morbidity outcomes estimated to be driven by ambient $PM_{2.5}$ emitted from the refining segment in California. Similar to the findings for premature mortality effects, projected impacts for the R-BAU and low carbon scenarios in the refining segment are larger than for the extraction segment.

In Figure VI.13., Panel a. shows that under the R-BAU scenario, the cumulative projected number of hospital visits for CVD and RD between 2019 and 2045 is 6,417. LCR1 and LCR2 scenarios result in 5,212 and 4,513 hospital visits, respectively, consistent with the lower levels of emitted ambient $PM_{2.5}$ under LCR1 and LCR2. The resulting net cumulative impact of LCR1 relative to R-BAU is a reduction in projected CVD and RD adverse health outcomes of -1,205 hospital visits, whereas for LCR2 results in 1,904 fewer hospital visits. The estimates in panels b. and c. in Figure VI.13. are similar to those in panel a., albeit smaller for ER visits for asthma conditions (panel b.) and for non-fatal heart attacks (panel c.). Comparing across the three morbidity outcomes, the LCR1 and LCR2 scenarios are projected to provide morbidity reduction benefits of 15% to 30%, relative to R-BAU over the period 2019–2045, with the larger benefits predicted under LCR2.

D. / PROJECTED MONETIZED IMPACTS ON PREMATURE MORTALITY AND MORBIDITY

We follow the standard approach in benefit-cost analysis of environmental policies conducted by the U.S. EPA and use an estimate of the value of statistical life (VSL) to convert the projected changes in premature mortality to monetary values in each scenario. To monetize the projected changes in morbidity outcomes, we use estimates of the willingness to pay (WTP) to avoid those health conditions and of the direct medical cost estimates ("cost of illness"). Thus, the estimates presented in this section are derived by applying standard methods to monetize changes in health outcomes to the results reported in Figures VI.10. through VI.13. As in Chapters VI.b. and VI.c., these health impacts are driven by the change in ambient $PM_{2.5}$ originating from emissions in the TFFSS under the low carbon scenarios, relative to the BAU scenarios.

Figure VI.14. presents estimates of the cumulative change in monetized health outcomes (avoided premature mortality and morbidity) between 2019 and 2045, discounted to 2019 in present value using a discount rate of 3%. We report the net impact of each low carbon scenario (LCE1, LCE2, LCR1, LCR2) relative to the BAU scenarios for extraction and refining (E-BAU and R-BAU). Negative values are interpreted as benefits denominated as monetized avoided mortality and adverse health outcomes.

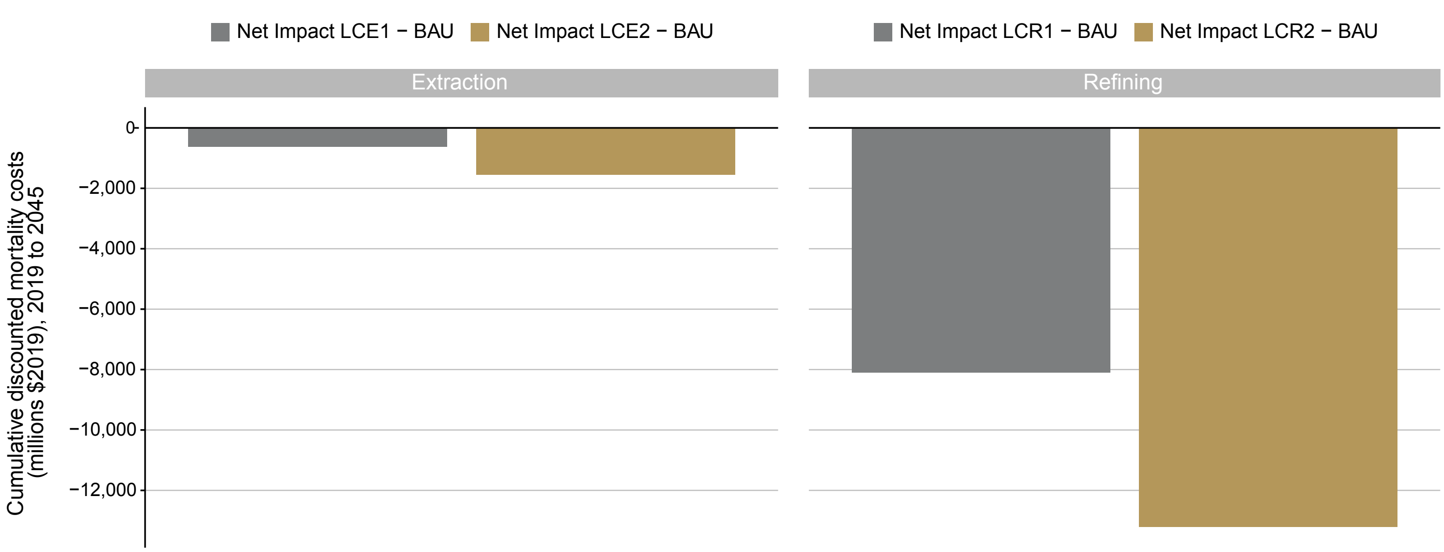


FIGURE VI.14. Present discounted value of monetized projected cumulative net impact of low carbon scenarios on health outcomes ($2019 millions).

For the extraction segment, the monetized benefits of LCE1 and LCE2 amount to $618.2 million to $1,559.2 million, which reflect the value of avoided mortality and adverse health outcomes. The monetized benefits associated with the change in ambient $PM_{2.5}$ from the low carbon refining scenarios are notably larger than those of the low carbon extraction scenarios, ranging from $8,130.8 million under LCR1 to $13,268.9 million under LCR2, in both cases relative to R-BAU.

E. / PROJECTED IMPACTS ON POPULATION-WEIGHTED EMISSION EXPOSURE FOR TACS

This section turns to the analysis of potential health impacts associated with the release of TACs. Chapter IV.a. provides a list of the TACs considered in this study and shows the trends in projected TAC releases from the extraction and refining segments under the BAU and low carbon scenarios. To this end, we use the "population-weighted emissions exposure" (PWEE) defined in Chapter II as a metric that captures the potential health impacts attributable to exposure to TACs. Larger values of the PWEE indicate larger potential for detrimental health impacts.

Figures VI.15. and VI.16. show the cumulative projected PWEE estimated to be driven by emissions of TACs originating from the extraction segment and refining segment. We estimate TAC releases using the emission factors for TACs and with modeled extraction and refining production quantities projected at the site level under the BAU and low carbon scenarios. We use population estimates to approximate the PWEE (along with site-specific projected TAC releases) at the census tract-level for the 2019 baseline and then project to 2045 using the California's Department of Finance projections.

Figures VI.15. and VI.16. show the sum of all PWEE projected under a given scenario from 2019 to 2045. The figures also report the impact of each low carbon scenario, net of the BAU. The net impact can be interpreted as an estimate of the benefit of the low carbon scenario, denominated in PWEE, that is reduced population exposure to TACs.

Figure VI.15. shows that emissions of high-toxicity TACs by the extraction segment in California result in sizable population exposure. Under the E-BAU scenario, the total PWEE between 2019 and 2045 is 150,000 million of person-kg exposure. We project that this exposure will be smaller under the LCE1 and LCE2 scenarios. The net impacts are reductions of 23,384 million PWEE for LCE1 and 55,853 million PWEE for LCE2, corresponding to impacts of -15% and -37%, respectively, relative to E-BAU.

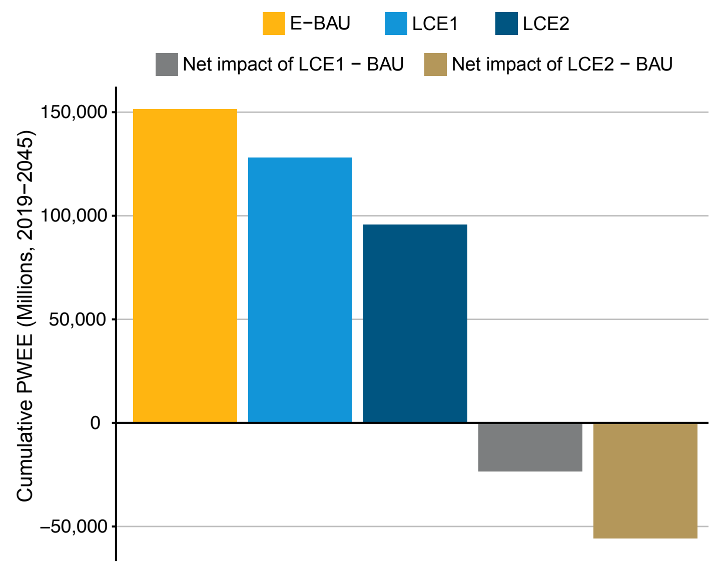


FIGURE VI.15. Cumulative projected population-weighted emissions exposure associated with emissions of TACs from the extraction segment under E-BAU, LCE1 and LCE2 scenarios from 2019 to 2045 (millions of person-kg exposure).

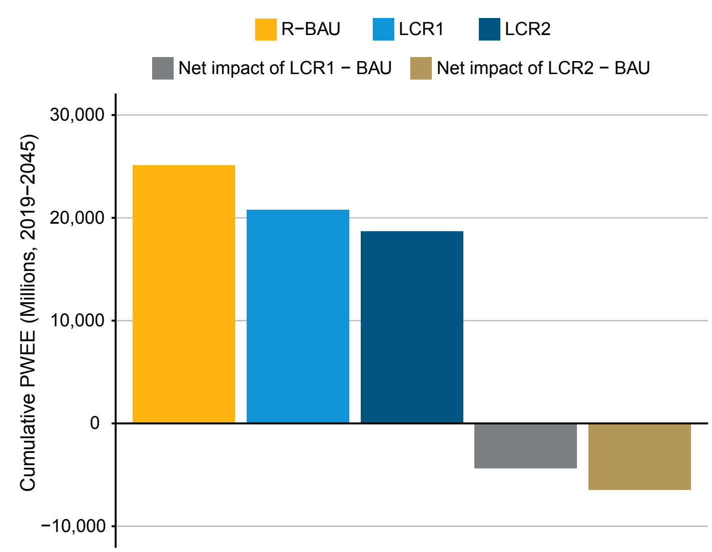


FIGURE VI.16. Cumulative projected population-weighted emissions exposure associated with emissions of TACs from the refining segment under R-BAU, LCR1 and LCR2 from 2019 to 2045 (millions of person-kg exposure).

Figure VI.16. shows similar patterns for the refining segment, although the PWEE resulting from emissions of TACs by refining segment in California is smaller than for the extraction sites. Under the R-BAU scenario, the total PWEE between 2019 and 2045 is 25,115 million of person-kg exposure, and we project it to be smaller under the LCR1 and LCR2 scenarios. The net impacts for the refining are reductions of 4,354 million PWEE for LCR1 and 6,437 million PWEE for LCR2, corresponding to impacts of -17% and -26%, respectively, relative to R-BAU.

F. / REGIONAL ANALYSIS OF HEALTH IMPACTS

This section presents a regional analysis of the health impacts associated with ambient $PM_{2.5}$ originating from TFFSS sites. We present estimates for the most impacted zip codes, and contrast the magnitude of projected health impacts between SB 535 disadvantaged communities, identified through CalEnviroScreen 3.0 (labeled as 'DACs'), and the rest of the state. The analysis underlying Tables VI.1. and VI.2. is conducted at the census tract-levels (which are all designed as DACs or non-DACs). By definition, a quarter of the state's census tracts and population resides in census tracts designated as DACs. Based on the data in CalEnviroScreen 3.0 (taken from the 2010 US Census), the population in DAC census tracts is 9.36 million (25% of the state population) and the population in non-DAC census tracts is 27.90 million (75% of the state population).

Table VI.1. reports estimates of the projected cumulative premature mortality associated with ambient $PM_{2.5}$ and PWEE associated with TACs that originates from emissions in extraction sites in California between 2019 and 2045. Across all census tracts statewide, the E-BAU scenario results in 686 premature deaths from 2019 to 2045. For the low carbon scenarios, this projection is reduced by 120 deaths (LCE1) and 257 deaths (LCE2). These estimates were reported earlier in Figure VI.10. However, Table VI.1. shows that between 27% and 30% of the statewide reduced mortality benefit from the low carbon scenarios applied to the extraction segment accrues to DACs census tracts.

Table VI.1. lists the 10 most impacted zip codes by ambient $PM_{2.5}$ attributable to the extraction segment. The table also shows the city in which the zip codes are located, the number of census tracts in each zip code, and the fraction of a zip code's census tract that are designated DACs. Bakersfield is most impacted by extraction-related ambient $PM_{2.5}$ under E-BAU. At the same time, the projected reductions in premature mortality under LCE1 and LCE2 are also the largest in Bakersfield. This city, in particular zip codes 93304 to 93308, have the most to gain in terms of projected reductions in premature mortality under LCE1 and LCE2. Notably, many of the listed zip codes for Bakersfield have a high percentage of DACs.

Table VI.1. breaks down the present discounted value (PDV) of monetized health benefits that include both mortality and morbidity impacts (e.g., corresponding to those reported in Figure VI.14.) for the entire state and for DAC census tracts. Under scenario LCE1, the PDV of the monetized change in health outcomes over 2019–2045 relative to E-BAU for the state is -$618.2 million (i.e., a reduction in monetized health impact in LCE1 compared to BAU), -$164.9 million of which is accrued by DACs (27% of statewide total). For the LCE2 scenario, the PDV of the monetized change in health outcomes over 2019–2045 relative to E-BAU for all census tracts is -$1,559.2 million (indicating a benefit of LCE2 compared to BAU), with -$464.0 million of which is accrued by DACs (30% of statewide total).

Finally, Table VI.1. reports the PWEE associated with emissions of TACs from the extraction segment in millions of person-kg as in Figure VI.16 for the entire state and by DAC census tracts. Under scenario LCE1, statewide PWEE is projected to drop by 23,384 million of person-kg between 2019 and 2045, relative to E-BAU. The corresponding reduction for DACs is 13,693 million of person-kg, or 59% of the statewide total reduction. For the LCE2 scenario, the reduction in cumulative PWEE over 2019–2045 relative to E-BAU are 55,853 and 28,438 million of person-kg, for the state as a whole and for DAC census tracts, respectively. Fifty percent of the reduction in PWEE under LCE2 takes place in DAC census tracts. Therefore at least 50% of the benefits of the low carbon scenarios for extract (reduction in PWEE for TACs) occurs in DACs (which account for 25% of the state population).

Table VI.2. is formatted as Table VI.1 and reports estimates of the projected cumulative premature mortality associated with ambient $PM_{2.5}$ and PWEE

TABLE VI.1. Regional analysis of projected cumulative premature mortality and morbidity associated with the change in ambient concentrations of $PM_{2.5}$ (in μg/m^3) originating from emissions in the extraction segment under E-BAU, LCE1 and LCE2 scenarios from 2019 to 2045

	Zip code	Number of census tracts	Percent DAC census tracts in zip code	E-BAU	LCE1 - E-BAU	LCE2 - E-BAU
Projected premature mortality (Deaths)						
All census tracts (state total)	—	8,035	25	686	-120	-257
in DAC census tracts	—	2,009	—	188	-32	-76
Percent of state impact to DAC census tracts	—	—	—	—	*27*	*30*
Top 10 Most Impacted Zip Codes (Nearby city listed below)						
Bakersfield	93306	351	8	38.6	-8.5	-10.6
Bakersfield	93305	189	71	13.6	-2.9	-3.8
Bakersfield	93307	351	92	11.5	-2.9	-3.8
Bakersfield	93308	270	70	9.5	-2.7	-3.2
Seal Beach	90740	189	0	9.3	-1.4	-3.5
Taft	93268	81	67	8.6	-2.7	-2.4
Bakersfield	93309	324	50	7.7	-2.1	-3.0
Long Beach	90815	297	0	7.4	-1.0	-3.1
Long Beach	90803	270	0	7.4	-1.1	-2.7
Bakersfield	93304	216	100	6.9	-1.9	-2.6
Total for top 10 zip codes	—	—	—	—	*-27*	*-39*
Average across all zip codes	—	*160*	*20*	*0.51*	*-0.09*	*-0.19*
Monetized Change in Health Outcomes (PDV, Mil of $2019)						
All census tracts (state total)	—	8,035	25	—	-618.2	-1,559.2
in DAC census tracts	—	2,009	—	—	-164.9	-464.0
Percent of state impact to DAC census tracts	—	—	—	—	*27*	*30*
Change in Population Weighted Emission Exposure (Mil. of person-kg)						
All census tracts (state total)	—	8,035	25	—	-23,384	-55,853
in DAC census tracts	—	2,009	—	—	-13,693	-28,438
Percent of state impact to DAC census tracts	—	—	—	—	*59*	*51*

associated with TACs attributed to the refining segment in California between 2019 and 2045. The R-BAU scenario projects 8,679 premature deaths statewide from 2019 to 2045. For the low carbon scenarios, this projection is reduced by 1,555 deaths (LCR1) and 2,467 deaths (LCR2), which can be interpreted as a benefit of these scenarios relative to R-BAU, and denominated in the number of avoided deaths. These estimates were reported earlier in Figure VI.11. Importantly, Table VI.2. shows that a more than proportional share of the reduced premature mortality benefits stemming from LCR1 and LCR2 occur in DACs. Between 37% and 39% of the statewide reduced mortality benefit from the low carbon scenarios applied to the refining segment accrues to DACs.

The 10 most impacted zip codes by ambient $PM_{2.5}$ attributable to the refining segment are primarily in cities in Los Angeles County (Long Beach, Norwalk, Bellflower, Hawthorne, Cerritos), whereas zip code 94806 in San Pablo represents the northern refinery cluster. These locations are projected to experience the largest gains in terms of projected reductions in premature mortality under LCR1 and LCR2. Many of the zip codes include a large share of DAC census tracts. In particular, 90805 (Long Beach), 90650 (Norwalk), 90706 (Bellflower) and 90250 (Hawthorne) all have percentages of DAC census tracts that exceed 75%.

Table VI.2. reports the PDV of monetized health benefits that include mortality and morbidity outcomes. Under LCR1, the PDV of the monetized change in health outcomes over 2019–2045 relative to R-BAU for the state is -$8,130.8 million, which can be interpreted as a benefit: a reduction in monetized health impact in LCR1 compared to R-BAU. Thirty-seven percent of this projected benefit (-$3,013.6 million) is accrued by DACs. For the LCR2 scenario, the PDV of the monetized change in health outcomes over 2019–2045 relative to R-BAU for all census tracts in California is -$13,268.9 million, indicating a benefit of LCR2 compared to BAU, with 39% (-$5,147 million) of which projected to occur in DAC census tracts.

Finally, Table VI.2. reports the PWEE associated with emissions of TACs from the refining segment in millions of person-kg as in Figure VI.17 for the entire state and by DAC census tracts. For the LCR1 scenario, the reduction in cumulative PWEE over 2019–2045 relative to R-BAU are 4,354 and 2,130 million of person-kg, for the state as a whole and for DAC census tracts, respectively. The reduction in DACs amounts to 49% of the statewide total reduction. Under scenario LCR2, statewide PWEE is projected to drop by 6,437 million of person-kg between 2019 and 2045, relative to R-BAU. The corresponding reduction for DACs is 2,595 million of person-kg, or 40% of the statewide total reduction.

TABLE VI.2. Regional analysis of projected cumulative premature mortality and morbidity associated with the change in ambient concentrations of $PM_{2.5}$ (in μg/m^3) originating from emissions in the refining segment under R-BAU, LCR1 and LCR2 scenarios from 2019 to 2045

	Zip code	Number of census tracts	Percent DAC census tracts in zip code	R-BAU	LCR1 - R-BAU	LCR2 - R-BAU
Projected premature mortality (Deaths)						
All census tracts (state total)	—	8,035	25	8,679	-1,555	-2,462
in DAC census tracts	—	2,009	—	3,349	-574	-957
Percent of state impact to DAC census tracts	—	—	—	—	*37*	*39*
Top 10 Most Impacted Zip Codes (Nearby city listed below)						
Long Beach	90805	513	89	145.4	-27.1	-29.1
Norwalk	90650	567	86	138.1	-26.7	-29.4
Long Beach	90807	216	0	137.2	-28.7	-28.6
Bellflower	90706	486	78	132.6	-25.1	-26.9
Lakewood	90712	189	0	115.2	-23.7	-24.3
Long Beach	90808	243	0	114.8	-25.0	-26.7
San Pablo	94806	297	45	100.2	-11.6	-15.4
Seal Beach	90740	189	0	95.1	-21.5	-29.7
Cerritos	90703	297	0	88.1	-17.9	-20.4
Hawthorne	90250	540	75	86.1	-11.4	-31.7
Total for top 10 zip codes	—	—	—	—	*-219*	*-262*
Average across all zip codes	—	*160*	*20*	*6.4*	*-1.2*	*-1.8*
Monetized Change in Health Outcomes (PDV, Mil of $2019)						
All census tracts (state total)	—	8,035	25	—	-8,131	-13,269
in DAC census tracts	—	2,009	—	—	-3,014	-5,147
Percent of state impact to DAC census tracts	—	—	—	—	*37*	*39*
Change in Population Weighted Emission Exposure (Mil. of person-kg)						
All census tracts (state total)	—	8,035	25	—	-4,354	-6,436
in DAC census tracts	—	2,009	—	—	-2,130	-2,595
Percent of state impact to DAC census tracts	—	—	—	—	*49*	*40*

G. / GLOBAL CLIMATE BENEFIT

We conclude our benefits quantification by valuing the global benefit of reduced GHG emissions from California's TFFSS. Following CARB's latest Climate Change Scoping Plan (64), we employ the central Social Cost of Carbon (SCC) estimate of $52.32 per ton of CO_2e (in $2019) from the U.S. government's Interagency Working Group on Social Cost of Greenhouse Gases released in December 2016 (65). We further apply the assumption that this SCC estimate increases annually at a rate equal to the discount rate. Note that, following CARB practice, our use of a global SCC value, rather than a value that captures only the California-component of the global SCC, quantifies the global benefit of reducing GHG emissions from California's TFFSS. This global scope for GHG-related benefits differs from our California-only scope when quantifying benefits from changes in local air quality in other parts of this Chapter.

For the extraction segment, we calculate that the global benefit of cumulative reduced GHG emissions between 2019 and 2045 under LCE1 relative to E-BAU, as shown in Figure IV.7., is $3,108 million (in $2019). For LCE2 relative to E-BAU, the global benefit is $3,244 million. For the refining segment, the global benefit of cumulative reduced GHG emissions between 2019 and 2045 under LCR1 relative to R-BAU, as shown in Figure IV.8. is $5,673 million. Under LCR2 relative to R-BAU, that global benefit is $8,740 million.

CHAPTER 7
CONCLUSIONS AND KNOWLEDGE GAPS

Photo by the Bureau of Land Management, California

A. / CONCLUSIONS

We present a unique and novel framework to quantitatively model the phase-out of crude oil extraction and associated refined petroleum products to achieve partial to full decarbonization of California's transportation fossil fuel supply sector (TFFSS) by 2045. To do this, we developed models of both refining and extraction segments; the output from these models in turn feeds into existing models of health, via emitted air pollution, and labor markets. We utilize the extraction model to analyze policy scenarios that have the potential to reduce GHGs, improve health outcomes, reduce air pollution exposure, and generate labor impacts over the time period 2019–2045. We utilize the refining model to project, for the fuel demand in the central low carbon scenario (LC1) developed by the complementary Study 1, changes in refined fuel production, GHG emissions, health and air pollution exposure, health outcomes and labor impacts, including testing the impact of two export provisions.

For in-state crude oil extraction, we examine two policies: (i) a statewide oil production quota on new and existing wells that reduces extraction first from fields with more costly extraction followed by fields with less costly extraction (or equivalently a severance or excise tax on production); and (ii) setbacks that prohibit extraction from new and existing oil wells within a certain distance of "sensitive" sites. By construction, stringent production quotas can lead to GHG reductions in the realm of 80% - 90% between 2019 and 2045. Additionally, a statewide oil production quota with auction permits or an excise tax generates a new source of revenue for the state. This revenue can be used to offset the labor market impacts of TFFSS decarbonization either through severance programs and income support for early retirement, expanded unemployment benefits, support for relocation, training partnership programs, investments to diversify local economies, or other programs to reduce the transitional costs for the TFFSS workforce.

Setbacks from oil wells for distances currently considered achieve lower GHG reductions. For example, a setback distance of 2,500 feet between wells and residences, schools, playgrounds, daycare centers, elderly care facilities, and hospitals leads to a 49% GHG reduction between 2019 and 2045. We find that when combined with a production quota, setbacks may provide a tradeoff between equitable health outcomes and statewide labor market impacts. For the same change in crude oil production, the use of setbacks in addition to a production quota induces more production cuts from oil fields that employ fewer workers. However, these oil fields are also near a more balanced share of disadvantaged communities (DACs) and non-DACs. This suggests that for the same drop in statewide crude oil production, the addition of setbacks to a production quota may result in -smaller labor market impacts but also a lower share of air quality benefits borne by DACs. Alternatively, the state may consider setback provisions that explicitly reduce oil production near disadvantaged communities. Such a modified setback rule, together with a statewide production quota with auctioned permits or an excise tax, could further narrow the pollution exposure gap between disadvantaged and other communities as the extraction segment decarbonizes.

For in-state refining, our modeling is driven by business-as-usual (Study 1 BAU) and central low carbon (LC1) fuel demand scenarios developed by complementary Study 1, with two different export policies considered (historic exports vs. limiting exports). If in-state refining follows the Study 1 BAU scenario, consumption of crude oil and renewable feedstocks by in-state refineries is reduced by 21% in 2045 compared to 2019. For the LC1 scenario, and if historical export levels are maintained, consumption of crude oil and renewable feedstocks by in-state refineries is reduced by 56% in 2045 compared to 2019. Limiting exports of refined fuels further reduces crude consumption to 69% in 2045, compared to 2019. For both low carbon refining scenarios LCR1 and LCR2, refined products in 2045 are dominated by renewable fuels and jet fuel. The corresponding reduction in GHGs emitted by refineries in 2045 relative to 2019 is 21% for R-BAU, 56% for historic exports and 69% for limiting exports.

A major finding from our refinery modeling is that continued demand for refined fuels, both crude-based and renewable, drives the need for a significant retention of refinery capacity, even in 2045. Assuming that California fuel demand (petroleum-based or renewable gasoline, diesel, and jet fuel) is met entirely by in-state refining capacity, California will need 31%–44% of its current refining capacity in 2045 to meet fuel demand associated with the two low carbon scenarios we considered. As a result, GHG emissions from refineries remain persistently high and comprise the larger part of TFFSS emissions in 2045 (56%–95% depending on scenario combination). Persistent refinery emissions are driven by the processing of renewable liquid fuels (assumed to be processed by existing refineries), processing of jet fuel for inter-state aviation transport, and potential exports of refined fuels.

Because refining activity is constrained by fuel demand, it is not possible to phase out California refineries in the same manner and with the same consequences as phasing out California extraction. Hence, limiting GHG emissions and pollutants from refineries is more challenging. Limiting exports of refined products would lead to lower GHG and pollutant emissions from California's refining segment. Policies that encourage innovation and technology development in the refining segment as well as conversion to renewable/zero-carbon fuel production could reduce emissions and carbon intensity of refined fuels. The alternative less desirable pathway, which is to substitute imported refined products for in-state refining, is likely to entail leakage of GHG emissions beyond California's borders.

Our modeling of different scenarios yields annual reductions in GHG emissions from the entire TFFSS in 2045 relative to 2019 that range from -28% for the combination of BAU extraction and refining scenarios, to -75% for the combination of either extraction scenario (i.e., 20% quota on crude oil extracted with or without setbacks) and the more restrictive (i.e., low carbon demand and limiting exports) refining scenario (LCR2).

The extraction and refining low carbon policy scenarios we consider are all associated with reductions in economic activity in these sectors when compared to the "no-policy" business-as-usual scenarios (E-BAU and R-BAU). Consequently, the net impact of the low carbon scenarios relative to the BAU scenarios is to reduce employment and worker compensation in the extraction and refining facilities directly impacted by the scenarios. Moreover, labor impacts also occur through indirect supply chain linkages for industries connected to the TFFSS and through induced or "forward-linkage" effects. These indirect and induced channels are found to be especially important for the refining segment of the TFFSS, mostly in Los Angeles County. As such, the estimates of total impacts (which include the direct, indirect and induced channels) on labor market outcomes are markedly larger than the estimates only considering the direct channel.

We estimate the labor market consequences of each low carbon scenario relative to the BAU scenario using a standard input-output model implemented at the industry by county level in California. Across the four low carbon scenarios we consider, the employment and worker compensation are projected to decline 14% to 37% cumulatively over 2019–2045 (or by 0.5% to 1.4% on an annualized basis), respectively, relative to the BAU scenario. For employment, these total impacts correspond to a reduction in job-years of 120,000 to 470,000 over 2019–2045, while for worker compensation, the present discounted value of the lost compensation ranges from $7 billion (LCE1 relative to BAU in $2019) to $23 billion (LCR2 relative to BAU in $2019). The impacts of the low carbon policies on the extraction segment are largest in Kern County while the low carbon policies for the refining segment have the largest impacts in Los Angeles County.

Ambient air pollution emitted by industrial sites can affect human health through multiple pollutants, channels, and health endpoints. This report focuses on the impact of primary emissions of $PM_{2.5}$ and its precursors (NO_x, SO_x, VOCs, NH_3) emitted by extraction and refining sites in California's TFFSS on premature mortality, hospital admissions for cardiovascular and respiratory conditions, emergency room visits due to asthma conditions, and non-fatal heart attacks.

Since the extraction and refining low carbon policy scenarios we consider are all associated with reductions in production activities in these sectors when compared to the "no-policy" BAU scenarios, we find that emissions of $PM_{2.5}$ and its precursors by extraction sites and refineries are all expected to decline between 2019 and 2045. We then use an atmospheric transport model to compute how exposure to ambient $PM_{2.5}$ changes at the census tract level when emissions in the TFFSS drop.

We estimate the health impact of each low carbon scenario relative to the BAU scenario using a standard health impact assessment approach implemented at the census tract level in California. Across the four low-carbon scenarios we consider, health outcomes are projected to improve. Specifically, premature mortality and the incidence of adverse health outcomes are projected to decline by 17% to 37% cumulatively over 2019–2045, relative to the relevant BAU scenarios. Population exposure to toxic air contaminants is also expected to decline cumulatively by 15% to 37% over the same period. Using standard methods to monetize the net health benefits (including the U.S. EPA's estimate of the value of statistical life) yields estimates ranging from $0.6 billion (LCE1 relative to E-BAU in $2019) to $13.3 billion (LCR2 relative to R-BAU, in $2019). As noted elsewhere in this report, these estimates of health benefits are likely to be understated.

The census tract-level analysis also allows us to contrast estimates of the net health benefits of the low carbon scenarios across DACs and non-DACs. We find that between 27% to 39% of the projected health benefits and between 50% to 59% of the reduced population exposure to TACs accrue to disadvantaged communities. For the LCE1 and LCE2 extraction scenarios, a significant share of the health benefits is captured by neighborhoods in the city of Bakersfield, while for the LC21 and LCR2 refining scenarios bring significant benefits to DACs in Long Beach, San Pablo, Norwalk and Hawthorne.

B. / KNOWLEDGE GAPS

Any exercise in projecting outcomes over long time horizons contains large uncertainties. In our case, uncertainties are perhaps greater given the unprecedented nature of the decarbonization policies examined. In this section, we highlight several of these uncertainties and how future research can help narrow knowledge gaps in order to facilitate a better understanding of the various consequences associated with TFFSS decarbonization in California.

Transitional costs are relevant for physical capital in the TFFSS as well. For example, refineries may continue to play a prominent role in supplying renewable fuels and hydrogen even if the TFFSS is phased out. There is much uncertainty regarding the difficulty in which existing refineries can modify their facilities to produce a less carbon-intensive slate of fuels and whether remaining GHG emissions can be mitigated through lowered costs in CCS. Continued research in both areas will shed light on the role refineries play in a low-carbon future.

In many ways, the costs and benefits considered in this study are incomplete. On the cost side, it was outside the scope of this study to examine how TFFSS decarbonization policies affect the price of final energy goods such as petroleum, renewable liquid fuels, and electricity. Changes in the price of final energy goods may be consequential and may also be inequitable, possibly affecting low-income households relatively more. A full understanding of energy price effects will require research into patterns of substitution, on both the supply and demand sides, across these various carbon-intensive and low-carbon fuels. It will also require an economy-wide analysis that includes other sectors that interact with the TFFSS. Such an economy-wide approach will also address key questions regarding the interaction between TFFSS-specific decarbonization policies and economy-wide decarbonization policies, such as a GHG cap-and-trade program and/or a carbon tax. For example, research in this area can answer, for a given statewide GHG target, whether it is more or less costly to reduce GHG emissions from the TFFSS or from another sector, and by how much.

On the benefits side, the estimated health impacts reported in this study do not account for all possible benefits of decarbonizing the TFFSS. Time constraints prevented us from modeling the changes in ambient ozone concentrations resulting from decarbonizing the TFFSS, and the associated health benefits. Additional research is needed to estimate those health benefits. Moreover, existing research is insufficient to conclusively document a broader array of health impacts from the TFFSS, including that from criteria air pollutants beyond $PM_{2.5}$, from TACs, as well as impacts on water quality and ecosystems, and hence our modeling does not capture those impacts on health outcomes.

Additional possible benefits associated with reductions in exposure to $PM_{2.5}$ such as increased productivity for workers working primarily outside, and improvements in educational outcomes are not considered. Even for $PM_{2.5}$, for which the existing literature enables us to quantify health impacts in terms of premature mortality and morbidity, future research is needed in order to generate health impact estimates that are more specific to California's households, in particular its more vulnerable populations, as well as to quantify impacts over the long-term (e.g., decadal scale) associated with changes in $PM_{2.5}$ concentrations. Further, the ongoing climate change crisis, which is expected to continue causing heat waves and wildfires may alter how $PM_{2.5}$ exposure affects health. More research is needed to ascertain the interaction between climate change driven extreme events and the health effects of ambient air pollution. Finally, recent research has shown that ambient air pollution, in addition to affecting health, reduces worker productivity and cognitive function (including performance on scholastic tests). Decarbonization of the TFFSS would bring additional benefits along those dimensions as well.

Our equity analyses maintain the assumption that the location of disadvantaged communities across California remains unchanged between now and 2045. Future changes in economic and demographic forces across the state in the decades to come are likely to alter how disadvantaged communities are defined and where they are located. As households move and economic conditions change, so would the equity consequences of TFFSS decarbonization. Future research should incorporate such dynamics using richer models that account for household migration and changes in economic conditions.

Finally, our analysis of TFFSS decarbonization in California assumes what happens in California does not affect policies and economic conditions beyond the state. This assumption, which we make for tractability, however, potentially overlooks the potential for "leakage" of GHG emissions, as well as that of labor and physical capital outside of the state. Accounting for such effects requires a global analysis that examines not just supply and demand of GHG-emitting sectors within California but also that of other parts of the world. These leakage effects may also differ across extraction and refining segments depending on the degree in which California-produced outputs can substitute with imports. Likewise, future research may examine the possibility that decarbonization policies enacted within California, may prompt the development of decarbonization policies elsewhere in the United States and the world, which may ultimately have indirect impacts on decarbonization outcomes within California.

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