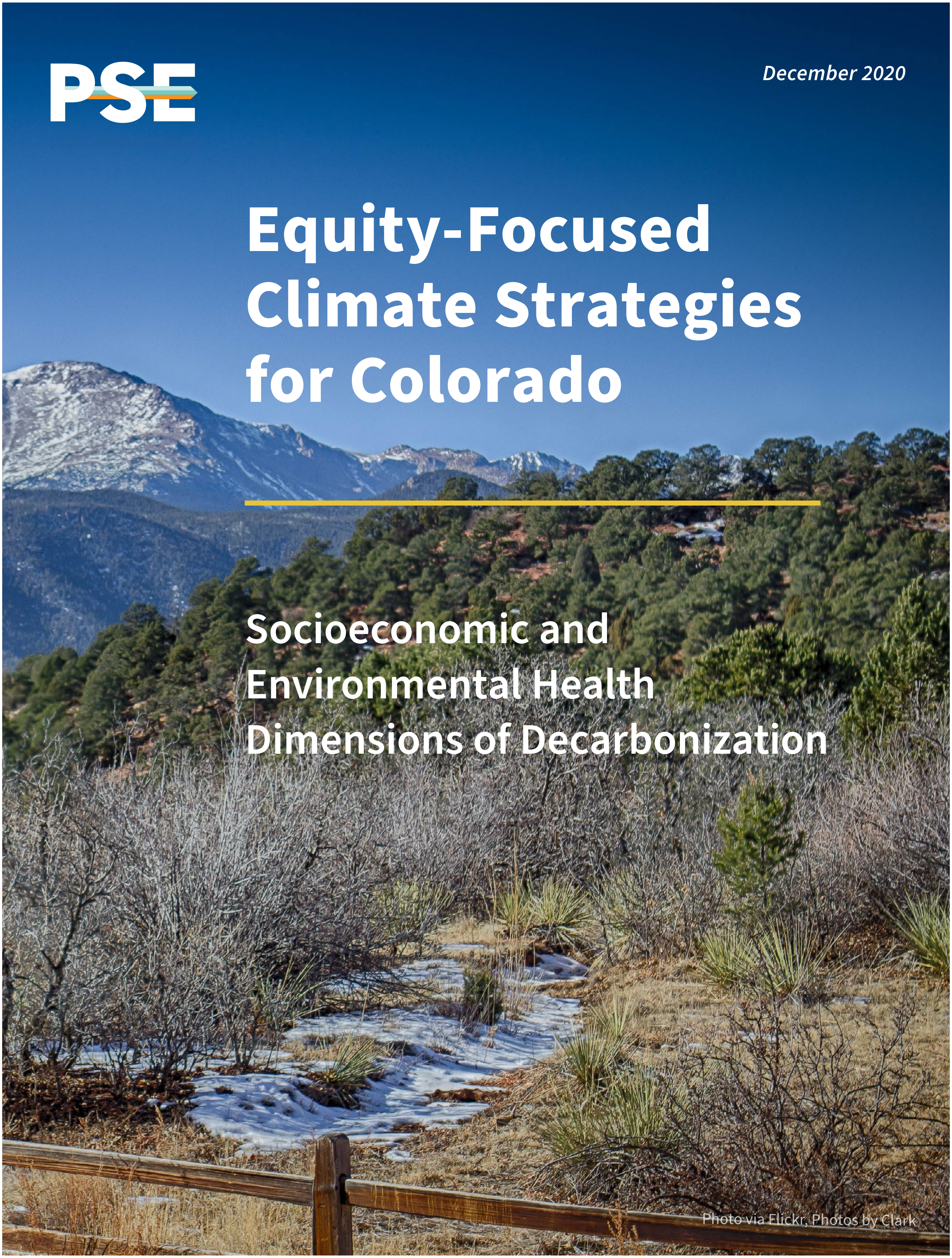

December 2020

Equity-Focused Climate Strategies for Colorado

Socioeconomic and Environmental Health Dimensions of Decarbonization

Photo via Flickr, Photos by Clark

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About PSE Healthy Energy

Physicians, Scientists, and Engineers for Healthy Energy (PSE) is a multidisciplinary, non-profit research institute that studies the way energy production and use impact public health and the environment. We share our work and translate complex science for all audiences. Our headquarters is located in Oakland, California.

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1 Introduction and Background

1.1 Motivation

In the face of a warming climate and associated climate change impacts, the State of Colorado is embarking on an ambitious multi-decade effort to dramatically cut carbon emissions while confronting a growing need to build climate resilience. The State recently set targets to expand renewable electricity generation while slashing economy-wide greenhouse emissions. It is now developing pathways and policies to achieve these goals.

Colorado's current fossil fuel-based energy infrastructure, however, is not only a source of greenhouse gas emissions, but also releases emissions of health-damaging air pollutants across the state due to products of incomplete combustion and other processes. Furthermore, low-income households often struggle to pay for the electricity and fuels they rely on to power their homes and vehicles. People of color historically face racialized discriminatory practices such as housing redlining, lack of capital, and access to financing for homeownership, increasing their dependency on landlords for clean and efficient appliances and homes. These social inequities impact every sector of the economy, and decarbonization efforts should consider these existing inequities in order to develop clean energy transition strategies that distribute benefits more evenly across the Colorado population. In this report, we use the phrase *energy equity* to encompass the participation and inclusion of historically marginalized populations in the energy economy—including energy ownership, production, and use—in order to shape energy policy that is more equitable, accessible, and economically beneficial.[1,2] In parallel, *environmental equity* ensures that no population faces a disproportionate share of environmental pollution and that all populations have access to the benefits of a clean environment and an opportunity to participate in the environmental policy decision-making process.[3]

As Colorado reshapes its energy system to reduce greenhouse gas pollutant emissions, it simultaneously has a unique opportunity to address the uneven environmental public health and economic burdens the current energy system places on the Colorado population. In this analysis, we assess opportunities and strategies to integrate pollution reduction, resilience, and energy and environmental equity into the state's decarbonization plans, with a focus on Colorado's most environmentally burdened and socioeconomically vulnerable communities.

To better understand the technical approaches Colorado could follow to achieve its climate targets, Evolved Energy Research—working with Sierra Club, NRDC, and GridLab—recently modeled four potential decarbonization pathways from 2020-2050.[4] These pathways rely on energy efficiency, renewable energy, and electrification measures to reduce fossil fuel use in buildings, transportation, power generation, and industry. While the *locations* of greenhouse gas emission sources are not important from a climate perspective, many greenhouse gases are co-mingled with health-damaging air pollutants including, but not limited to, criteria air pollutants and hazardous air pollutants. As such, in this report, we add spatial dimensions to these techno-economic statewide decarbonization pathways to better understand the ways in which climate policy could reduce—or exacerbate—health-damaging air pollutant emissions, energy cost burdens, and climate impacts in different communities throughout the state.[5]

Rapid and effective decarbonization across economic sectors is a critical step to the protection of the climate and subsequently the health and safety of all communities. However, it is important to note that a reduction in greenhouse gas emissions alone can

1 US Department of Energy. Office of Economic Impact and Diversity. The Equity in Energy Initiative (2020).

2 California Energy Commission. SB 350 Barriers Study (2016).

3 US Environmental Protection Agency. Environmental Equity: Reducing Risk for All Communities (1992).

4 Arjun Krishnaswami, Ariana Gonzalez, and Matthew Gerhart. Committing to Climate Action: Equitable Pathways for Meeting Colorado's Climate Goals. *Evolved Energy, GridLab, NRDC, and Sierra Club* (2020).

5 An economy-wide clean energy transition away from fossil fuels will also have job impacts in some sectors and communities and provide workforce development opportunities in others. These workforce considerations will be addressed in a forthcoming companion report in Spring 2021.

facilitate, but does not always guarantee, a concurrent decrease in emissions of health-damaging air pollutants[6] nor does it necessarily reduce cost burdens of energy access in any one community.[7] Moreover, recent research has found that even though overall air pollution levels have declined nationwide, disparities in exposure between neighborhoods have persisted for decades.[8] As such, it is advisable that solutions to existing disparities with respect to environmental pollution and energy cost burdens should be explicitly engineered into decarbonization policies to ensure that benefits of this transition are both rapidly and equitably realized. A focus on decarbonization that prioritizes emission reductions and decreases cost burdens in places that are disproportionately burdened with infrastructure that also emits health-damaging air pollutants or where households struggle to afford their energy bills would generate more equitable health and economic outcomes than policies focused exclusively on carbon equivalent emission reductions regardless of location and demographics. Such strategies might include targeted efficiency measures for low-income households, for example, or the electrification of heavy-duty equipment in polluted industrial neighborhoods.

To explore the analytical basis upon which to make decarbonization pathway decisions that simultaneously address social and health disparities we undertake the following

1. ***Identify regions and populations currently facing high cumulative emissions from fossil fuel production and use.***
2. ***Characterize household and transportation energy cost burdens and clean energy access across the state.***
3. ***Identify decarbonization strategies that simultaneously reduce health-damaging air pollution and energy cost burdens while increasing climate resilience.***

After discussing our findings and conclusions, we provide actionable policy and research recommendations that emerge from our analyses in this report.

1.2 Background

Worldwide, the planet's average surface temperature has warmed approximately 2˚F since the late 1800s,[9] but this warming is unevenly distributed; average temperatures in Colorado's Western Slope, for example, have increased more than 3˚F on average. In 2020, multiple Colorado counties—including Mesa, Montrose, and Ouray—measured their warmest August on record.[10] The 2020 Pine Gulch and Cameron Peak fires broke state records for acreage burned—and at time of writing, the latter was still burning.[11] The state is projected to face an increasing number of extreme heat days,[12] growing wildfire threats, and drought[13] in the coming decades, in addition to changes in weather and precipitation patterns.

TABLE 1. Key Colorado climate targets.

6 Smith, Kirk R., *et al.* Public Health Benefits of Strategies to Reduce Greenhouse-Gas Emissions: Health Implications of Short-Lived Greenhouse Pollutants. *The Lancet*. 374.9707 (2009): 2091-2103.

7 Shonkoff, Seth B., *et al.* The Climate Gap: Environmental Health and Equity Implications of Climate Change and Mitigation Policies in California—A Review of the Literature. *Climatic Change* 109.1 (2011): 485-503.

8 Colmer, Jonathan, *et al.* Disparities in $PM_{2.5}$ Air Pollution in the United States. *Science* 369.6503 (2020): 575-578.

9 NASA Jet Propulsion Laboratory. "Global Climate Change: Vital Signs of the Planet." Oct. 2, 2020. Available at: https://climate.nasa.gov/evidence/

10 NOAA National Centers for Environmental information, "Climate at a Glance: County Time Series." Sept. 2020. Available at: https://www.ncdc.noaa.gov/cag/

11 NASA Earth Observatory. "Record-Setting Fires in Colorado and California." Oct. 22, 2020. Available at: https://earthobservatory.nasa.gov/images/147443/record-setting-fires-in-colorado-and-california

12 Climate Impact Lab, "Climate Impact Map." 2020. Available at: http://www.impactlab.org/map/

13 NASA's Scientific Visualization Studio. "Megadroughts in U.S. West Projected to be Worst of the Millennium." Feb. 12, 2015. Available at: https://svs.gsfc.nasa.gov/4270

Category	Year	Target
Statewide greenhouse gas reductions	2025	26% below 2005 levels
	2030	50% below 2005 levels
	2050	90% below 2005 levels
Electricity generation	2030	80% reduction in power sector GHGs from 2005 levels[14]
	2040	100% renewable electricity

To help mitigate climate change, Colorado has committed to transitioning away from fossil fuels and reducing economy-wide greenhouse gas (GHG) emissions by 2050 through a combination of goals set by Governor Jared Polis and targets laid out in House Bill 19-1261.[15] The state's core climate goals are summarized in **Table 1**.

The State of Colorado has published a GHG Pollution Reduction Roadmap to help it achieve these targets.[16] However, this roadmap only briefly addresses air pollution from fossil fuel use and energy equity concerns. Colorado is not alone in this omission: decarbonization planning nationwide frequently fails to account for public health, environmental impacts, and social equity. Those models that do take health impacts into account, however, find that it is possible to increase health co-benefits by prioritizing them alongside decarbonization goals. Incorporating health co-benefits not only improves societal wellbeing, but can improve the cost-effectiveness of decarbonization by reducing medical expenditures associated with the health impacts of air pollution.[17]

For example, Driscoll *et al*. (2015) found that power sector decarbonization policies emphasizing demand-side energy efficiency yielded the greatest public health benefits,[18] and Fann *et al*. (2011) illustrated strategies to maximize health benefits and reduce inequality in pollution burdens by focusing on multi-pollutant reductions in vulnerable communities.[19] These examples illustrate a few possible ways to build energy and environmental equity into decarbonization plans, although there are many ways in which energy systems intersect with such considerations. Below, we summarize the primary public health and social equity frameworks underlying this report.

1.2.1 Public Health

The development, production, and extraction of oil and gas, and mining of coal, as well as other fossil fuels and their use in buildings, power plants, transportation, and industry can contribute to a wide array of public health impacts, most directly through air and water pollution. This report uses air pollution as its primary indicator of public health hazards and risks due to publicly available air pollution emissions data and the subsequent ease of comparing air pollutant data across sectors. Air pollution impacts on human health result from both the emissions of primary pollutants, such as criteria air pollutants including particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and volatile organic compounds (VOCs), and from the secondary formation of air pollutants (e.g., ozone and $PM_{2.5}$) in the atmosphere from precursors including nitrogen oxides (NO_x), SO_2, and VOCs.

The health impacts of PM, NO_x, SO_2, and ozone are well-established and are included in a class of criteria air pollutants regulated through National Ambient Air Quality Standards set by the US Environmental Protection Agency (EPA).[20] Acute and chronic exposure

14 Mandatory for Xcel Energy and voluntary for other utilities.

15 Colorado General Assembly. HB 19-1261 (2019).

16 Colorado Energy Office. "GHG Pollution Reduction Roadmap (Draft)" (2020). Available at: https://energyoffice.colorado.gov/climate-energy/ghg-pollution-reduction-roadmap

17 Scovronick, Noah, *et al*. The Impact of Human Health Co-Benefits on Evaluations of Global Climate Policy. *Nature Communications* 10.1 (2019): 1-12.

18 Driscoll, Charles T., *et al.* US Power Plant Carbon Standards and Clean Air and Health Co-Benefits. *Nature Climate Change* 5.6 (2015): 535-540.

19 Fann, Neal, *et al.* Maximizing Health Benefits and Minimizing Inequality: Incorporating Local-Scale Data in the Design and Evaluation of Air Quality Policies. *Risk Analysis: An International Journal* 31.6 (2011): 908-922.

20 US Environmental Protection Agency. "Criteria Air Pollutants" (2020). Available at: https://www.epa.gov/criteria-air-pollutants

to ozone and $PM_{2.5}$ are associated with adverse cardiovascular and respiratory health outcomes such as asthma and heart attacks, as well as other poor health outcomes including premature mortality.[21] NO_2 and SO_2 are associated with respiratory irritation and difficulty breathing, in addition to their roles alongside other NO_x and SO_x compounds as ozone and $PM_{2.5}$ precursors.[22,23] In addition to criteria air pollutants such as those listed above, EPA regulates hazardous air pollutants, including some VOCs, typically due to their potential for cancer or other serious health effects.[24]

The health impacts of emissions from the combustion of fossil fuels tend to be most elevated for those living near and downwind from these activities, but can also extend across broader regions, hundreds of miles from the pollution source. Conversely, exposure can also be very localized. For example, residential combustion of natural gas, propane, fuel oil, and wood for heating, cooking, and other uses can contribute to elevated concentrations of air pollutants and exposure via poor indoor air quality.[25,26]

Primary pollutant emissions, mostly from fossil fuel use, across Colorado's commercial, industrial, power, residential, and transportation sectors are shown in **Figure 1**. As noted above, many of these primary pollutants also contribute to the secondary formation of ozone and particulate matter. Furthermore, direct emissions of carbon dioxide do not fully reflect the lifecycle greenhouse gas emissions of fossil fuel use, notably from methane leakage throughout the production, processing, transmission, and use of natural gas. This methane leakage is estimated to increase the radiative forcing of natural gas combustion by 92 percent over a twenty-year time period.[27] **Figure 1** includes fugitive methane leakage estimates derived from the Colorado GHG Roadmap, reflecting the State's assumed leakage rate of 2.5 percent of gas production and 0.5 percent of gas along distribution pathways.[28]

It is worth noting that Colorado produces roughly four times the natural gas it consumes in-state,[29] so upstream methane emissions in the state are far greater than would be associated with lifecycle estimates for Colorado's gas consumption alone.

The sectors in **Figure 1** capture the majority of the state's energy consumption and associated emissions and categorize them in a way that is pertinent to the structure of decarbonization policies. We use this sectoral framework throughout this report. It is important to note the wide variability in pollutant emissions by sector and fuel type, illustrating that reductions in carbon dioxide emissions can achieve very different co-pollutant reduction benefits depending upon the sector.

Low-income, communities of color, and other socioeconomically vulnerable communities across the country disproportionately live near fossil fuel infrastructure and are exposed to a disproportionate share of its pollution. Studies have found, for example, that communities of color are disproportionately exposed to air pollution,[30] including from fossil fuel sources like transportation,[31] and that communities with high socioeconomic burdens are more likely to live near fossil fuel infrastructure, such as power plants.[32,33] Living near

21 Pope III, C. Arden, and Douglas W. Dockery. Health Effects of Fine Particulate Air Pollution: Lines that Connect. *Journal of the Air & Waste Management Association* 56.6 (2006): 709-742.

22 US Environmental Protection Agency. "Nitrogen Dioxide Pollution." Sept. 8, 2016. Available at: https://www.epa.gov/no2-pollution/basic-information-about-no2#Effects

23 US Environmental Protection Agency. "Sulfur Dioxide Pollution" (2019). Available at: https://www.epa.gov/so2-pollution/sulfur-dioxide-basics#effects

24 US Environmental Protection Agency. "Health and Environmental Effects of Hazardous Air Pollutants" (2017). Available at: https://www.epa.gov/haps/health-and-environmental-effects-hazardous-air-pollutants

25 Seals, Brady and Andee Krasner. Health Effects from Gas Stove Pollution. *Rocky Mountain Institute* (2020).

26 Semmens, Erin O., *et al.* Indoor Particulate Matter in Rural, Wood Stove Heating Homes. *Environmental Research* 138 (2015): 93-100.

27 Alvarez, Ramón A., *et al.* Assessment of Methane Emissions from the US Oil and Gas Supply Chain. *Science* 361.6398 (2018): 186-188.

28 Distribution-level leakage rates, including behind-the-meter, still have significant uncertainty and may be higher than assumed by the State of Colorado, but a deeper discussion of methane leakage rates and uncertainties is beyond our scope here.

29 US Energy Information Administration. "Colorado" (2020). Available at: https://www.eia.gov/state/?sid=CO

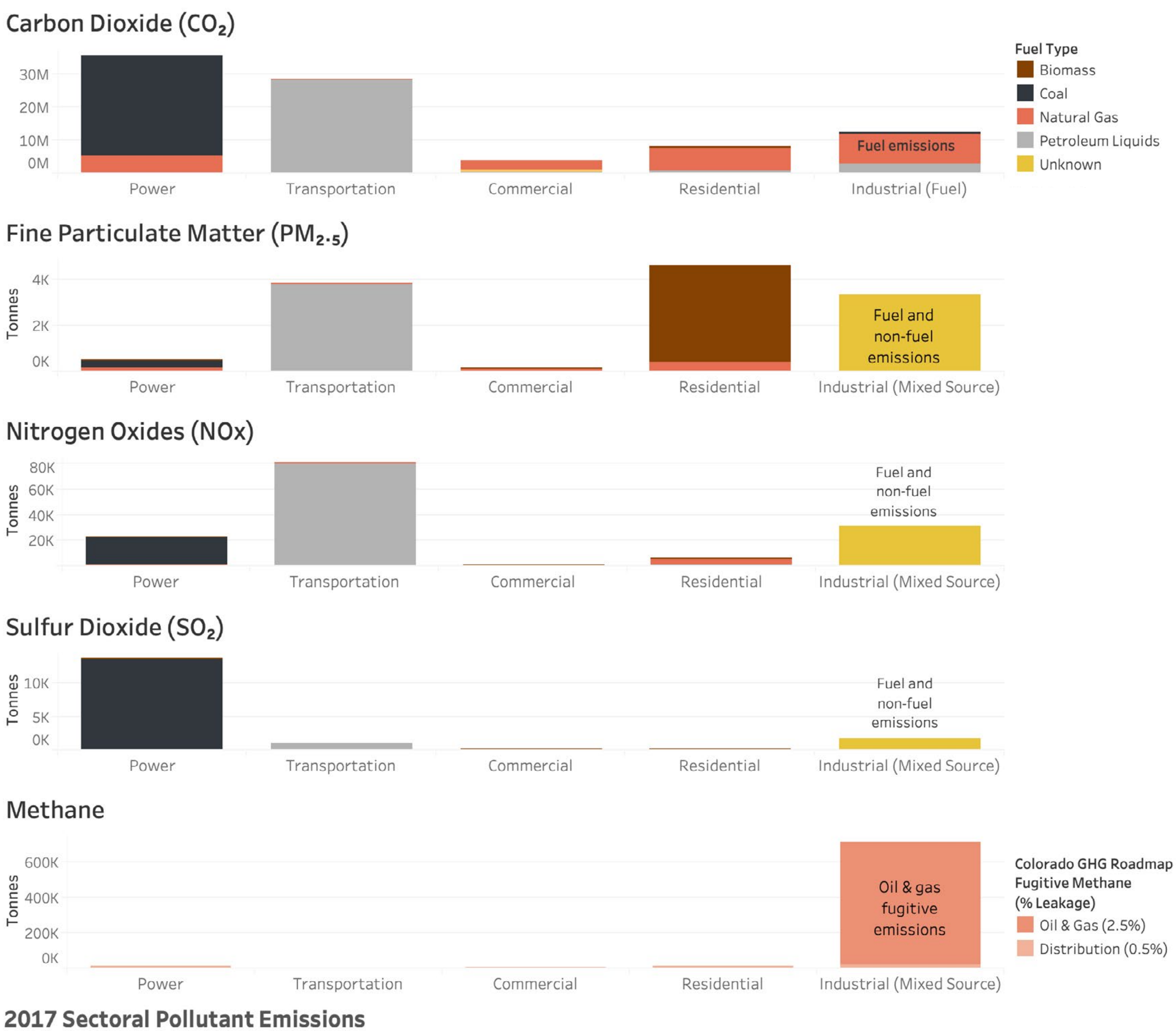
30 Tessum, Christopher W., *et al.* Inequity in Consumption of Goods and Services Adds to Racial–Ethnic Disparities in Air Pollution Exposure. *Proceedings of the National Academy of Sciences* 116.13 (2019): 6001-6006.

31 Clark, Lara P., Dylan B. Millet, and Julian D. Marshall. Changes in Transportation-Related Air Pollution Exposures by Race-Ethnicity and Socioeconomic Status: Outdoor Nitrogen Dioxide in the United States in 2000 and 2010. *Environmental Health Perspectives* 125.9 (2017): 097012.

32 Krieger, Elena M., Joan A. Casey, and Seth B.C. Shonkoff. A Framework for Siting and Dispatch of Emerging Energy Resources to Realize Environmental and Health Benefits: Case Study on Peaker Power Plant Displacement. *Energy Policy* 96 (2016): 302-313.

33 EPA, "EJ Screening Report for the Clean Power Plan," US Environmental Protection Agency, Tech. Rep.Docket: EPA–HQ–OAR–2013–0602, (2015).

FIGURE 1. Cross-sector primary emissions of carbon dioxide, methane, and some criteria air pollutants by fuel type.[34,35] Industrial criteria air pollutant emissions include fuel- and non-fuel emissions from stationary point sources, as well as from non-point sources associated with oil and gas exploration, drilling, extraction, and transport to central processing facilities.[36] Methane leakage estimates derived from the GHG Roadmap include oil and gas production fugitive emissions (2.5 percent leakage rate) and distribution methane leakage (0.5 percent).[37] The variation in co-pollutant emissions indicates that the reduction of greenhouse gases from different sectors will have different impacts on criteria air pollutant reductions.[38]



34 Coal generation fell 13 percent between 2017 and 2019, somewhat reducing coal-related emissions in recent years.

35 Data includes internal modeling and the following sources: US Environmental Protection Agency, "National Emissions Inventory (NEI)" (2017), available at: https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei; US Energy Information Administration, "Energy-Related CO_2 Emission Data Tables," available at: https://www.eia.gov/environment/emissions/state/; US Energy Information Administration, "Emissions by Plant and by Region," available at: https://www.eia.gov/electricity/data/emissions/

36 NEI emissions estimates for industrial nonpoint sources may be underestimates, as a result of underreporting of pipeline emissions between wellheads and gas processing facilities, as well as the existence of above-average high-emitting oil and gas sites (Grant, John *et al.* U.S. National Oil and Gas Emission Inventory Improvements. (2017)).

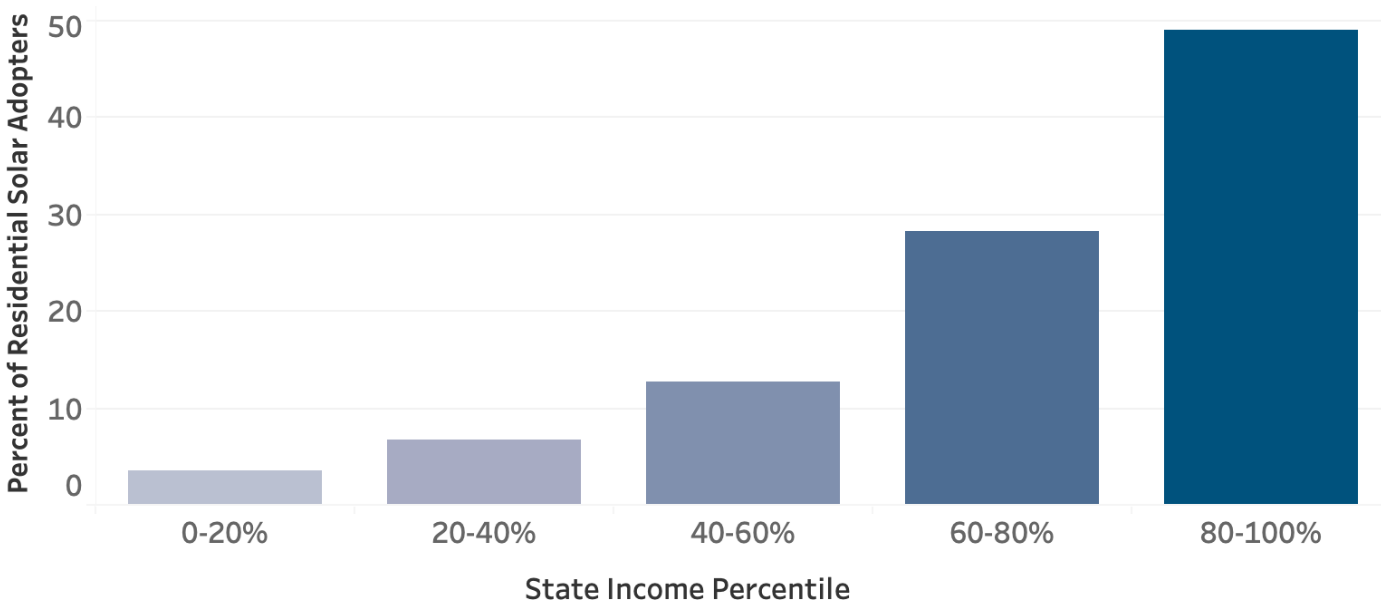
37 Colorado Energy Office. "GHG Pollution Reduction Roadmap (Draft): Energy + Environmental Economics Technical Appendix" (2020). Available at: https://energyoffice.colorado.gov/climate-energy/ghg-pollution-reduction-roadmap

38 While many nonroad mobile sources serve industrial facilities, we include them in the transportation sector here, as they will likely require similar technical and policy solutions to on-road vehicles in terms of vehicle electrification and electric vehicle charging infrastructure.

facilities such as power plants is associated with adverse health effects such as respiratory disease[39] and adverse birth outcomes.[40,41] Additionally, some vulnerable populations, such as young children, the elderly, and those with pre-existing medical conditions, are particularly sensitive to health impacts from environmental pollution.[42] Decarbonization efforts, such as power plant retirements, have the potential to reduce fossil fuel co-pollutant exposures and health impacts for these communities and populations.[43]

Assessments of cumulative environmental burdens and socioeconomic vulnerabilities can help identify populations for whom interventions to reduce pollution may be particularly beneficial.[44] California uses an environmental justice screening tool, CalEnviroScreen 3.0,[45] to identify disadvantaged communities and develop incentives to increase clean energy access and reduce pollution burdens for these populations. The US EPA has also developed an environmental justice screening tool, EJSCREEN, to identify similar highly polluted and vulnerable communities nationwide.[46]

FIGURE 2. Residential solar adoption by Colorado state income percentiles in 2018.[47] The highest-income 20 percent of households were responsible for 49 percent of solar installations, as compared to 3 percent of solar installations among the 20 percent lowest-income households.



39 Liu, Xiaopeng, Lawrence Lessner, and David O. Carpenter. Association Between Residential Proximity to Fuel-Fired Power Plants and Hospitalization Rate for Respiratory Diseases. *Environmental Health Perspectives* 120.6 (2012): 807-810.

40 Ha, Sandie, *et al.* Associations Between Residential Proximity to Power Plants and Adverse Birth Outcomes. *American Journal of Epidemiology* 182.3 (2015): 215-224.

41 Casey, Joan A., *et al.* Retirements of Coal and Oil Power Plants in California: Association with Reduced Preterm Birth Among Populations Nearby. *American Journal of Epidemiology* 187.8 (2018): 1586-1594.

42 Pope III, C. Arden, and Douglas W. Dockery. Health Effects of Fine Particulate Air Pollution: Lines that Connect. *Journal of the Air & Waste Management Association* 56.6 (2006): 709-742.

43 Martenies, Sheena E., *et al.* Health and Environmental Justice Implications of Retiring Two Coal-Fired Power Plants in the Southern Front Range Region of Colorado. *GeoHealth* 3.9 (2019): 266-283.

44 Sadd, James L., *et al.* Playing It Safe: Assessing Cumulative Impact and Social Vulnerability through an Environmental Justice screening Method in the South Coast Air Basin, California. *International Journal of Environmental Research and Public Health* 8.5 (2011): 1441-1459.

45 California Office of Environmental Health Hazard Assessment. CalEnviroScreen. Available at: https://oehha.ca.gov/calenviroscreen

46 US Environmental Protection Agency. EJSCREEN. Available at: https://www.epa.gov/ejscreen

47 Data source: Berkeley Lab. "Solar Demographics Tool" (2020). Available at: https://emp.lbl.gov/solar-demographics-tool

1.2.2 Energy Cost Burdens and Clean Energy Access

Residential and transportation energy use can contribute to high utility and fuel bills, which weigh particularly heavily on lower-income households. Lower-income households tend to pay less (in total magnitude) for energy than higher-income households, but also tend to live in less efficient homes, drive less efficient vehicles, and spend a larger fraction of their paycheck on energy use. For example, the American Council for an Energy Efficient Economy estimates that low-income households (<80 percent area median income) in the Denver metropolitan area spend a median of 7 percent of their income on residential energy bills, and a quarter of low-income households spend more than 11 percent, as compared to just over 3 percent for the average household.[48] Moreover, low-income households may struggle to pay fluctuating bills, face the risk of utility shutoffs, and otherwise struggle with energy insecurity, which can exacerbate underlying health conditions[49] and reduce resilience to climate extremes.

Certain clean energy interventions can help alleviate energy cost burdens. Residential efficiency and weatherization measures, for example, can reduce electric bills and the need for heating and cooling. Rooftop solar or community solar can provide long-term economic savings and stable electric bills.

Unfortunately, low-income households and people of color often face barriers to adoption for these kinds of technologies. Some technologies, such as air source heat pumps, solar panels, or electric vehicles, are capital-intensive. They may be cheaper over the lifetime of the equipment, but lower-income households often lack access to capital, financing, or credit that makes these investments accessible. Many of these households may be linguistically isolated or lack access to information that energy-saving technologies are available. As many people of color and low-income families live in rental apartments, their ability to replace appliances or adopt efficiency measures in their homes is limited. This barrier is termed the *split incentive problem*, wherein renters pay utility bills but landlords own energy sources and appliances and have limited incentives to invest in efficiency measures. In addition, some clean energy measures—such as energy efficiency—may reduce average bills but increase electricity rates. While average energy bills may go down, those households which do not adopt energy-savings measures may face higher bills. Due to the aforementioned barriers, low-income households are at particular risk for such bill increases.

The impact of these kinds of barriers is reflected in rooftop solar adoption rates across Colorado. **Figure 2** shows solar adoption rates by income bracket in 2018. The wealthiest 20 percent of households adopted rooftop solar at 16 times the rate of the lowest-income 20 percent of households.

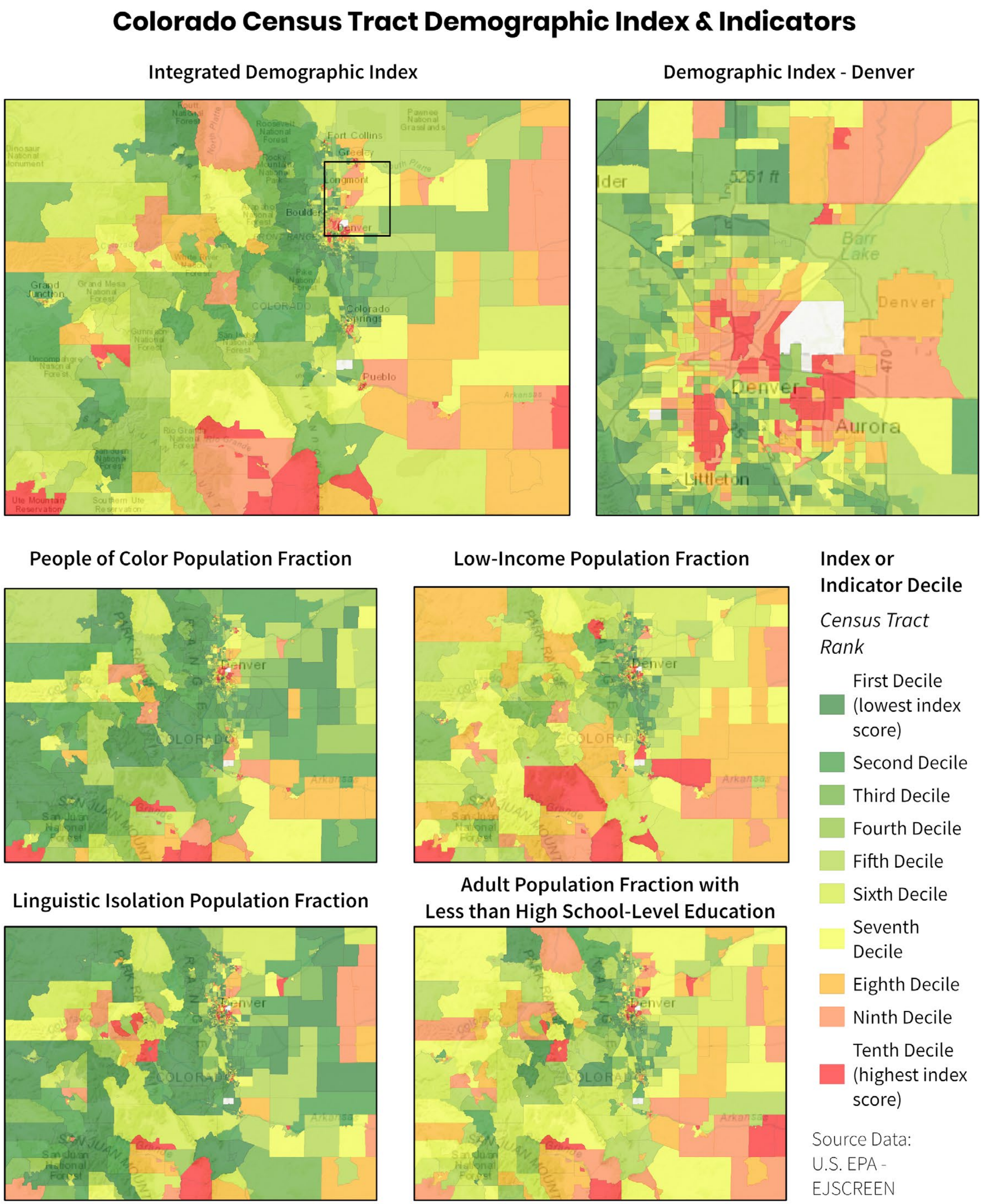
TABLE 2. Description of decarbonization scenarios.

Scenario	Description
Reference	State implements no new climate policies and does not achieve greenhouse gas targets.
Core	Central cost-optimized decarbonization pathway, relying primarily on near-term decarbonization of the power sector and retirement of coal plants, combined with building efficiency and electrification of transportation and fuel use in buildings and industry.
Low Demand	Energy demand is lower than in the core scenario due to lower vehicle miles traveled (e.g. due to public transit or behavioral changes) and more energy efficiency in buildings.
Fossil Free	Current state greenhouse gas targets are surpassed and fossil fuel production, extraction, and use is eliminated by 2050.
Slow Coal Retirement	Decarbonization of the power sector lags behind the core scenario, requiring more rapid adoption of energy efficiency and electrification measures across the building and transportation sectors to ensure 2030 climate targets are met.

48 Drehobl, Ariel and Lauren Ross. Lifting the High energy cost burden in America's Cities: How Energy Efficiency Can Improve Low-Income and Underserved Communities. *American Council for an Energy Efficient Economy*, (2016).

49 Hernández, Diana, and Stephen Bird. Energy Burden and the Need for Integrated Low-Income Housing and Energy Policy. *Poverty & Public Policy* 2.4 (2010): 5-25.

FIGURE 3. Integrated Demographic Index for Colorado and Denver, and individual statewide demographic indicators. In the Demographic Index, neighborhoods that are orange or red have a higher share of combined low-income, minority, low educational attainment, linguistically isolated, elderly, and very young populations than other Colorado census tracts.



1.3 Approach

In this assessment, we examine current environmental and energy cost burdens and socioeconomic and racial disparities across the Colorado population and how different approaches to decarbonization may increase or decrease these burdens. We relied on a variety of publicly available datasets that enabled us to evaluate the types, magnitudes, and geography of energy, environmental pollutants, and technologies as well as the distribution of costs and benefits across demographics of Colorado's human population. To inform our technical analyses, we also conducted extensive statewide outreach with various nongovernmental organizations, advocacy groups, and other community organizations. This outreach enables us to identify key topics, concerns, and priorities. This analysis is meant to provide an initial screen of pollution and energy cost burdens and identify policy levers to intervene and approaches to integrating energy and environmental equity into decarbonization research and policy moving forward. In addition, the development of energy equity and pollution-focused policies should include extensive engagement and outreach to affected communities to help identify concerns and barriers, and develop policies reflecting community needs and priorities.

We first mapped existing fossil fuel infrastructure and energy-related pollutant emissions across the commercial, residential, transportation, industry, and power sectors, and analyzed the demographics of nearby populations. Next, we estimated average baseline residential and transportation energy cost burdens for households across the state. We applied Evolved Energy's four decarbonization scenarios (see below) to these baseline pollution and energy consumption data to assess impacts on pollution and energy bills in relation to spatial and socioeconomic indicators.

1.3.1 Decarbonization Scenarios

Evolved Energy Research developed cost-optimized decarbonization pathways using a combination of two energy system analysis platforms: EnergyPATHWAYS, a bottom-up energy sector model which calculates future energy demand; and the Regional Investment and Operations (RIO) platform, which optimizes costs while ensuring demand is reliably met. Together, these models estimate future energy use, appliance and vehicle turnover, electricity generation and demand, greenhouse gas emissions, and costs from 2020-2050. Importantly, in Evolved Energy's models and throughout our accompanying analysis, estimated energy consumption and greenhouse gas and criteria air pollutant emissions in the year 2020 do not reflect the impacts of COVID-19 on energy production and use. Evolved Energy Research assessed five scenarios, including a reference "business-as-usual" scenario and four additional scenarios ensuring Colorado achieves its climate targets. These scenarios are outlined in **Table 2**. For a full description of Evolved Energy Research's scenarios, as well as underlying models, assumptions and inputs, please see the accompanying report by Evolved Energy Research, GridLab, Natural Resources Defense Council (NRDC), and Sierra Club.[50]

1.3.2 Integrating Health and Energy Equity Analysis

Our initial environmental and energy cost burden analysis provides a baseline for us to identify areas where clean energy adoption and emissions reductions might be particularly valuable to reduce pollution or energy cost burdens in socioeconomically or environmentally overburdened communities. To create this baseline, we aggregated public datasets reporting fossil fuel emissions from power plants and industrial facilities, estimated transportation emissions from highway vehicle counts and standard vehicle emission factors, and conducted a regression analysis based on household characteristics to estimate residential fuel use on a census tract level. In addition to calculating emissions, we estimated household energy cost burdens based on these fuel consumption estimates.

50 Arjun Krishnaswami, Ariana Gonzalez, and Matthew Gerhart. Committing to Climate Action: Equitable Pathways for Meeting Colorado's Climate Goals. *Evolved Energy, GridLab, NRDC, and Sierra Club* (2020).

In order to identify Colorado communities that may be particularly vulnerable to the impacts of air pollution, we analyzed demographic characteristics of populations across the state. From this analysis we screened for census tracts that have comparatively high socioeconomic burdens as compared to other census tracts in Colorado. As part of this screen, we developed a Demographic Index for Colorado census tracts, which combines measures on income, education, linguistic isolation, very young, elderly, and minority populations (see **Appendix I: Methods**). We then used this index to assess where socioeconomically overburdened communities are also exposed to high environmental pollution or have high energy cost burdens.

In **Figure 3**, we show this Demographic Index for Colorado. This map reflects a mix of socioeconomically overburdened populations, in both urban and rural communities. In many cases in the following sections, we use demographic indicators to explore relationships between specific pollutant sources (e.g. on-road vehicles) and population characteristics across Colorado. A closer look at the Denver metropolitan areas is presented as well. Here, we can see a number of potentially overburdened neighborhoods, notably including the heavily industrial Commerce City and communities along Interstates 25, 76, and 70.

We note that these combined demographic indicators only reflect those measures that are included in the EJSCREEN tool. Additional measures, such as underlying health conditions (e.g. asthma rates or preterm births) are not included in these indices but may be valuable for identifying populations sensitive to pollution.[51] We therefore include additional indicators within some of our analyses below. These include climate indicators (e.g. wildfire and heat day risks), health indicators (e.g. life expectancy), and environmental indicators (e.g. federal ozone nonattainment areas, and days ozone or particulate matter standards are exceeded). These additional metrics provide more specific insight into the types of vulnerabilities and environmental burdens faced across the state. Our analysis provides an initial screen for polluted and otherwise environmentally vulnerable communities, however direct community engagement can help identify additional environmental concerns and socioeconomic burdens not available within our datasets.

By combining the fossil fuel pollution and energy use data with the demographic indicators above, we identified certain regions where communities live near numerous sources of environmental pollution, and other communities (some overlapping) where household adoption of clean energy and transportation technologies may help provide economic and resilience benefits. We projected these baseline estimates across decarbonization scenarios and modeled where benefits might accrue— and we identified potential risks where carbon-only decarbonization policies might actually lead to negative externalities such as economic impacts on socioeconomically vulnerable households. We combined these baseline and decarbonization modeling results in a discussion of policy options for Colorado to incorporate health, environment, and energy equity into its decarbonization planning.

51 We also separately assessed the cumulative environmental metrics included in EJSCREEN, but found these data to be heavily limited by the data types included in the dataset. We decided instead to primarily assess pollution from the data we aggregated and modeled across sectors.

2 Results

Overview of Findings

Across Colorado, we find that decarbonization has the potential to improve public health and reduce energy cost burdens. However, our analysis suggests that these co-benefits may not accrue evenly across the state and that disparities in fossil fuel pollution and economic impacts may be exacerbated with a decarbonization strategy focused exclusively on carbon emissions.

In order to develop strategies that help reduce economic and environmental disparities, we first identified communities facing inequitable environmental and economic burdens from the existing system and elevated risk from climate change. In the Denver metro area, as well as other Colorado cities and towns, we found that certain census tracts have a high number of emission sources, particularly from the transportation and industrial sectors. Some of these areas, such as Commerce City, are home to vulnerable populations with significant portions of populations of color and low-income households. Switching from fossil fuels to low-emissions sources has the potential to reduce much of this pollution. This approach may be particularly valuable for the Denver region because it is out of attainment for federal ozone standards. However, we find that in the near term, transportation emissions could *increase* in some neighborhoods due to increased trucking, if old, high-emitting trucks remain active. Furthermore, even as the state decarbonizes, we project ongoing operation of industrial facilities currently located in environmentally overburdened communities, such as the Suncor Refinery and natural gas plants utilized for grid reliability.

In buildings, the electrification of natural gas appliances will help reduce indoor air pollution, but low-income and renter households are less likely than wealthier households to see these benefits in the near term due to the increased clean energy adoption barriers that these households typically face. Policies targeted at providing clean energy for these households may be particularly valuable.

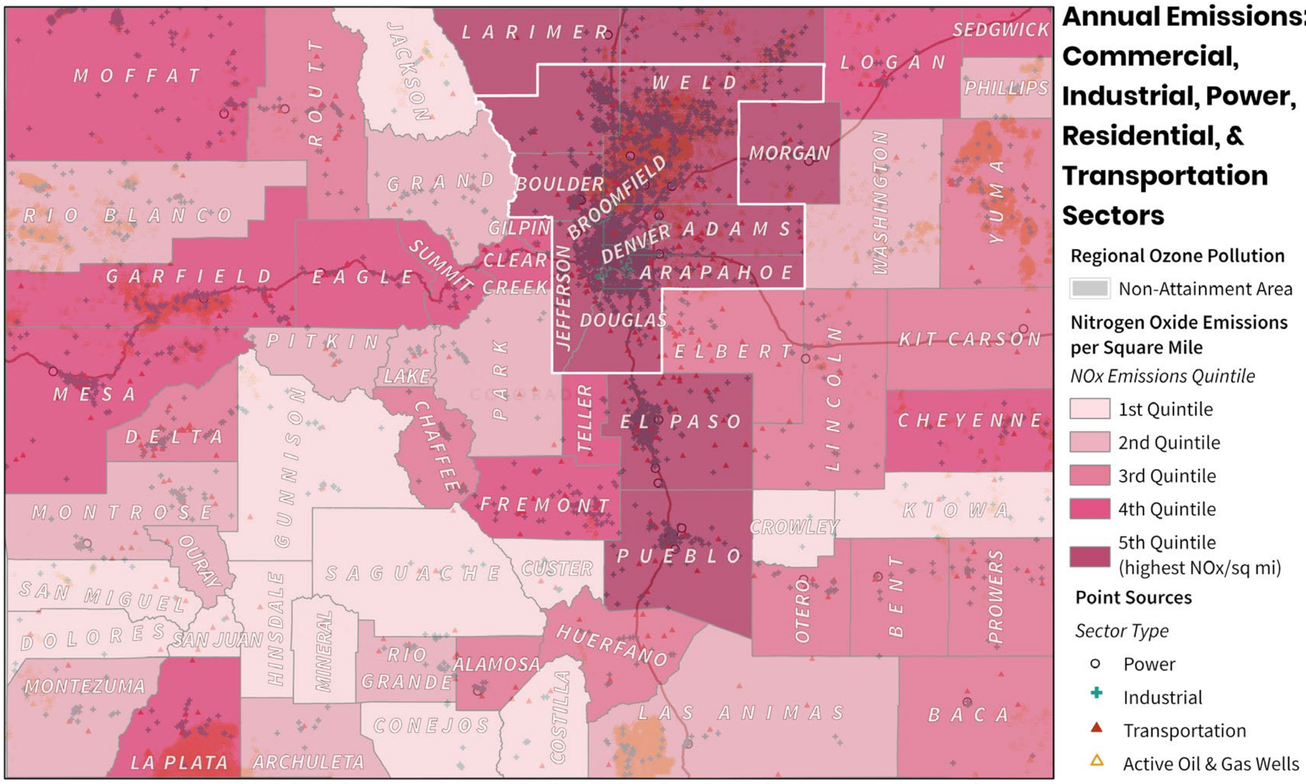
Across rural Colorado, we find higher energy cost burdens on average than in urban areas due to high residential utility bills and longer average driving distances.[52] Even though only a small portion of these households burn wood, those that do contribute to a disproportionate share of residential pollutant emissions, including particulate matter, which can contribute to poor indoor and outdoor air quality. Residential emissions from wood burning are not currently projected to significantly change under any decarbonization pathway.

Rural counties like Mesa and Ouray will face increased extreme heat days, drought, and wildfires as the climate warms. These regions may particularly benefit from clean energy technologies like efficiency measures to reduce energy cost burdens and solar panels with battery storage (solar+storage) to provide emergency backup power in the face of increasingly frequent extreme weather events. Furthermore, while there tend to be fewer cumulative emissions per unit area in rural and suburban regions than in Colorado's urban census tracts, as shown in **Figure 4** below, this trend could change. For example, if oil and gas production continues while the rest of the economy decarbonizes—which will likely reduce air pollution in urban areas in particular—many rural households will not see these improvements and continue to be exposed to pollutants such as benzene, NO_x, ozone, and VOCs.

Decarbonization has the potential to reduce emissions like those shown in **Figure 4**, but existing disparities in emissions burdens may persist unless there are policies in place to ensure emission reductions are achieved in areas that currently have high cumulative emissions. Some of the long-term emission impacts may depend on regional decisions beyond Colorado's borders; for example, interstate truck emissions, as well as export-driven oil and gas production, will likely depend in part on regional and national decarbonization goals, suggesting a need for Colorado to work with its neighbor states on decarbonization policies. There is also a risk that without explicit policies, clean energy access may lag and fossil infrastructure may be left behind in environmentally and socioeconomically

52 Throughout the report, "urban" refers to combined US Census Bureau metropolitan and micropolitan statistical areas, while "rural" refers to all census tracts excluded from these categories.

FIGURE 4. Cumulative NO_x emissions from electricity generation, buildings, transportation, and industry in 2017. The federal ozone nonattainment area is outlined in white. Given the limited available data for oil and gas well emissions, we map their locations as a proxy for the spatial distribution of their emissions.



Source Data: U.S. Energy Information Administration - NEI 2017 Commercial, Industrial Point, Industrial Non-Point, Power Sector, Transportation Non-Road, Transportation Non-Point Emissions; Federal Highway Administration - 2018 Annual Average Daily Traffic; U.S. EPA - MOVES Database Emission Factors; Min et al./PSE Healthy Energy - Residential Energy Modeling, California Air Resources Board - Residential Emission Factors

overburdened communities, leaving out populations who may benefit most from measures like efficiency savings and potentially leaving them to shoulder the cost of maintaining an aging fossil infrastructure in the coming decades.

We walk through these findings in detail in the following sections. We first discuss our findings for each individual sector and then address cross-sector themes for clean energy access, emission reductions, and resilience.

2.1 Electricity Generation

Colorado currently has 53 natural gas, coal, oil, and biofuel power plants—facilities reliant on fuels which release greenhouse gases and criteria air pollutants when combusted. Of the plants that could be confirmed as operational, one burns primarily woody biomass, three burn landfill gas, eight burn oil, nine burn coal, and 25 burn natural gas, although many of these burn multiple fuels. Twenty-two of these plants—burning a mix of coal and natural gas—generate 99 percent of the electricity supplied by all of these facilities. The remaining units, which report limited emissions data, are often only a few megawatts in size but many burn primarily oil. Improved data collection would help to better characterize their potential public health risks. The state also imports electricity, but does not currently count the associated emissions towards its climate targets.

Colorado's coal plants are largely located in rural areas. These plants have high emissions of health-damaging co-pollutants, such as NO_x and SO_2, as shown in **Figure 5**. Nucla, the power plant with the highest emission rates, retired at the end of 2019. Coal plants also produce other pollutants, including primary particulate matter and mercury. In addition, NO_x and SO_2 can oxidize in the atmosphere and react with other compounds to form

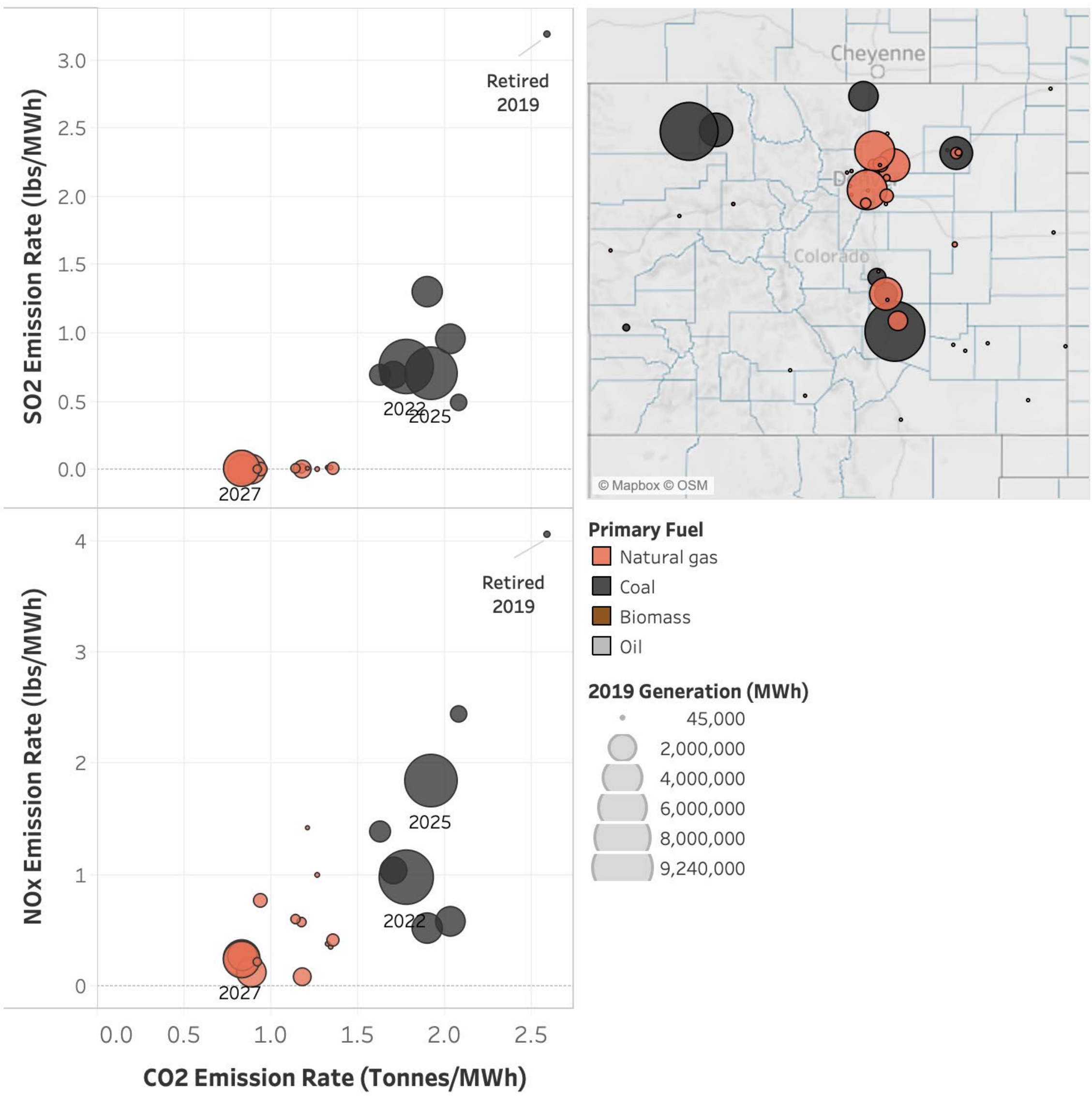


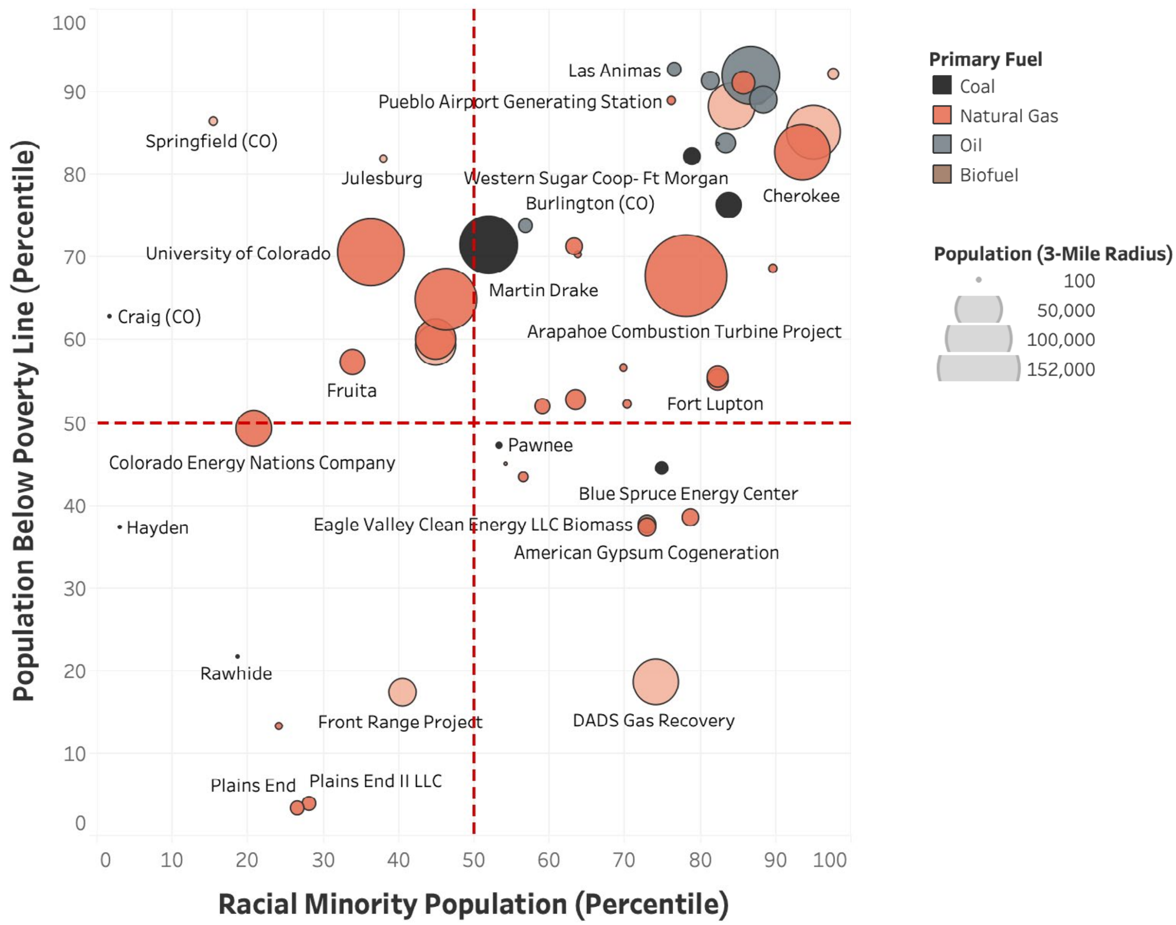
FIGURE 5. Power plant emission rates of CO_2, NO_x, and SO_2 in 2019. Bubble size reflects the total electricity generated by that plant in 2019. Date labels indicate plants with planned retirement dates. Some plants show much higher emission rates than others for every megawatt-hour (MWh) of electricity generated; the plant with the highest rates retired in 2019.

secondary particulate matter and ozone. The health impacts of these pollutants are typically highest *per capita* near the plants but their impacts can stretch for hundreds of kilometers downwind.[53] While coal has largely been eliminated from the urban Denver area, which is considered out of attainment for federal ozone standards, the region is still home to numerous gas plants, which produce the ozone precursor NO_x.

As noted, health impacts are not limited to the populations closest to power plants, but living next to power plants is associated with increased rates of adverse health outcomes. We therefore analyzed the demographics of populations living within a three-mile radius of Colorado's power plants. In **Figure 6**, we plot power plants by the demographics of those living within a three-mile radius. We found that 86 percent of the power plants are in communities with

53 Levy, Jonathan I., Lisa K. Baxter, and Joel Schwartz. Uncertainty and Variability in Health-Related Damages from Coal-Fired Power Plants in the United States. *Risk Analysis: An International Journal* 29.7 (2009): 1000-1014.

FIGURE 6. Demographics of populations living within a three-mile radius of Colorado power plants. These plants, particularly the urban ones (those represented by larger bubbles), are disproportionately located in the state's low-income communities and communities of color.

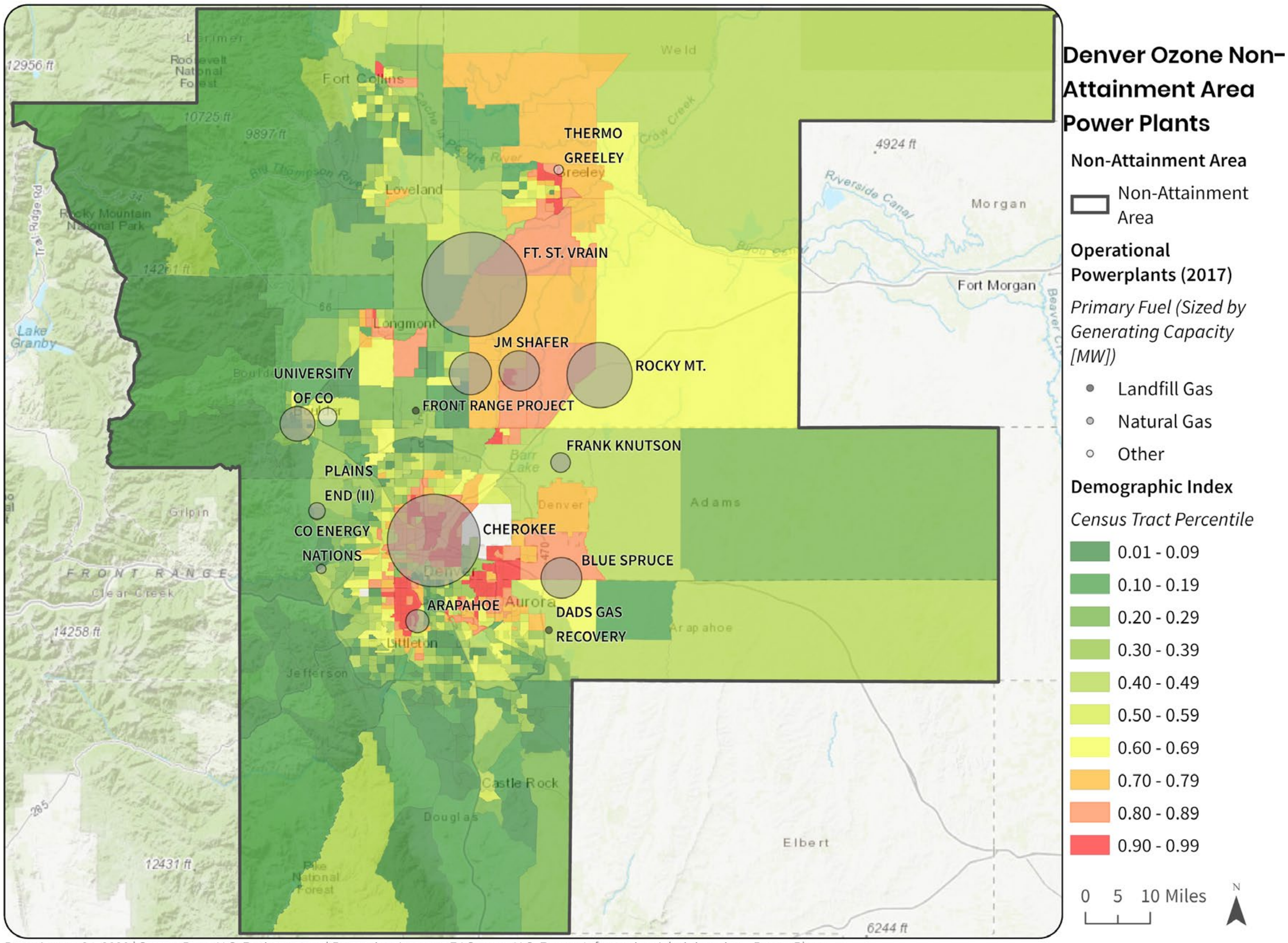


an above-the-median percentage of low-income populations and/or above-the-median percentage of racial minority populations as compared to census tracts across the state; more than half of the communities near plants have both low-income and minority populations above the median. These communities are also more likely to be urban and have larger populations, as reflected in the larger bubble sizes.

Rapid decarbonization of Colorado's power sector is central to achieving the state's 2030 climate goals. In the Core decarbonization pathway (see **Table 2**), coal electricity generation—which supplied 45 percent of in-state electricity generation in 2019—is almost entirely phased out by 2025 and fully eliminated by 2030. Renewable electricity generation supplies 98 percent of in-state electricity by 2030, with the remainder from other sources, including natural gas. However, even in 2050, the Core scenario assumes natural gas is combusted at a number of facilities for reliability purposes—in contrast to the Fossil Free scenario, where this gas is replaced with carbon-neutral fuels. The transition to renewable energy yields two primary opportunities for environmental and social equity benefits: reduction of total health damaging air pollutants from power plants, and the prioritized retirement of facilities in pollution-overburdened communities. However, the realization of these benefits depends on the transition pathway itself.

The modeled decarbonization pathways prioritize the retirement of coal plants, but all leave thermal capacity in place and burn either natural gas, synthetic fuels, biofuels, or hydrogen. While these plants are expected to operate infrequently to help meet peak demand—total NO_x emissions fall 99 percent in the Core scenario between 2020 and 2030—they will continue to generate some electricity, and therefore may still produce NO_x

FIGURE 7. Map of gas plants in the Denver Metro/North Front Range's ozone nonattainment region, along with the Demographic Index. Some of the most heavily emitting power plants in the ozone nonattainment region are in communities which score highly on our Demographic Index. Prioritizing their retirement presents opportunities to further environmental and social equity while improving regional air quality.



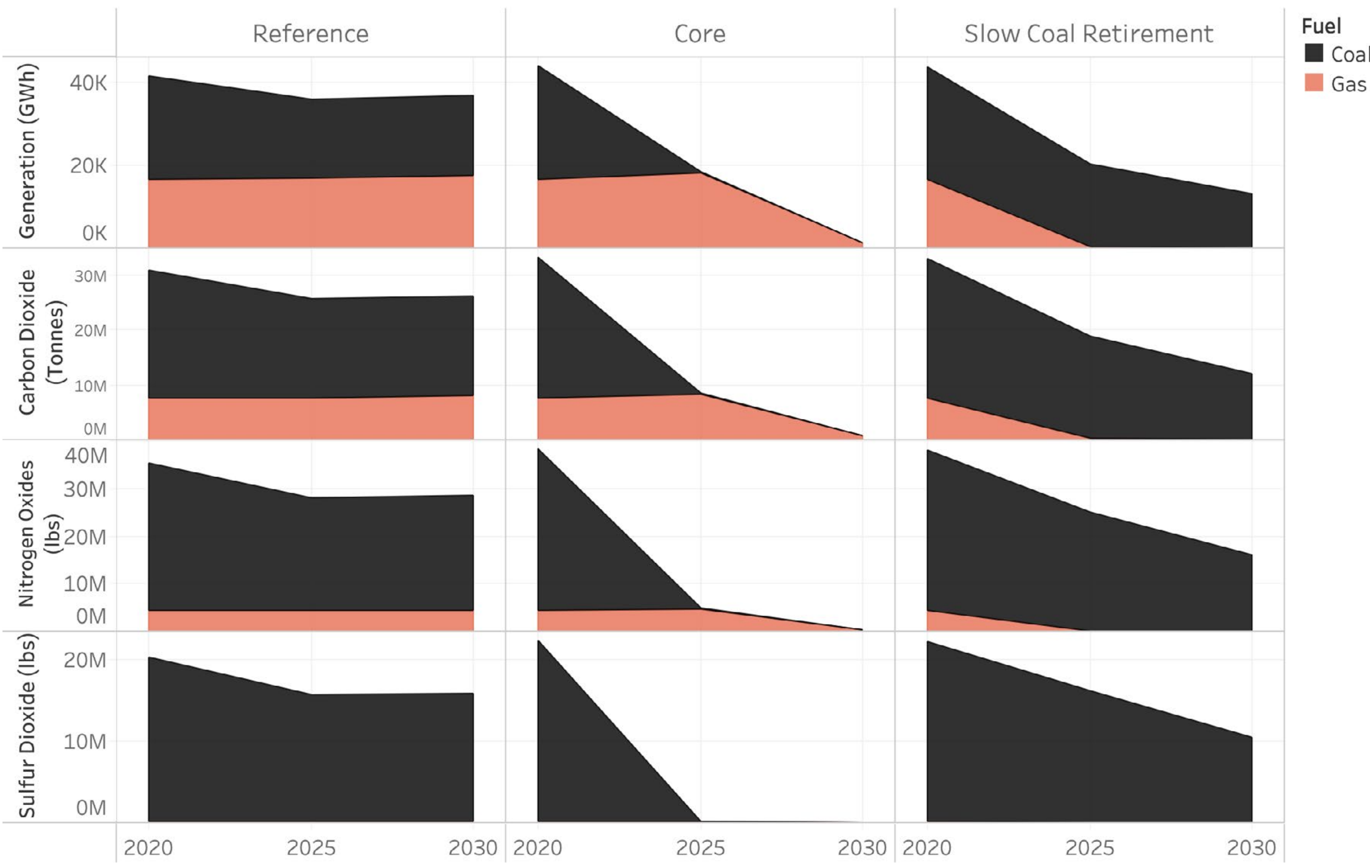
Date: August 24, 2020 | Source Data: U.S. Environmental Protection Agency - EJ Screen, U.S. Energy Information Administration - Power Plants

emissions, particularly to meet cooling loads on hot summer days when ozone is already high. Without clear policy directives to help determine which plants are being used for these reliability needs, the state runs a risk of leaving gas plants disproportionately in urban, low-income communities and communities of color, particularly in the Denver area, shown in **Figure 7**. Current energy storage technologies may be able to replace some of these gas plants in the near term. Even in the Fossil Free scenario, the *type* of carbon-neutral fuel replacing natural gas in power plants may affect the associated health risks. For example, the combustion of hydrogen produces water as a by-product, but the combustion of biogas can still produce criteria and hazardous air pollutants. In the long term, developments in long-duration energy storage may render ongoing combustion capacity unnecessary altogether and eliminate these concerns.[54]

In **Figure 8** we show the electricity generation (MWh) and total emissions of carbon dioxide (CO_2), NO_x, and SO_2 for the Reference (business-as-usual), Core, and Slow Coal Retirement decarbonization scenarios from 2020-2030. The Low Demand and Fossil Free scenarios look similar

54 Dowling, Jacqueline A., *et al.* Role of Long-Duration Energy Storage in Variable Renewable Electricity Systems. *Joule* 4.9 (2020): 1907-1928.

FIGURE 8. Electricity generation, CO_2, SO_2 and NO_x emissions from 2020-2030 for the Reference, Core, and Slow Coal Retirement scenarios. Low Demand and Fossil Free scenarios are similar to Core scenario. SO_2 and NO_x emissions are only slightly lower than the Reference scenario in the Slow Coal Retirement scenario.



to the Core scenario for the power sector during this time frame. In the Core scenario, coal emissions fall to almost zero in 2025, but natural gas emissions linger across the decade. In the Slow Coal Retirement scenario, however, coal generation is only reduced by half by 2030, leaving significant emissions of SO_2 and NO_x in 2030. Notably, as we saw in **Figure 1**, coal plants account for more than 80 percent of the state's SO_2 emissions. While the Core scenario eliminates these emissions, in the Slow Coal Retirement scenario they fall only by half, even though power sector CO_2 emissions are cut by two-thirds.

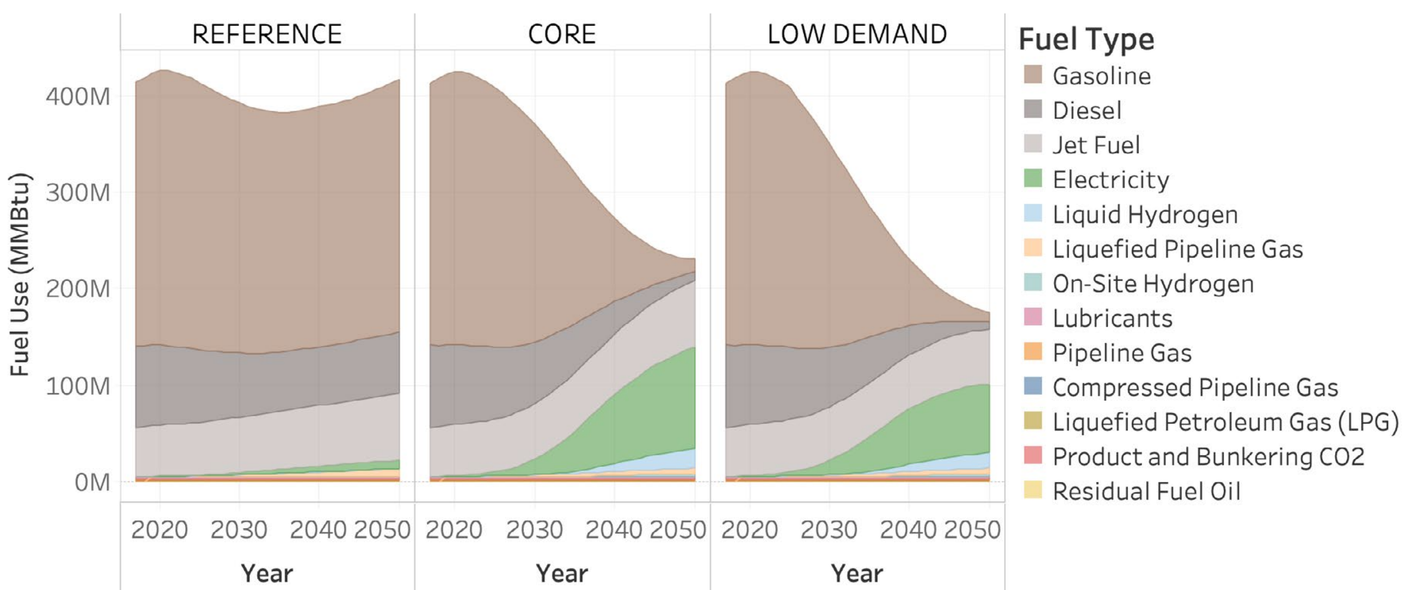
Indeed, SO_2 emissions in the Slow Coal Retirement scenario are only moderately lower than in the Reference case. Prioritizing the retirement of plants with the highest SO_2 emission rates, shown in **Figure 5**, can eliminate another 15 percent of these 2030 SO_2 emissions in the Slow Coal Retirement scenario, but the best public health strategy is to retire coal plants entirely.

2.2 Transportation

2.2.1 Transportation Sector Overview

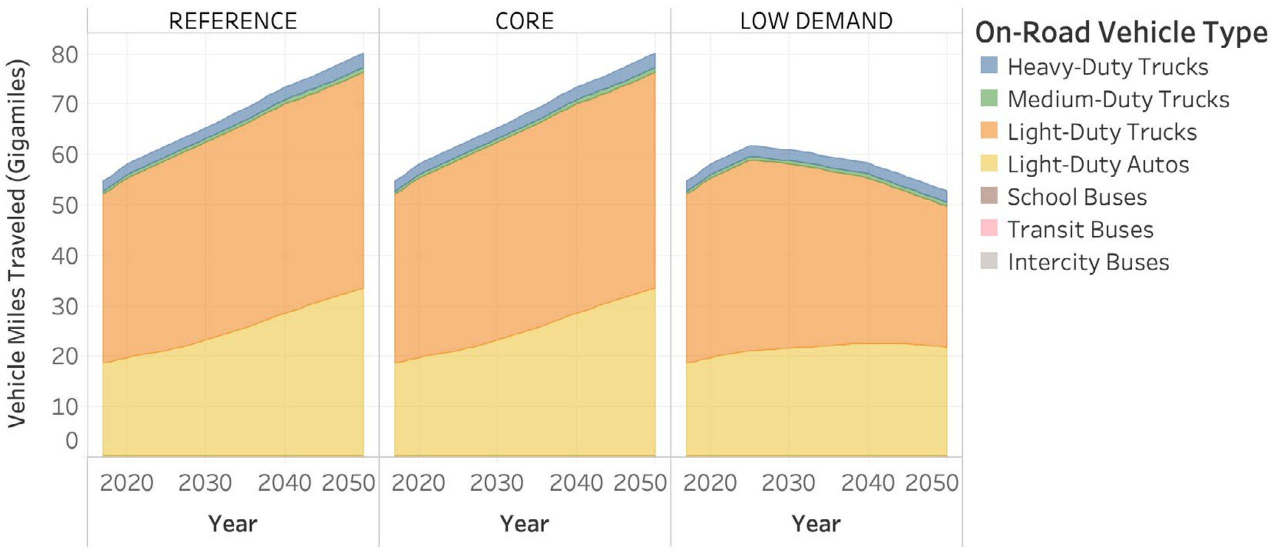
Colorado's transportation sector—including light-duty vehicles, buses, medium- and heavy-duty trucks, nonroad vehicles,[55] aviation, and rail—is responsible for a third of statewide CO_2 emissions and more than half of statewide NO_x emissions. In addition to the ozone and secondary particulate matter formed by reactions of NO_x in the atmosphere, transportation also contributes nearly a third of primary $PM_{2.5}$ emissions statewide. Many of these emissions occur in population-dense urban areas at ground level, and can contribute to local pollution hotspots. Decarbonization of the transportation sector is largely enabled by vehicle electrification, which reduces tailpipe pollutant emissions, though at uneven rates across the state due to different rates of electrification between vehicle classes. Moreover, low-income households currently spend a large portion of their income on vehicle fuel, but may face barriers to purchasing fuel-efficient electric vehicles due to high up-front costs and lack of access to charging infrastructure. Health and energy equity-focused decarbonization policies can help accelerate vehicle turnover in highly polluted areas, reduce barriers to adoption, and—under certain approaches—reduce vehicle use altogether by expanding access to public transit and facilitating active, transit-friendly built environments.

FIGURE 9: Fuel consumption by fuel type across all transportation subsectors, including aviation, passenger and freight rail, and on-road vehicles. Fuel consumption by the transportation sector in 2017 is dominated by gasoline, followed by diesel and jet fuel. The dip in fuel use in the Reference scenario is due to increased fuel efficiency and low levels of electric vehicle adoption, followed by an overall increase in travel and associated fuel demand. Because electricity is more energy efficient than fossil fuels, total energy consumption (MMBtu) declines even as total vehicle miles traveled increases in the Core scenario.



55 While non-road mobile sources include construction equipment and other mobile sources serving the industrial sector, we include these sources in the transportation sector, as they likely require similar technical and policy solutions to on-road vehicles in terms of vehicle electrification and electric vehicle charging infrastructure.

FIGURE 10: Colorado vehicle miles traveled by on-road vehicle type. Vehicle miles traveled in light-duty passenger cars and light-duty trucks, which dominate total on-road vehicle miles traveled, grow in both the Reference and Core cases. Only the Low Demand scenario reduces vehicle travel compared to the Reference case.



2.2.2 Fuel Consumption and Vehicle Travel

Fuel consumption by the transportation sector is currently dominated by gasoline (65 percent), followed by diesel (20 percent) and jet fuel (12 percent). Under the modeled decarbonization scenarios, gasoline and diesel fuel usage in the transportation sector are replaced primarily by electricity, as shown in **Figure 9**. Because electricity is more energy efficient as a fuel source, total fuel consumption declines even as total vehicle miles traveled increases in the Core scenario. Jet fuel use increases in all of the decarbonization scenarios, however, including in the Low Demand case. Aviation poses an ongoing challenge in terms of emission reductions due to the lack of technological options for replacing jet fuel.

As shown in **Figure 10**, passenger vehicle and truck miles decrease significantly in the Low Demand scenario compared to projected travel in the Reference and Core scenarios. The Low Demand scenario can be achieved through a combination of city planning and public transit efforts, and if strategically designed with energy equity considerations in mind, can improve transportation options for low-income households while reducing total pollutant emissions. This scenario maximizes public health co-benefits by replacing automobile trips with active transit such as walking and cycling, which are associated with myriad health and economic benefits,[56,57] alongside public transit expansion. While on-road vehicle travel declines in the Low Demand scenario, airline, freight rail, and passenger rail travel still increase. As airports emit significant amounts of health-damaging criteria air pollutants, the projected increase in airline travel in all decarbonization scenarios could exacerbate emissions burdens for communities living in close proximity to Colorado airports. According to the 2017 National Emissions Inventory, Denver International Airport is Colorado's highest-emitting point source of VOCs and hazardous air pollutants, the third highest emitter of NO_x, and among the ten highest emitters of SO_2. Other airports throughout the state likewise contribute outsized portions of Colorado's criteria air pollutant and health-damaging hazardous air pollutant emissions.

56 US Department of Transportation. "Integrate Health and Transportation Planning." Available at: https://www.transportation.gov/mission/health/Integrate-Health-and-Transportation-Planning.

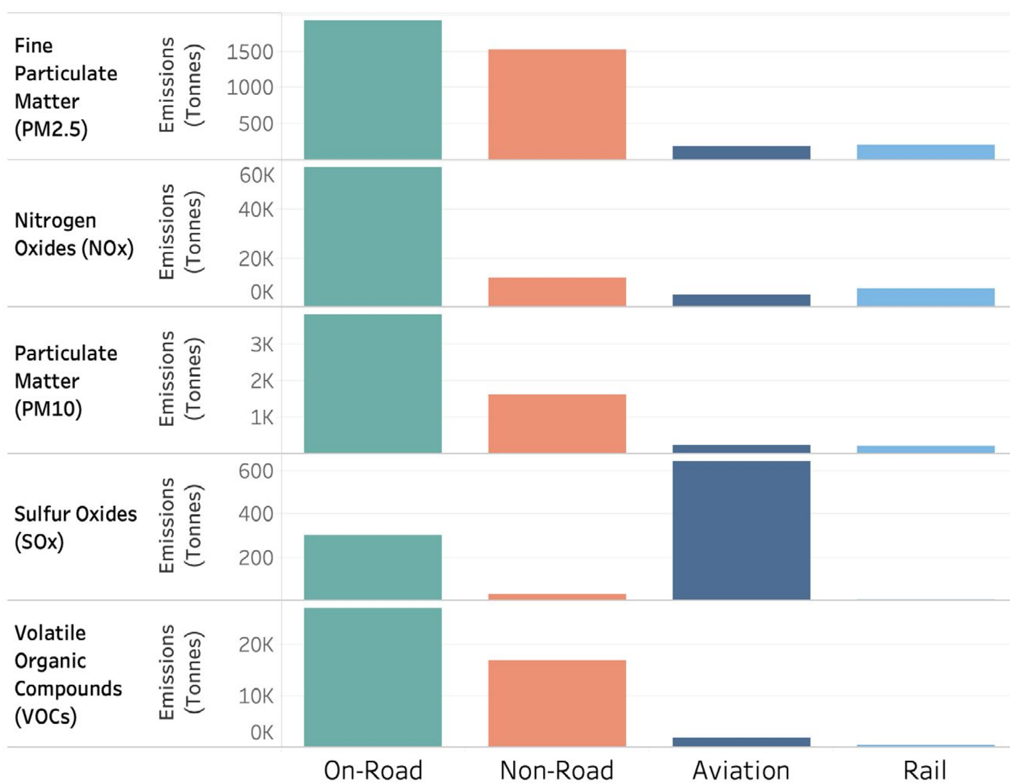
57 Giles-Corti, Billie, *et al.* The Co-Benefits for Health of Investing in Active Transportation. *New South Wales Public Health Bulletin* 21.6 (2010): 122-127.

2.2.3 Statewide Baseline and Projected Emissions

As shown in **Figure 11**, on-road mobile sources, including light-duty vehicles, buses, and medium-duty and heavy-duty trucks, contribute the largest share of transportation-related ground-level $PM_{2.5}$, NO_x, PM_{10}, and VOC emissions in Colorado. The nonroad sector, which spans both the transportation and industrial sectors, includes mobile sources such as off-road recreational vehicles, construction equipment, lawn and garden equipment, and industrial and farm equipment. This sector contributes a substantial portion of particulate matter and VOC emissions. The aviation sector, which accounts for take-off and landing emissions but excludes in-flight emissions, emits the largest share of transportation-related SO_x emissions. Criteria air pollutant emissions from rail are significantly lower than from other sources.

In the subsequent analysis, we focus primarily on on-road mobile sources due to their large share of transportation-related criteria air pollutant emissions and the availability of spatially granular data for these sources. We estimate on-road vehicle emissions by combining highway vehicle counts with emission factors based on vehicle fuel and type (see **Technical Appendix: Methods**). We find that while light-duty vehicles, including passenger cars and light-duty trucks, make up the vast majority of on-road vehicle miles traveled (as shown in **Figure 10**), heavy-duty trucks contribute disproportionately to NO_x and particulate matter emissions due to their higher emission rates of these pollutants.[58] The modeled total criteria air pollutant emissions by vehicle type from 2020-2050,[59] shown in **Figure 12**, shows both the high share of emissions from light-duty trucks and passenger cars across pollutants, as well as the disproportionate contribution of heavy-duty trucks to $PM_{2.5}$, PM_{10}, and NO_x emissions relative to their share of total vehicle miles traveled.

FIGURE 11. 2017 transportation sector criteria air pollutant emissions in Colorado.[60] On-road vehicles contribute the largest share of transportation-related ground-level $PM_{2.5}$, NO_x, PM_{10}, and VOC emissions, while airports dominate transportation-related SO_x emissions.

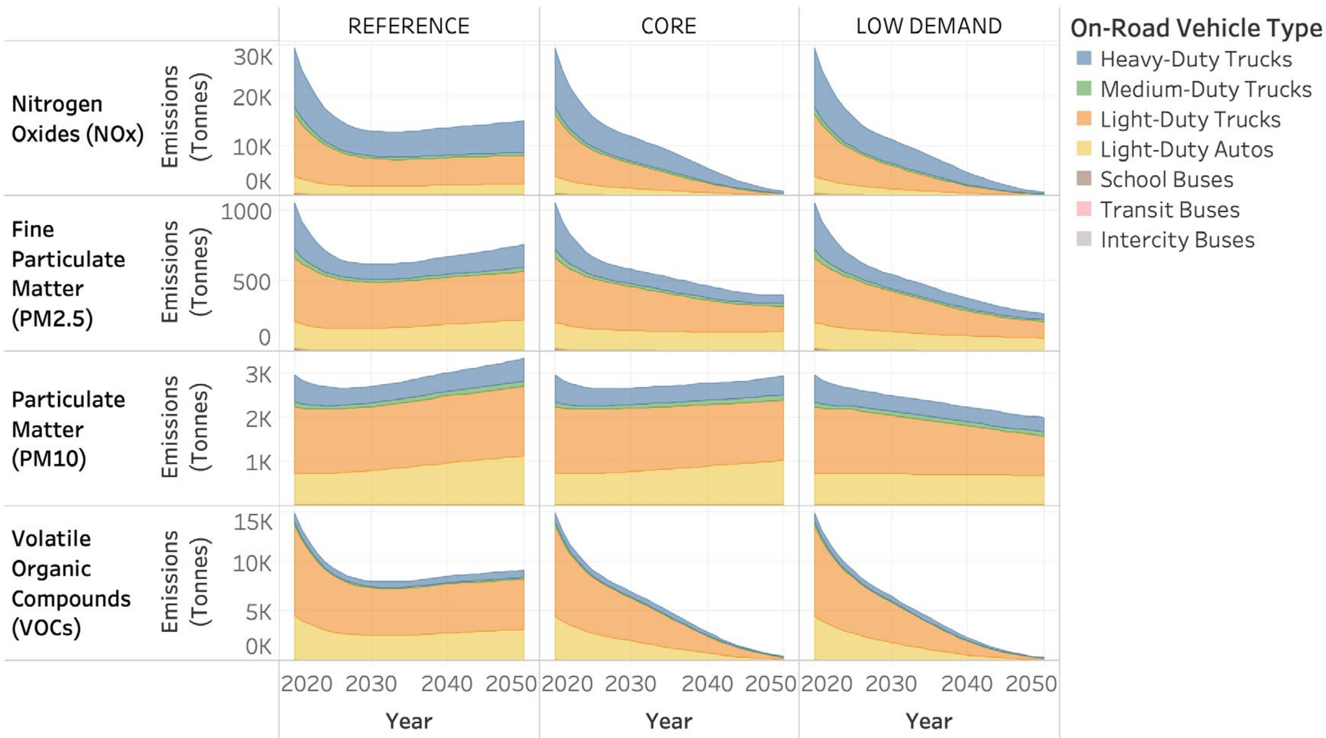


58 Throughout our analysis, "medium-duty trucks" refer to single-unit trucks and "heavy-duty trucks" refer to combination-unit trucks.

59 Modeled emissions in the year 2020 do not reflect the impacts of COVID-19 on travel patterns and associated changes in fossil fuel use within the transportation sector.

60 Aviation, non-road, and rail emissions are from the 2017 National Emissions Inventory (NEI). On-road vehicle emission estimates are from our own analysis, verified against the 2017 NEI (see Technical Appendix: Methods).

FIGURE 12. On-road vehicle transportation emissions by decarbonization scenario, 2020-2050. Light-duty passenger vehicles and light-duty trucks dominate $PM_{2.5}$, PM_{10}, and VOC, while heavy-duty trucks contribute a disproportionate share of $PM_{2.5}$, PM_{10}, and NO_x emissions relative to their fraction of total vehicle miles traveled.



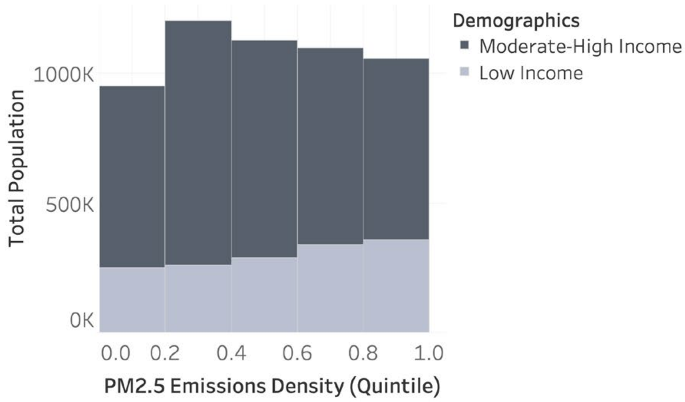
2.2.4 Baseline Emissions: Demographic Analysis

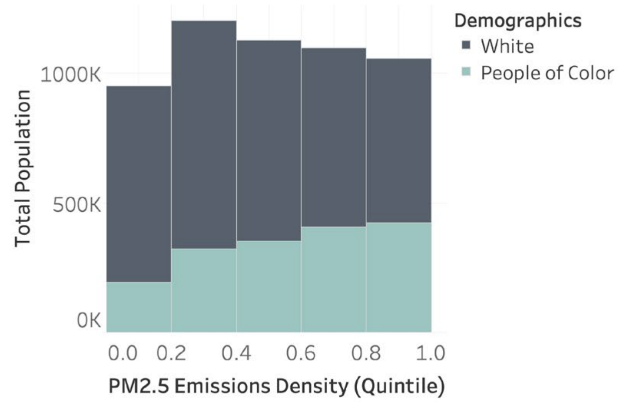
Rural and urban areas differ significantly in terms of transportation characteristics and associated criteria air pollutant emissions. Heavy-duty trucks make up a greater fraction of total vehicle miles traveled in rural areas and along urban interstates, while light-duty vehicles make up a greater fraction of vehicle miles traveled in most urban areas. Because heavy-duty and light-duty vehicles are not distributed evenly across road segments, the amount and composition of primary pollutant emissions from on-road vehicles vary throughout the state.

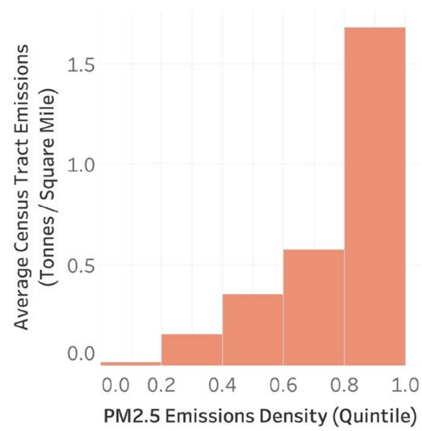
While the distribution of primary pollutant emissions can provide an initial screening of areas with particularly high levels of local emissions, it is important to note that primary pollutant emissions do not necessarily correspond to local air pollutant concentrations. Secondary pollutants such as ozone can form downwind of emissions sources, contributing to health-damaging air pollution in regions of the state far from the initial source of primary pollutants. As modeling the formation of secondary pollutants was outside the scope of our analysis, we used the spatial distribution of primary $PM_{2.5}$ emissions—which have a well-documented positive correlation with local health impacts[61]—as a proxy to represent local risk of exposure to air pollution from on-road mobile sources. Additionally, as census tracts serve as our spatial unit of analysis for demographic data, we normalize emissions estimates by census tract land area (tonnes emitted per square mile) in

61 Loomis, Dana *et. al*. IARC Evaluation of the Carcinogenicity of Outdoor Air Pollution. *The Lancet Oncology* 14 (2013):1262–1263.

FIGURE 13: 2017 $PM_{2.5}$ emissions from on-road vehicles and demographics of nearby populations. A higher fraction of the population are people of color and low-income in census tracts with higher $PM_{2.5}$ emissions densities. The x-axis groups census tracts into quintiles based on their $PM_{2.5}$ emissions density (tonnes / square mile) from on-road vehicles. The top two figures show the total population of census tracts in each quintile, along with the population fraction in each quintile that is low-income (left) and people of color (right). The y-axis of the bottom figure is the $PM_{2.5}$ emissions density (tonnes / square mile) for the average census tract in each quintile. The density of $PM_{2.5}$ emissions from on-road vehicles increases exponentially across quintile brackets.





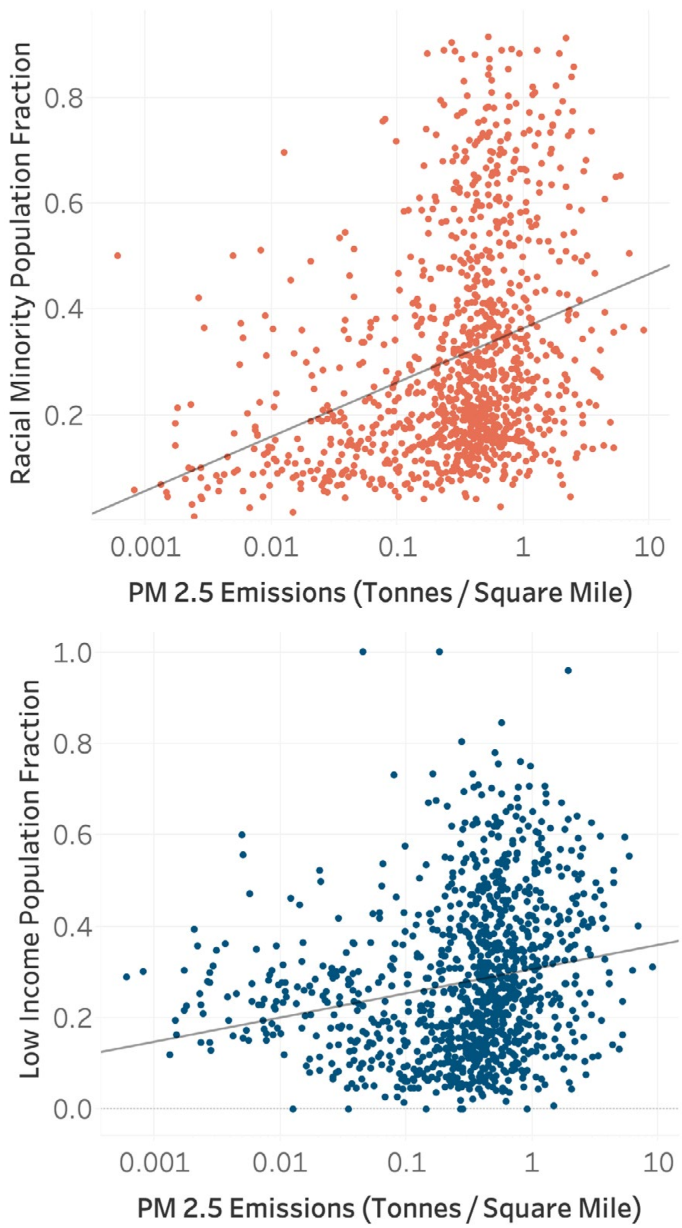


order to compare air pollution exposure risk between populations living in census tracts of varying size. We refer to area-normalized emission estimates as *emissions density* throughout this report, using this metric as a proxy for exposure risk to air pollution in our analysis of transportation and cross-sectoral emissions.

Traffic (total vehicle miles traveled from all vehicle types) is more highly concentrated in urban areas, resulting in higher criteria air pollutant emissions per unit area in urban census tracts. In part because people of color make up a greater fraction of urban populations compared to rural populations in Colorado, census tracts with higher proportions of people of color tend to have higher emissions densities across all criteria air pollutants, as shown in **Figure 13** for $PM_{2.5}$. This trend is also true for census tracts with higher proportions of low-income households. As we used statewide average emissions factors to estimate tract-level emissions from on-road vehicles, our methodology may even underestimate emissions in lower-income census tracts, where households tend to drive older vehicles with higher criteria air pollutant emission rates.[62]

62 US Energy Information Administration. U.S. Households Are Holding on to Their Vehicles Longer. Aug. 21, 2018.

FIGURE 14. 2017 $PM_{2.5}$ emissions density (tonnes / square mile) from on-road vehicles and demographic indicators in urban areas. Each dot represents a census tract within a US Census Bureau-defined metropolitan or micropolitan statistical area in Colorado. The x-axis is $PM_{2.5}$ emissions density, shown on a logarithmic scale. The y-axis is the population fraction that is people of color (top) and low-income (bottom). The correlation between $PM_{2.5}$ emissions density from on-road vehicles and low-income and racial minority populations in urban areas is statistically significant (p-value < 0.01).



Even within urban areas, however, there is a positive trend between these demographic indicators and emissions density, as shown in **Figure 14**. This suggests that differences between rural and urban transportation characteristics only explain part of the correlation between emissions density and communities of color across the state. Even within urban areas in Colorado, there is a racial disparity in traffic proximity and exposure risk to near-roadway air pollution.

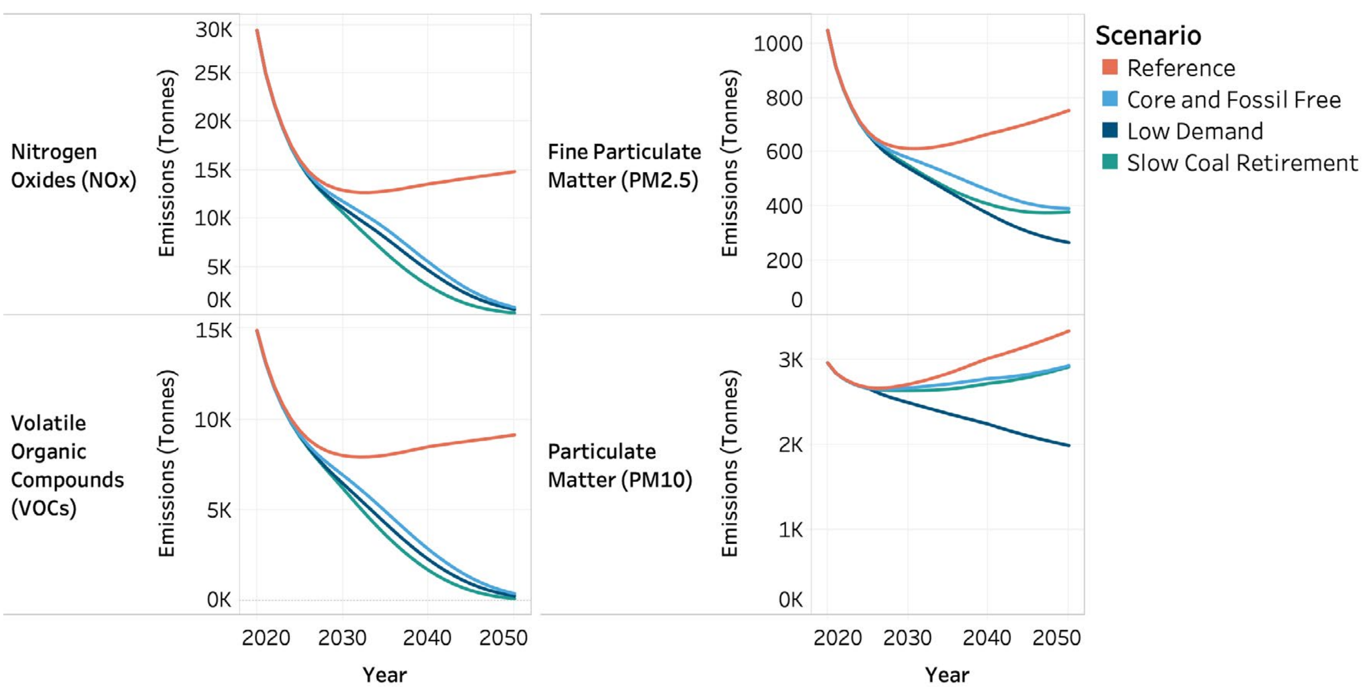
Within rural areas, we found a statistically significant ($p<0.05$) positive correlation between racial minority population fraction and $PM_{2.5}$ emissions density, but found no significant correlation between low-income population fraction and $PM_{2.5}$ emissions density.

2.2.5 Projected Emissions: Demographic Analysis

Electrification of on-road vehicles in each of the decarbonization scenarios reduces criteria air pollutant emissions significantly compared to the Reference case, although these impacts are largely seen after 2025 (**Figure 15**). From 2020-2025, the sharp decline in criteria air pollutant emissions in both the Reference and decarbonization scenarios is largely driven by the retirement of old, high-emitting vehicles with outdated pollution control technologies (**Figure 15**).

While NO_x and VOC emissions reach near-zero emissions by 2050 in all four decarbonization scenarios, a significant portion of $PM_{2.5}$ emissions remain in all scenarios and PM_{10} emissions are only reduced in the Low Demand scenario (**Figure 15**). Electric vehicles still contribute non-exhaust $PM_{2.5}$ and PM_{10} emissions through tire and brake wear, which are reflected in the emission factors we used to estimate emissions from alternative fuel vehicles (**Figure 16**).[63, 64]

FIGURE 15. Air pollutant emission reductions by scenario, 2020-2050.[65] Unlike the other pollutants, PM_{10} emissions do not decrease substantially from 2020-2050 in the Core, Fossil Free, and Slow Coal Retirement scenarios due to an increase in total vehicle miles traveled and a corresponding increase in emissions from tire and brake wear. The Low Demand scenario achieves the greatest $PM_{2.5}$ and PM_{10} emission reductions, underscoring the public health benefits of reduced vehicle travel.

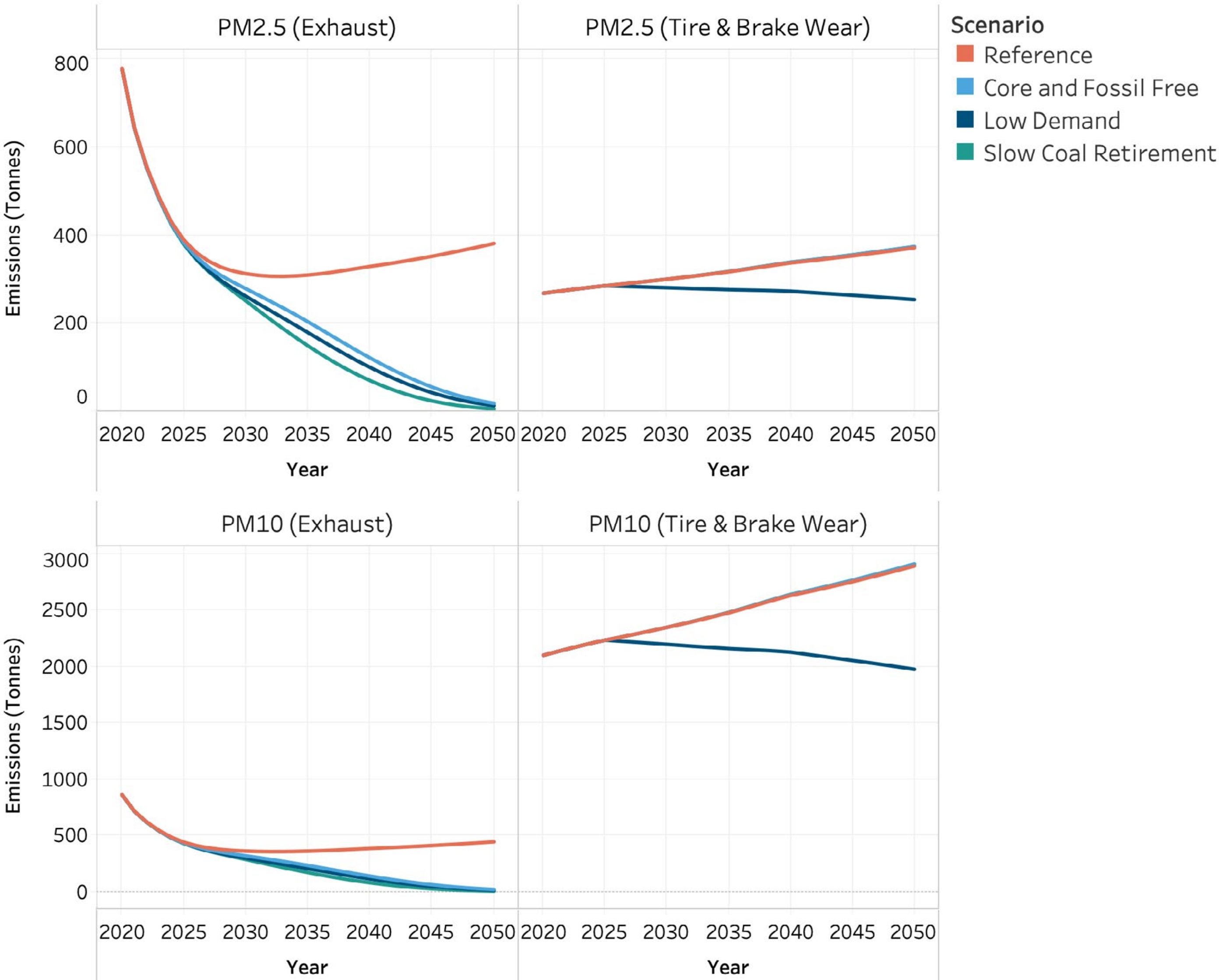


63 Working Party on Integrating Environmental and Economic Policies, Organisation for Economic Co-operation and Development (OECD). Non-Exhaust Emissions from Road Transport: Causes, Consequences and Policy Responses, (2020)

64 Argonne National Laboratory. "Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool," (2019). Available at: https://greet.es.anl.gov/afleet.

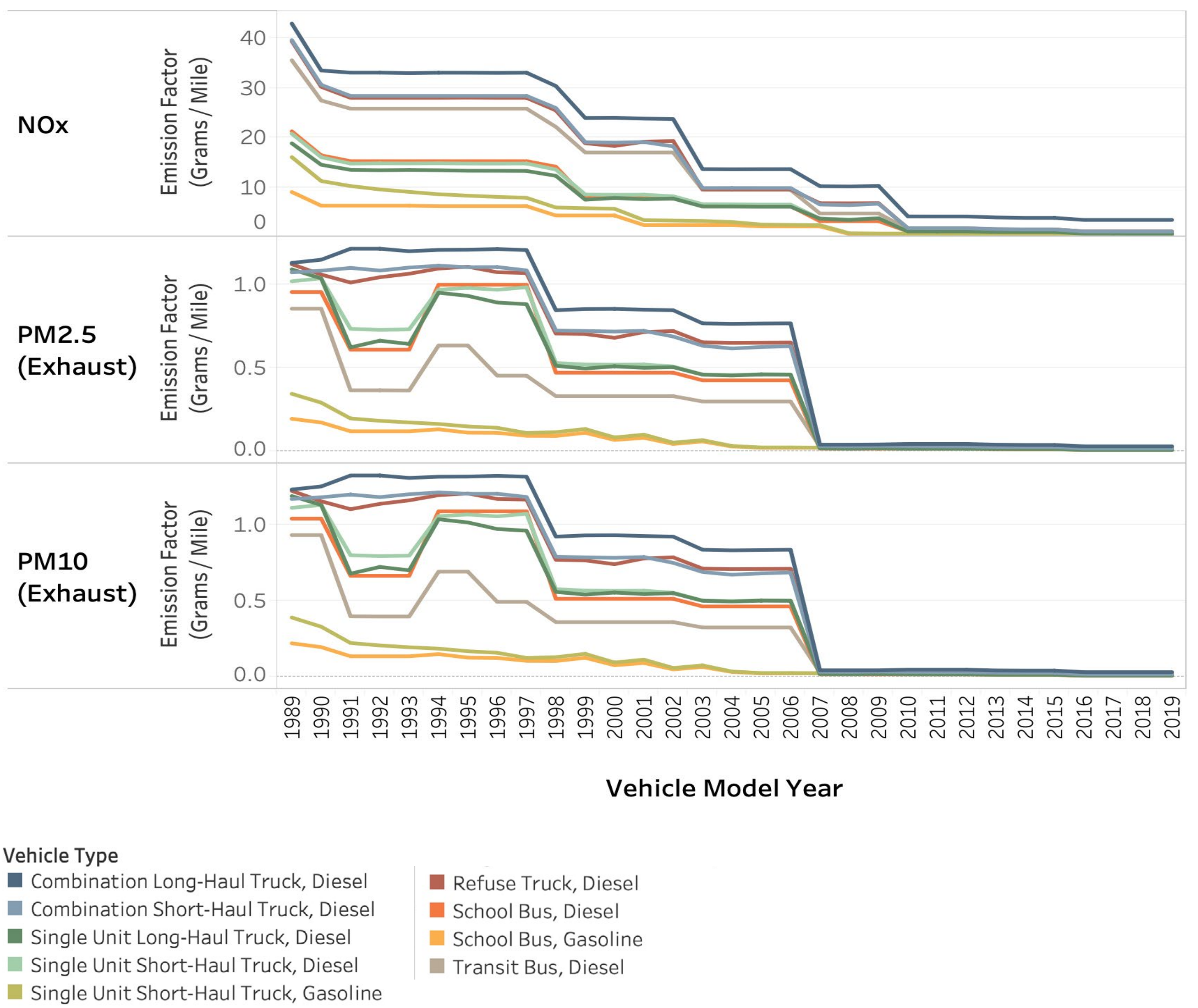
65 Projected emission estimates are based on Evolved Energy's assumed allocation of vehicle miles traveled by vehicle vintage in each analysis year. Our transportation baseline year (2017) emission estimates throughout the report are based on EPA MOVES' default vehicle age distribution, and are verified against the National Emissions Inventory (NEI) 2017 emission estimates. Due to discrepancies in the assumed vehicle age distribution utilized by these two methods, they result in different baseline emission estimates for the transportation sector across pollutants. This underscores the need for better state-specific data on the vehicle age distribution and allocation of vehicle miles traveled by vehicle vintage for each vehicle type.

FIGURE 16. $PM_{2.5}$ and PM_{10} exhaust and non-exhaust emissions by scenario, 2020-2050. While all decarbonization scenarios eliminate exhaust emissions of $PM_{2.5}$ and PM_{10}, only the Low Demand scenario reduces non-exhaust emissions of $PM_{2.5}$ and PM_{10} by 2050. Because vehicle PM_{10} emissions are largely due to tire and brake wear rather than exhaust, increased vehicle travel across scenarios from 2020-2050 results in an increase in overall PM_{10} emissions in the Reference case, and no substantial reduction in PM_{10} emissions in the Core, Fossil Free, and Slow Coal Retirement scenarios.



Projected on-road vehicle emissions are highly dependent on the assumed vehicle age distribution underlying the fleet of each vehicle type. Across pollutants, older vehicles have higher emission factors than newer vehicles because of the different technological and regulatory constraints in place at the time they were manufactured (**Figure 17**). The modeled rate of vehicle turnover in each year of the decarbonization analysis as well as the assumed allocation of vehicle miles traveled by vehicle vintage therefore heavily impact the rate of emission reductions achieved throughout the decarbonization timeline. **Figure 18** illustrates the sensitivity of our modeled emission projections to underlying vehicle age distribution assumptions, and highlights the impact that prioritized retirement of older vehicles has on total emissions. The retirement of older heavy-duty and medium-duty trucks has a particularly significant impact on near-term $PM_{2.5}$ and NO_x emission reductions, as emission factors for these vehicle types have declined substantially over the past several decades (**Figure 17**).

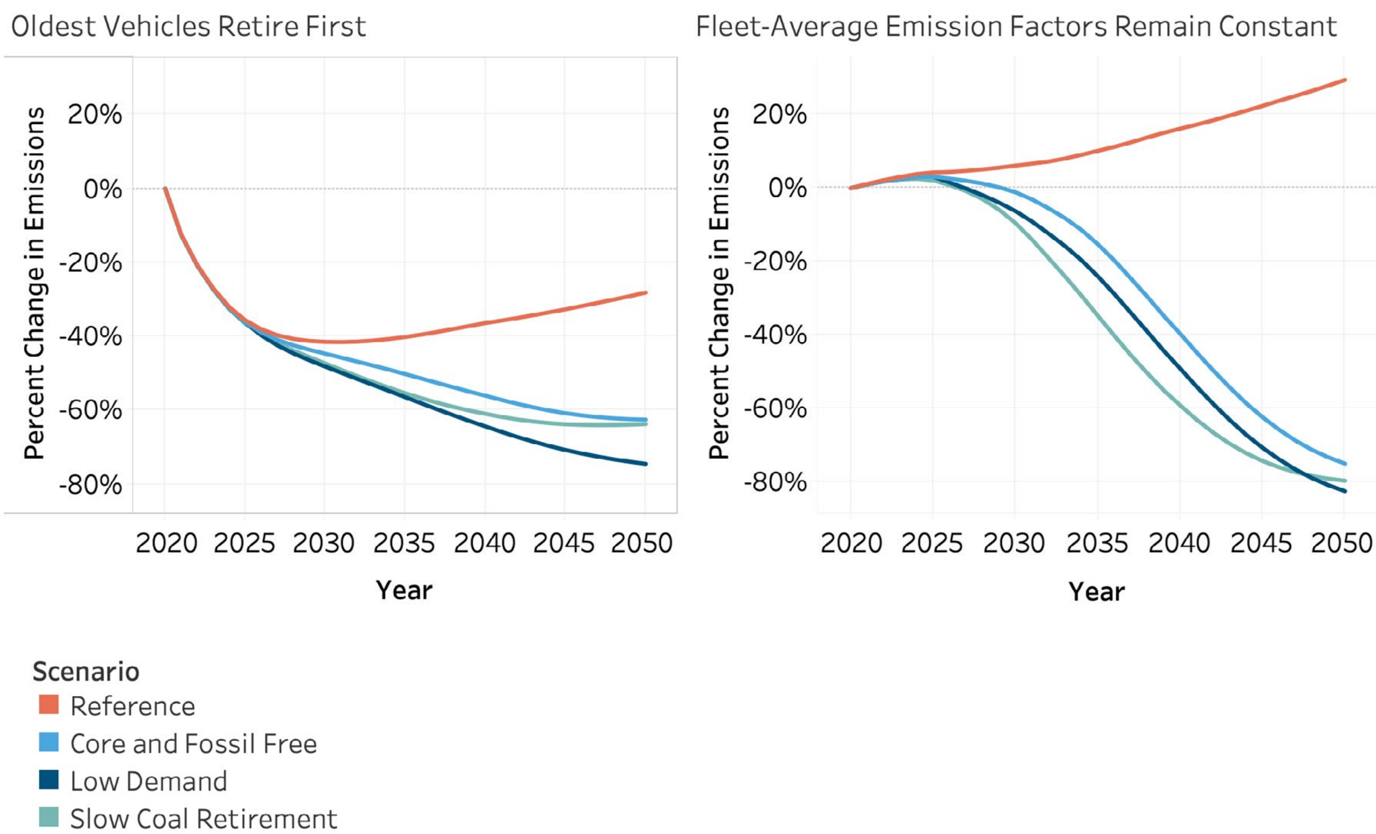
FIGURE 17. Colorado heavy-duty and medium-duty vehicle emission factors by model year (1989-2019).[66] The substantial decline in emission factors over the last several decades underscores the need to retire older vehicles first in order to achieve maximal emission reductions in the coming decade. The sharp reduction in $PM_{2.5}$ and PM_{10} emission factors from model year 2006 to model year 2007 reflects the adoption of an EPA rulemaking in 2000 that required all on-road diesel heavy-duty vehicles, starting with the 2007 model year, to use a diesel particulate filter.[67] The same rulemaking required a phased-in adoption of NO_x exhaust control technology from 2007-2010, reflected in the more gradual decline of NO_x emission factors below.



66 We accessed EPA MOVES 2014a emission factors through the Argonne National Laboratory's 2019 AFLEET tool. We are unaware of an explanation for the dip in EPA MOVES emission factors from 1990-1994 for several vehicle types.

67 Manufacturers of Emission Controls Association (MECA). U.S. EPA 2007/2010 Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements.

FIGURE 18. Projected on-road $PM_{2.5}$ emissions: sensitivity to assumed vehicle age distribution. Because older vehicles have higher emission factors, projected on-road vehicle emissions are highly sensitive to the assumed vehicle age distribution for each vehicle type. In the left figure, we assume that the oldest internal combustion engine vehicles are continually replaced by newer, less-polluting internal combustion engine vehicles throughout decarbonization. In the right figure, we assume that fleet-average emission factors for internal combustion engine vehicles remain constant over time,[68] modeling only the emission reductions achieved through fuel switching and vehicle electrification. The discrepancy between these two results emphasizes the significant impact that retiring old vehicles, particularly trucks, has on emission reductions.



Criteria air pollutant emission reductions do not occur uniformly across the state. Because heavy-duty and light-duty vehicles make up different proportions of total vehicle miles traveled in different parts of the state, and each vehicle class reduces pollution at a different rate, certain regions see more aggressive emission reductions than others throughout the decarbonization timeline. Different assumptions about the underlying vehicle age distribution, as discussed above, affect where emission reductions are greatest in the near-term.

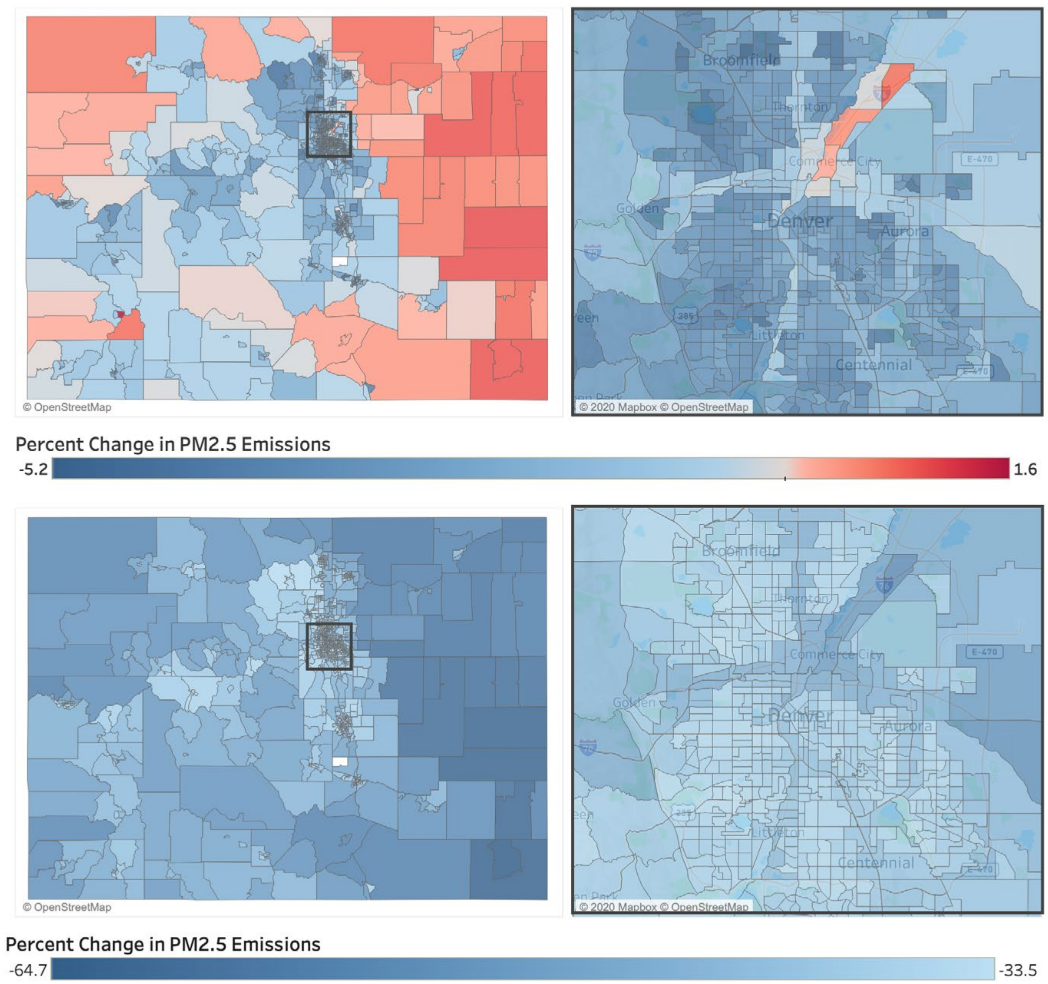
If we assume that fleet-average emission factors remain constant over time for conventional fuel vehicles, census tracts in close proximity to trucking routes lag behind other areas in reducing emissions from 2020-2030 in the Core scenario (**Figure 19**, top panel). Some census tracts in rural areas and along urban interstate corridors, where heavy-duty and medium-duty trucks make up a greater fraction of vehicle miles traveled, even see an increase in emissions over the next decade. This is because heavy-duty and medium-duty trucks electrify more slowly than light-duty vehicles, while still seeing an increase in vehicle miles traveled over this period.

68 Fleet-average emission factors are calculated by weighting emission factors for each model year using the EPA MOVES 2014a default vehicle age distribution for each vehicle type in analysis year 2019.

FIGURE 19.Modeled percent change in on-road vehicle $PM_{2.5}$ emissions by census tract from 2020-2030 in the Core scenario under different vehicle age distribution assumptions. Under the assumption that fleet-average emission factors for internal combustion engine vehicles remain constant over time, the Core scenario results in an increase in $PM_{2.5}$ emissions along trucking routes from 2020-2030 due to increased vehicle travel and associated emissions (top). Under the assumption that, in addition to vehicle electrification, the oldest internal combustion engine vehicles are continually replaced by newer, less-polluting internal combustion engines throughout decarbonization, the Core scenario results in emission reductions everywhere in the state by 2030, with more aggressive emission reductions along trucking routes (bottom). The contrast between these two trajectories emphasizes the significant impact that retiring old trucks has on emission reductions and environmental equity outcomes.

Fleet-Average Emission Factors Remain Constant

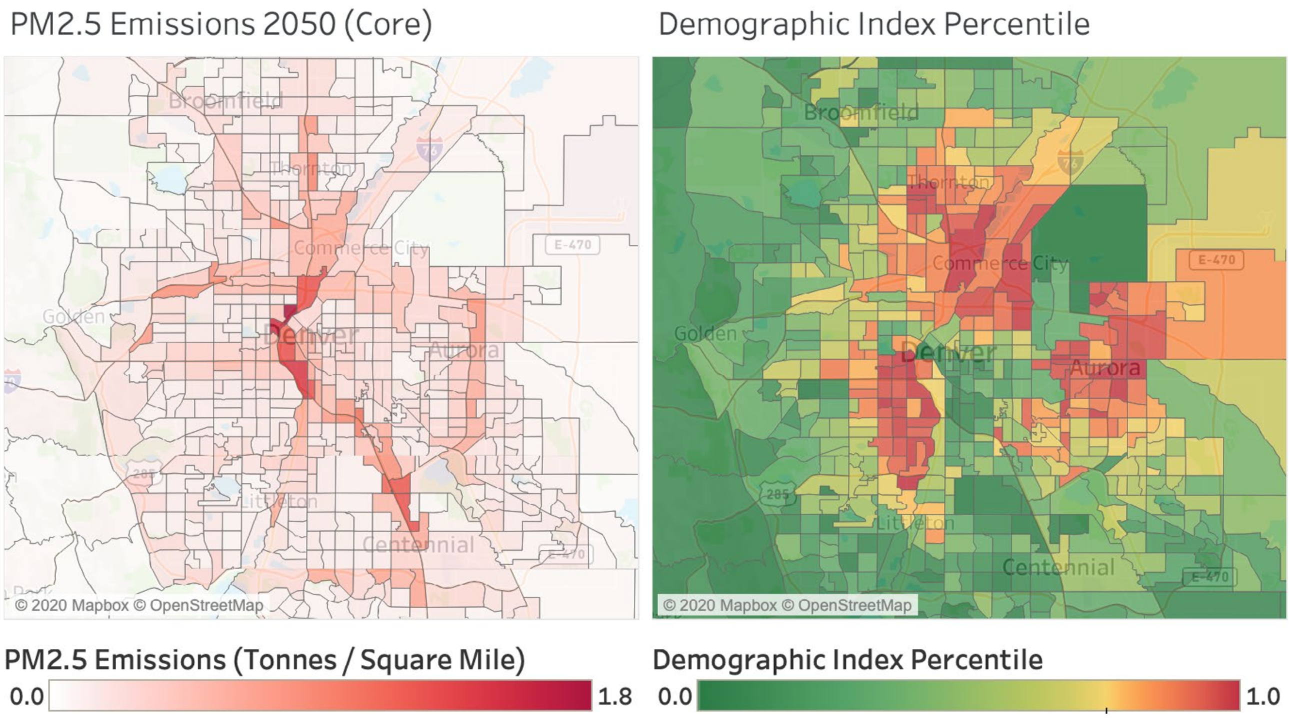
Oldest Vehicles Retire First



If we assume that fleet-average emission factors change over time due to the retirement of old, high-emitting conventional fuel vehicles, however, census tracts in close proximity to trucking routes see more aggressive emission reductions than other areas from 2020-2030 in the Core scenario (**Figure 19**, bottom panel). Retiring old heavy-duty and medium-duty trucks has an outsized impact on emission reductions, because these vehicle types have seen particularly sharp declines in PM_{10}, $PM_{2.5}$ and NO_x emission factors over the last several decades.

The two different emission reduction trajectories depicted in **Figure 19** indicate that the prioritized retirement of old, high-emitting vehicles may heavily impact environmental equity outcomes. Communities living in close proximity to urban interstates in the Denver metro area tend to have a relatively high score on the Demographic Index (**Figure 20**). These communities live in census tracts where pollution from vehicles is the most dense per unit area, even in 2050 (**Figure 20**), and where high-emitting industrial point sources such as the Suncor Refinery are located (**Box 1**).

FIGURE 20. Residual on-road $PM_{2.5}$ emissions in 2050 in the Core scenario, alongside Demographic Index percentile in the Denver metropolitan region. $PM_{2.5}$ emissions are most concentrated in census tracts along urban interstates, and remain in these areas in 2050 due to continued emissions from vehicle tire and brake wear. Many of these census tracts have high Demographic Index percentile rankings compared to the rest of the state.



If old, high-emitting heavy-duty and medium-duty trucks remain on the road, these census tracts could see slower rates of emission reductions compared to other areas in the coming decade. Incentivizing the retirement of these highly-polluting older vehicles, by contrast, could help to achieve greater emission reductions in these areas, which currently face high cumulative emission burdens from multiple sectors.

Incorporating measures from the Low Demand scenario, such as investment in public transit and the reduction of vehicle travel, could help to mitigate the environmental equity issues associated with residual $PM_{2.5}$ and PM_{10} emissions along urban interstate corridors in the Core scenario. In addition, prioritizing electric vehicle charging infrastructure along urban interstate highway corridors, rerouting heavy-duty and medium-duty trucks to less populated areas, addressing bus and truck idling in urban and industrial areas, and electrifying trucks and non-road vehicles associated with industrial activity in dense urban areas could help to address the inequitable emissions burden faced by urban low-income communities and communities of color.

2.2.6 Household Fuel Cost Burdens

In addition to the disproportionate traffic density and associated emissions occurring in low-income neighborhoods, these communities often have high transportation energy cost burdens. Although higher-income households drive more than lower-income households on average, lower-income households tend to spend a greater fraction of their income on fuel costs (**Figure 21**). Our fuel cost burden estimates for low-income households are likely an underestimate, as low-income households tend to drive older, more fuel-intensive vehicles.[69] In addition, these estimates do not include the public transit costs incurred by the many low-income households that lack access to vehicles or are unable to drive. Their inclusion in the following estimates would likely result in higher average transportation cost burdens among low-income households due to their

69 US Energy Information Administration. U.S. Households Are Holding on to Their Vehicles Longer. Aug. 21, 2018.

FIGURE 21. a) Average annual household vehicle miles traveled and b) average transportation fuel burden by census tract median household income. Lower-income households drive less but have a higher transportation fuel cost burden than higher-income households on average. Urban areas refer to combined US Census Bureau metropolitan and micropolitan statistical areas, while rural areas refer to all other census tracts.

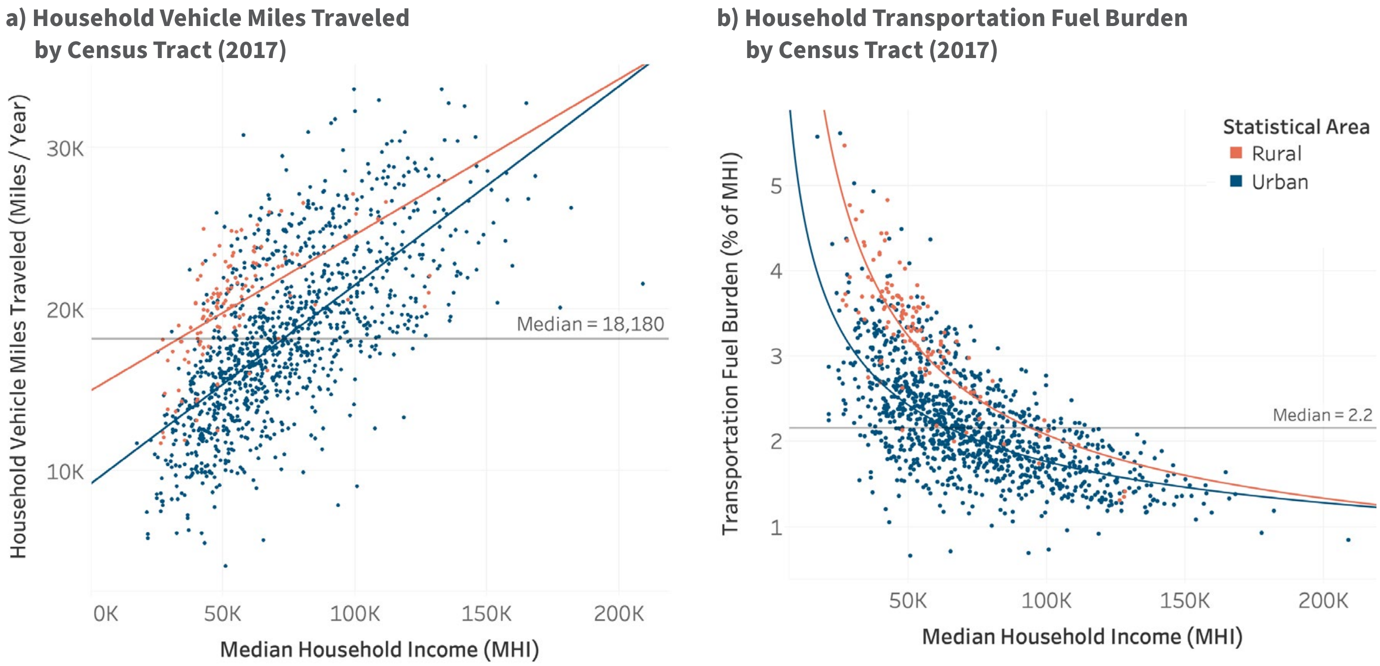
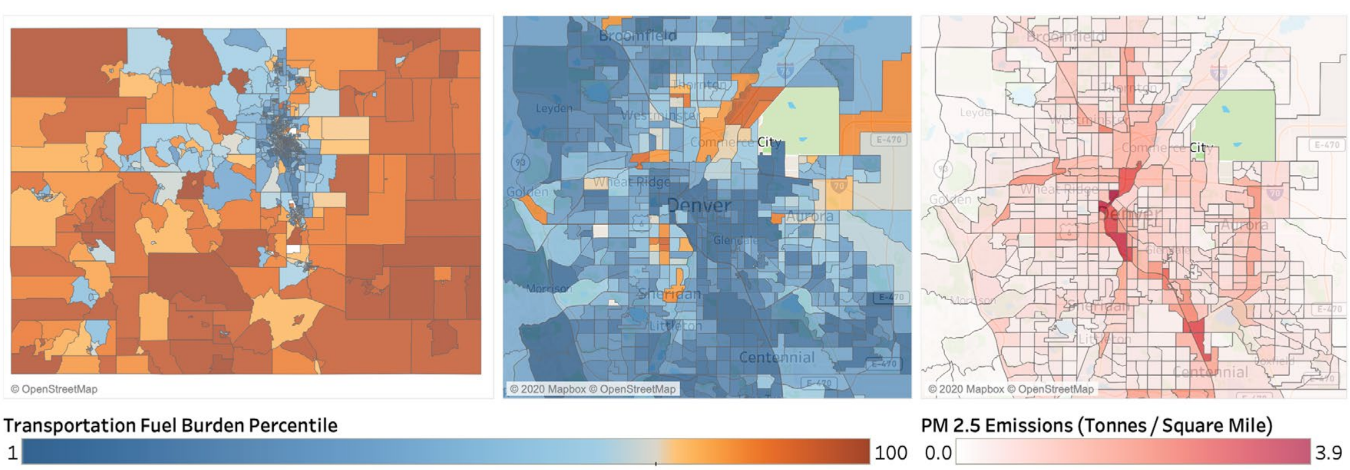


FIGURE 22: Transportation fuel burden percentile by census tract statewide and in Denver, alongside 2017 $PM_{2.5}$ emissions from light-duty vehicles in Denver. Certain areas of the Denver region, such as Commerce City, face high household transportation fuel cost burdens as well as high $PM_{2.5}$ emissions densities from light-duty vehicles.



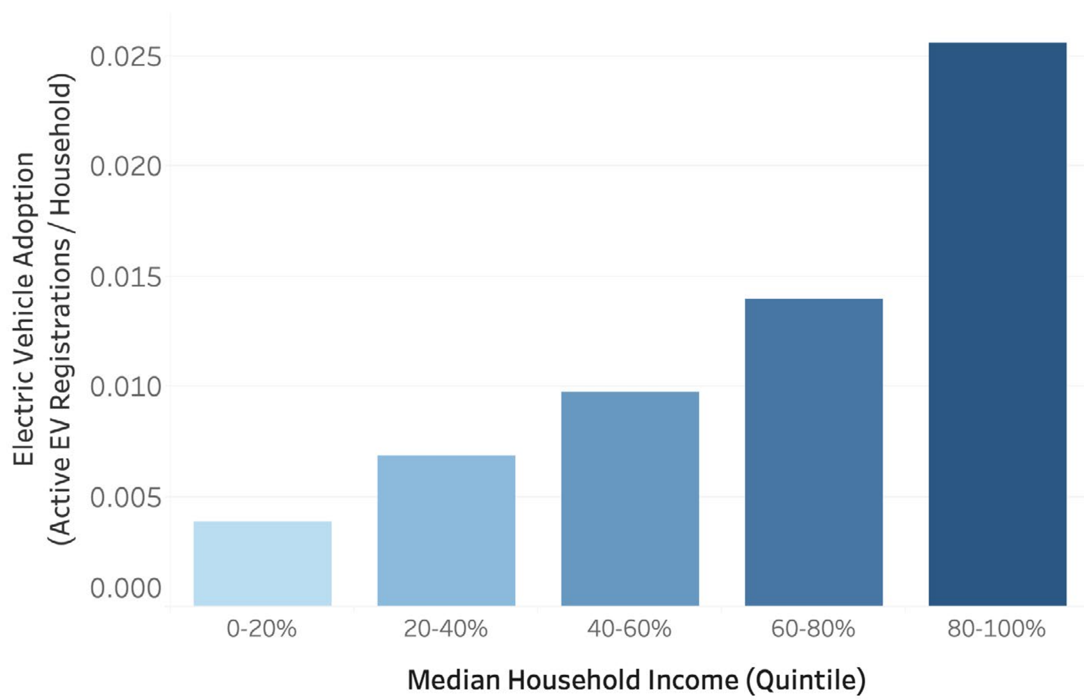
lower level of vehicle ownership and higher reliance on public transit.[70,71] Policies designed solely to reduce carbon emissions from household travel would likely fail to address the transportation-related financial burden faced by low-income households, as higher-income households drive more and consume more fuel on average,[72] and therefore likely contribute more to transportation-related carbon emissions.

In certain areas of Denver, high $PM_{2.5}$ emissions density from light-duty vehicle traffic overlaps with high household fuel burden (**Figure 22**). These areas may benefit from programs targeted at low-income households, such as improved public transit and financing for electric vehicles. These measures may help reduce some local transportation emissions, but further analysis is needed to determine what percentage of these local emissions are associated with locally-owned vehicles. Emission reductions will likely require coupling these efforts with targeted programs to reduce emissions from trucks.

2.2.7 Electric Vehicle Adoption

Throughout our analysis, we assume that vehicle electrification occurs uniformly across the state, meaning that the electric vehicle adoption rates vary by vehicle class but not by geographic location. In Colorado, however, the distribution of active electric vehicle registrations per household is inequitable by income. As of October 2020, the number of active electric vehicle registrations per household was higher in ZIP Codes with higher household median incomes (**Figure 23**). To date, households in the wealthiest 20 percent of ZIP Codes in Colorado have adopted electric vehicles at seven times the rate of households in the lowest-income ZIP Codes (bottom 20 percent).

FIGURE 23. 2020 electric vehicle adoption rate (active electric vehicle registrations / household) and median household income by ZIP Code.[73,74] Households in the 20 percent highest-income ZIP Codes have adopted electric vehicles at 7 times the rate of households in the 20 percent lowest-income ZIP Codes.



70 US Department of Transportation, Federal Highway Administration. 2017 National Household Travel Survey (2017). Available at: https://nhts.ornl.gov.

71 Transportation Research Board. 2018 National Household Travel Survey Workshop. Aug. 8-9, 2018.

72 US Energy Information Administration. Household Spending on Gasoline and Public Transit Varies by Region, Income. Aug. 13, 2015.

73 Atlas Public Policy. *State EV Registration Data*. Retrieved on Oct. 20, 2020.

74 Electric vehicle registration data are by US Postal Service (USPS) ZIP Code service area. Median household income and household count data are by US Census Bureau ZIP Code Tabulation Area, an approximate area representation of USPS ZIP Code service areas.

If the inequitable distribution of electric vehicle registrations persists throughout decarbonization, low-income households may be excluded from the financial and emissions reduction benefits associated with vehicle electrification. As lower-income households tend to drive older, less fuel-efficient, and more polluting vehicles,[75] vehicle electrification has the potential to achieve higher emission reduction benefits *per vehicle mile traveled* for this population segment. While higher-income households drive more on average, and likely contribute more to overall CO_2 emissions from vehicle travel, replacing a lower-income household's car with an electric vehicle would likely achieve greater emissions reductions per vehicle mile traveled by replacing an older, less-efficient vehicle.

Lower-income households and communities are likely to see disproportionately low electric vehicle adoption rates, much like trends we see for residential rooftop solar adoption,[76] unless the cost of electric vehicles declines substantially or policies are implemented to reduce barriers to electric vehicle access. Additionally, if electric vehicle charging infrastructure is built in areas with high early adoption rates, rather than equitably distributed to incentivize electric vehicle adoption in all regions, the availability of public charging stations could become the primary barrier to electric vehicle adoption as vehicle costs decline and become more affordable. Proactively building out public, multi-family, and rural charging infrastructure could help the state to reach households with historically low electric vehicle adoption rates.

2.3 Residential Buildings

We used a regression model based on geographic, climatic, demographic, and housing-related variables to estimate census tract-level fuel use (see **Technical Appendix: Methods**). Our analysis includes the most common residential fuels in Colorado: natural gas, propane, and wood. A small portion of Colorado households use other fuels, such as fuel oil, which are excluded from this analysis because they are uncommon.

Residential fuel use across Colorado creates both indoor and outdoor air pollution, and when combined with electricity use can contribute to burdensome utility bills, particularly for low-income households. Electrification of natural gas and propane appliances, as well as whole-building efficiency measures, can save energy, reduce bills, and improve indoor air quality. However, these benefits may accrue unevenly and even exacerbate energy cost burdens in the absence of policies aimed to reduce barriers to clean energy upgrades for low-income households.

2.3.1 Baseline and Projected Emissions

Fuel use in residential buildings accounts for only ten percent of Colorado's CO_2 emissions and five percent of the state's NO_x emissions, but more than a third of primary $PM_{2.5}$ emissions, largely due to wood burning. NO_x also contributes to the secondary formation of particulate matter and ozone. While these emissions contribute in part to statewide ambient air quality impacts, in-home fuel combustion is of particular concern for indoor air quality. Like ambient air pollution, indoor air pollution is associated with adverse respiratory and cardiovascular health outcomes. Furthermore, the average American spends roughly 90 percent of their time indoors,[77] increasing the potential for adverse exposures.[78]

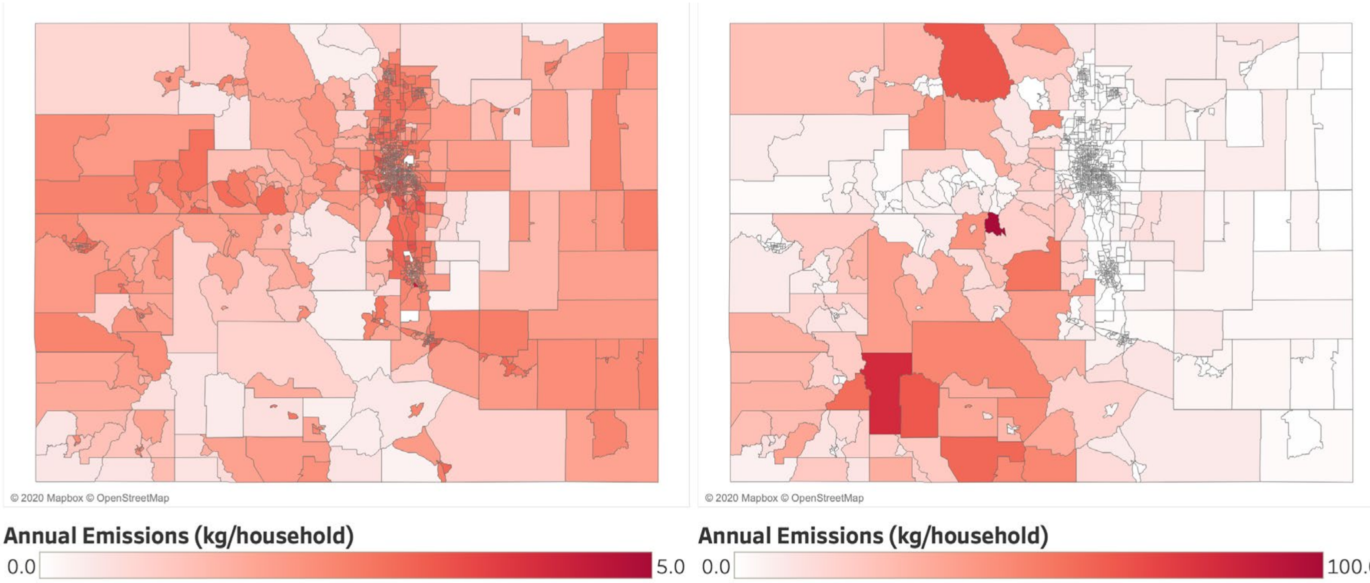
75 US Energy Information Administration. U.S. Households Are Holding on to Their Vehicles Longer. Aug. 21, 2018.

76 Lukanov, Boris R., and Elena M. Krieger. Distributed Solar and Environmental Justice: Exploring the Demographic and Socio-Economic Trends of Residential PV Adoption in California. Energy Policy 134 (2019): 110935.

77 Klepeis, Neil E., *et al.* The National Human Activity Pattern Survey (NHAPS): A Resource for Assessing Exposure to Environmental Pollutants. *Journal of Exposure Science & Environmental Epidemiology* 11.3 (2001): 231-252.

78 US Environmental Protection Agency. "Indoor Air Quality." Available at: https://www.epa.gov/report-environment/indoor-air-quality#health

Figure 24. Average NO_x (left) and $PM_{2.5}$ (right) household emissions by census tract. NO_x emissions from natural gas are highest in urban areas, while $PM_{2.5}$ emissions from wood are highest in rural mountain areas in the western half of the state.



Natural gas combustion can contribute to significant in-home emissions of carbon monoxide, NO_x, $PM_{2.5}$, and formaldehyde.[79,80,81] Leakage of unburned natural gas from appliances, in addition to releasing methane, may also result in increased exposure to known human carcinogens including benzene and other VOCs. There is a lack of research on the magnitude of exposure to health-damaging air pollutants and associated health impacts due to incomplete combustion and natural gas leakage.

As of 2017, natural gas dominated residential fuel combustion in Colorado (86 percent by energy generated) and produced the most CO_2 emissions (81 percent). Propane and biomass each provided roughly seven percent of residential energy, and emitted eight percent and 11 percent of residential CO_2, respectively. Reducing residential carbon emissions therefore requires reducing natural gas use in buildings.

Although natural gas accounts for the majority of residential carbon emissions, its use is clustered in urban and suburban areas (**Figure 24**).[82,83] The lack of availability of natural gas in more rural areas means that many homes rely on propane and wood. The latter emits ten times as much $PM_{2.5}$ as natural gas annually (4,200 tonnes vs. 420 tonnes) despite generating less than a tenth as much energy statewide, though it is largely constrained to the mountainous western part of the state (**Figure 24**). About 40,000 households in rural Colorado currently use wood as their primary heat source. Decarbonization efforts focused solely on natural gas will therefore risk leaving significant $PM_{2.5}$ emissions across rural parts of the state.

79 Seals, Brady and Andee Krasner. Health Effects from Gas Stove Pollution. *Rocky Mountain Institute* (2020).

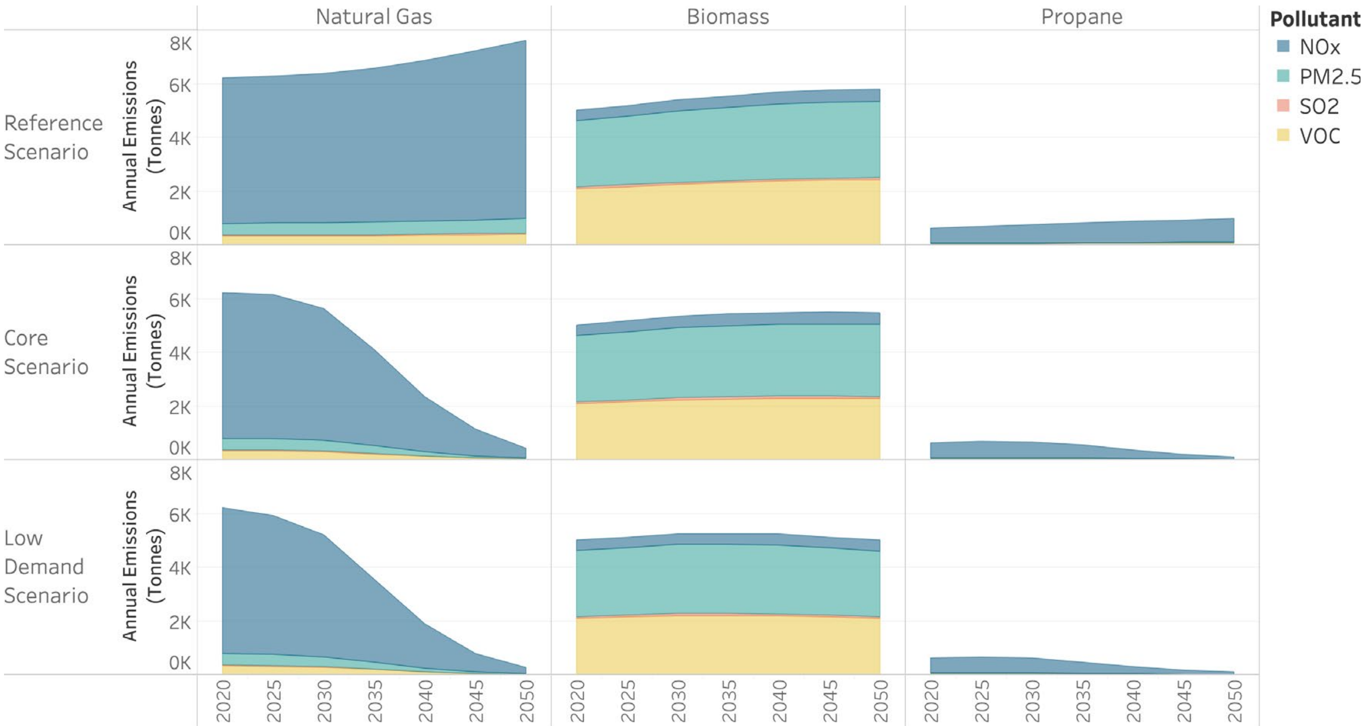
80 Mullen, Nasim A., *et al.* Results of the California Healthy Homes Indoor Air Quality Study of 2011–2013: Impact of Natural Gas Appliances on Air Pollutant Concentrations. *Indoor Air* 26.2 (2016): 231-245.

81 Logue, Jennifer M., *et al.* Pollutant Exposures from Natural Gas Cooking Burners: A Simulation-Based Assessment for Southern California. *Environmental Health Perspectives* 122.1 (2014): 43-50.

82 US Department of Homeland Security. “Natural Gas Service Territories.” Sept. 2017. Available at: https://hifld-geoplatform.opendata.arcgis.com/datasets/natural-gas-service-territories

83 Colorado Energy Office. “Natural Gas Utilities in Colorado” (2020). Available at: https://energyoffice.colorado.gov/natural-gas

FIGURE 25. Criteria air pollutant emission projections by residential fuel for three decarbonization scenarios. Due to uneven fuel switching, propane and natural gas-associated emissions decline substantially by 2050 while biomass-related emissions (wood) remain relatively fixed.



Our modeled emission projections under the decarbonization scenarios reveal the possibility of such an occurrence. **Figure 25** below compares projected emissions for the Reference scenario to emissions under the Core and Low Demand scenarios. The other scenarios are omitted from the figure for readability, though they show similar patterns to those depicted. For both scenarios shown, natural gas-related emissions begin declining nearly immediately, speeding up in 2030 and reaching significantly lower levels than baseline by 2050. $PM_{2.5}$, SO_2, and VOC emissions from natural gas start low and reach near-zero levels; and only a small quantity of NO_x emissions remain by 2050. Similar patterns exist for propane, though propane is responsible for a smaller portion of overall emissions at baseline, making the magnitude of emission reduction lower for this fuel.

In contrast to natural gas and propane, wood use and resultant emissions remain relatively constant across scenarios, with little change from baseline to 2050. This trend is the product of the assumption in the energy system modeling that, from a decarbonization standpoint, natural gas and propane appliances would be the primary targets for fuel switching. $PM_{2.5}$ and VOCs are the major constituents of wood-related pollution and remain high through all projected years, though some SO_2 and NO_x are emitted as well. The high emission rate of wood and continued emissions across scenarios suggest that, absent targeted efforts to reduce wood-related emissions, rural regions of Colorado with high baseline wood use may continue to contribute relatively high emissions of health-damaging pollutants such as $PM_{2.5}$.

FIGURE 26. Census tract projected criteria air pollutant emission changes by scenario for 2020 and 2050. In the medium term, rural areas experience modest residential emission increases across scenarios. Long term emission changes are scenario-dependent, with some scenarios (e.g. Low Demand) producing more equitable outcomes than others. Criteria air pollutants and precursors included are NO_x, $PM_{2.5}$, SO_2, and VOCs.

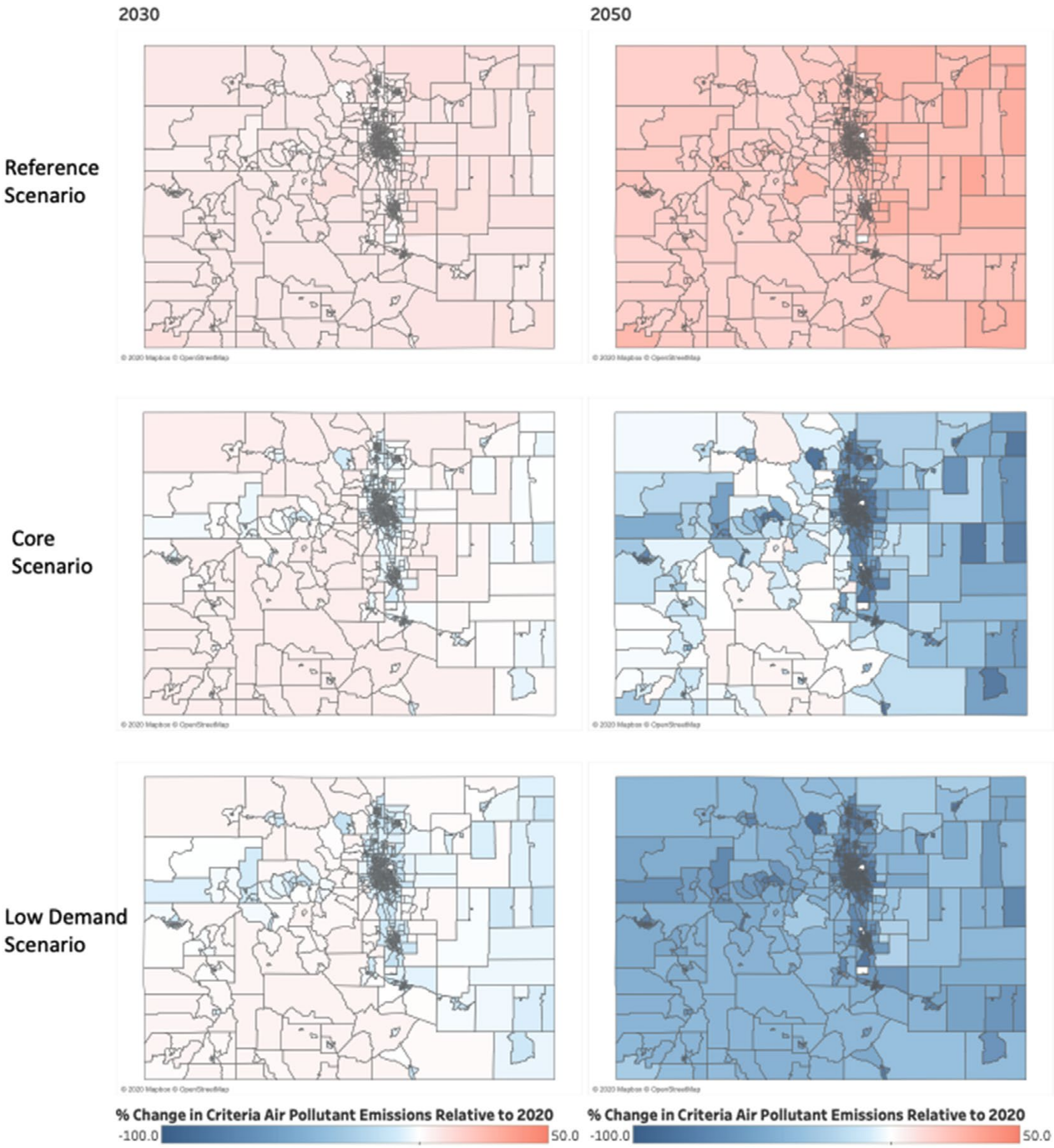
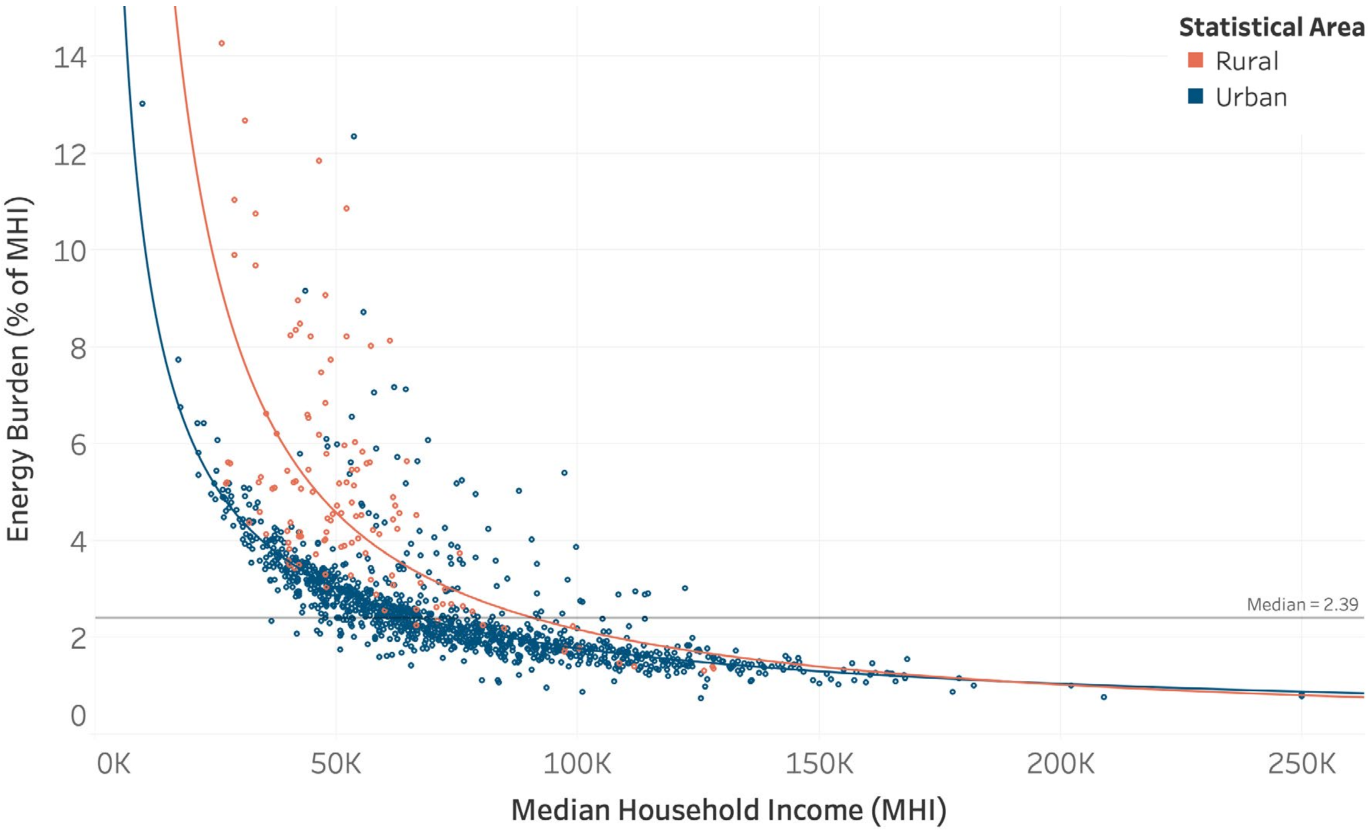


FIGURE 27. Census tract average energy cost burden as a percentage of household income. Lower-income households tend to spend a much greater portion of their income on energy bills.



Due to uneven fuel switching across scenarios and geographically clustered use of each fuel at baseline, the spatial distribution of residential air pollution could grow increasingly uneven moving forward (**Figure 26**). Core and Low Demand scenario projections for 2030 show modest criteria air pollutant emission increases across rural parts of the state despite reductions in urban and suburban census tracts. By 2050, this urban/rural gap largely closes for the Low Demand scenario, with most tracts showing overall decreases in criteria air pollutant emissions. This is not the case for all scenarios though. By 2050, many rural tracts show a small increase in emissions under the Core scenario while urban tracts generally display decreased emissions. These findings suggest it may be valuable to incorporate considerations for replacing in-home wood use into energy transition strategies.

2.3.2 Household Energy Cost Burdens

Similar to the transportation sector, residential energy cost burdens are inversely correlated with household income. **Figure 27** shows that on average, households in the lowest income census tracts spend an appreciably higher percentage of their annual income on energy (maximum ~ 14 percent) than most others (median ~ 2.4 percent).[84] Energy cost burdens also tend to be higher in rural areas. At the same time, household income is positively correlated with energy consumption, with higher income households consuming more energy on average and more natural gas as a fraction of their total energy use (**Figure 28**). Policy strategies to reduce per-household energy consumption may therefore maximize economic and public health co-benefits if tailored towards low-income households. Conversely, strategies which primarily target households with large carbon

84 These values reflect estimated *average* energy cost burdens by census tracts. Some individual households within these tracts may have significantly higher energy cost burdens, and some will be lower.

FIGURE 28. Census tract average energy use and median household income. Higher income households tend to use more energy than lower-income households.

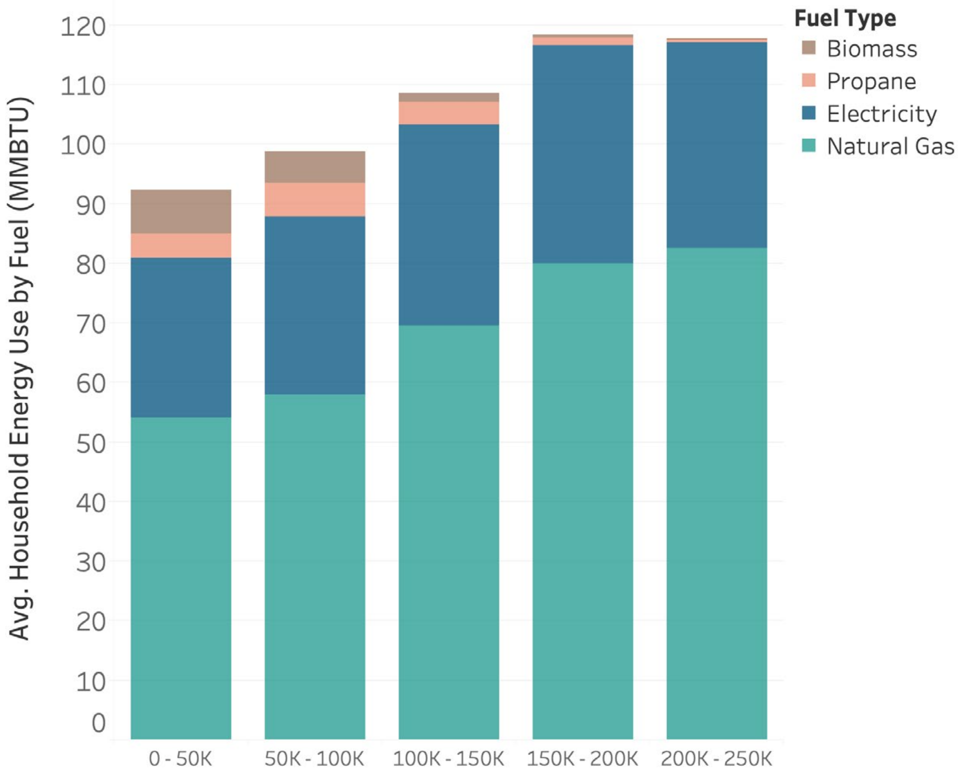


FIGURE 29. Projected energy cost burden change by scenario for urban and rural areas. Rural areas tend to have the largest decreases in energy cost burden across scenarios, though urban and suburban areas also experience decreases under certain scenarios.

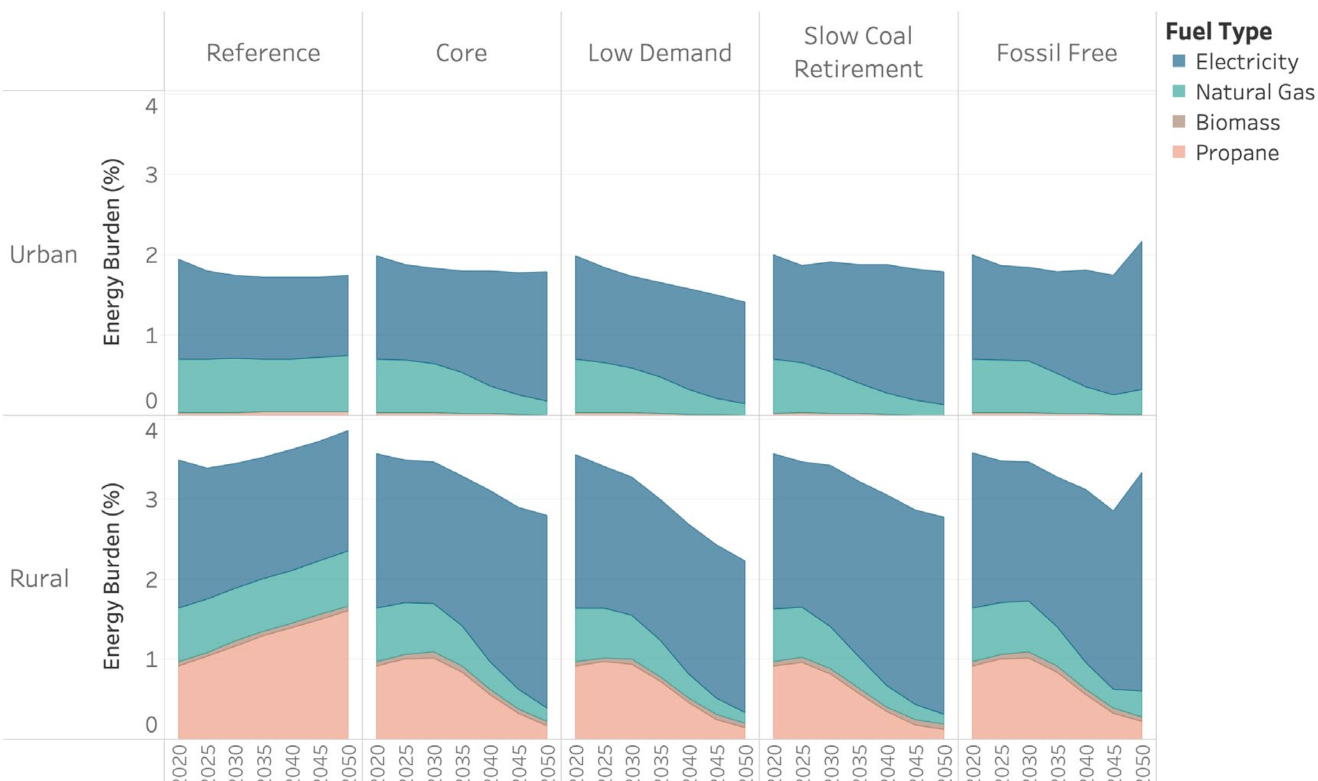


Figure 30. Change in monthly aggregate energy bills for electricity plus in-home natural gas for clean energy adopters of electrification and efficiency measures versus non-adopters over time. Households which do not adopt clean energy technologies may face skyrocketing utility bills by mid-century, particularly under the Fossil Free and Slow Coal Retirement scenarios.

footprints may disproportionately benefit the least economically vulnerable households and exacerbate existing socioeconomic disparities. Of course, carbon reductions and energy cost burden issues do not have to be mutually exclusive and it is critical for policies to be structured in ways that achieve both objectives.

Although residential fossil fuel-focused decarbonization strategies result in greater emission reductions in urban areas than rural areas, we project energy cost burdens will decrease more in rural areas on average (**Figure 29**). This is largely due to the gradual curtailment of propane use in rural areas and its replacement with electric heating. Our analysis of energy cost burden reflects median values for each census tract and focuses on broad geographic patterns, though individual households may face higher energy cost burdens.

The finding that rural households experience the greatest average decrease in energy cost burden is particularly true of the Slow Coal Retirement, Core, and Low Demand scenarios. Under Slow Coal Retirement and Core, urban and suburban area energy cost burdens stay relatively constant but rural energy expenditures relative to household income decrease by more than half a percentage point. Under Low Demand, rural households still experience the largest decrease in energy cost burden, but urban and suburban energy cost burdens also decrease on average—making this scenario the most beneficial overall for reducing energy cost burdens.

2.3.3 Bill Impacts

Models for each scenario assume that a certain percentage of households are included in decarbonization efforts and adopt some combination of clean energy technologies such as electrification and efficiency measures,
leaving the remaining households with less efficient appliances and with pollutant-emitting fuel sources such as natural gas.

Natural gas use is largely phased out across the state according to a timeline which varies by scenario, but some households continue using natural gas past 2040 even as other homes switch most residential energy consumption to electricity. Assuming that households which continue to use gas are located throughout the state and the entire gas distribution system must remain in-place to avoid energy disruption to these homes, the cost of maintaining fossil fuel distribution systems will remain relatively fixed and will need to be distributed among fewer and fewer users.

Figure 30 illustrates how distributing these costs among fewer households has the potential to lead to significant energy bill increases for households which do not transition to clean energy technologies. Monthly bills are consistently higher for non-adopters than adopters over time, but the gap between the two groups varies between 2020 and 2050. For all scenarios, non-adopters' bills are only moderately higher than those of clean energy adopters until roughly 2035-2040, at which time they increase dramatically to cover the cost of maintaining remnant gas infrastructure. This trend is particularly true of the Fossil Free and Slow Coal Retirement scenarios, where non-adopting households could see their energy bills increase by as much as 400 percent. Though projected energy bill increases are highest for non-adopting households under the Fossil Free and Slow Coal Retirement scenarios, all scenarios yield some monthly bill increase relative to the Reference Scenario by 2050, including for clean energy adopters. This increase is smallest for clean energy adopters under the Low Demand Scenario, where energy bills remain relatively flat due to higher implementation of energy efficiency measures.

This analysis raises important questions about the future of the gas distribution system post 2040 and how to prepare in the coming decades to maximize economic co-benefits and minimize adverse bill impacts to socioeconomically vulnerable groups in the 2040-2050 timeframe. Our findings underscore the importance of policy interventions that provide bill protections for low-income households and make clean energy technologies accessible to households with high baseline energy cost burdens, both of which may be disproportionately impacted by potential bill increases.

In addition, our findings suggest that infrastructure maintenance may become challenging for gas utilities past 2040 as demand and revenue decrease in the decarbonization scenarios. A residential gas distribution

TABLE 3. Approximate solar capacity required to meet demand for vulnerable groups by 2030 under the Core Scenario

Population Subset	Number of Households	Solar Required to Meet Projected 2030 Electricity Needs (Core Scenario)		
		Total GW	% of Total Solar in 2030 (5.4 GW)	% of Rooftop Solar in 2030 (1.7 GW)
Total Colorado Households	2,450,000	14.2 GW	263%	835%
Base Demographic & Geographic Groups				
Very Low-Income Households (below Federal poverty line)	230,000	1.5 GW	28%	89%
Low-Income Households Qualifying for Colorado Weatherization Program (below double Federal poverty line)	555,000	3.7 GW	69%	218%
Rural Households	217,000	1.3 GW	24%	76%
Projected Extreme Heat County Households (90th percentile annual days over 95˚F)	168,000	0.8 GW	15%	47%
Projected High Heat County Households (75th percentile annual days over 95˚F)	696,000	3.8 GW	70%	224%
Medical Baseline Customers	112,000	0.6 GW	11%	35%
Households within Tribal Lands	5,600	0.05 GW	1%	3%
Combination Demographic & Geographic Groups				
Low-Income, Rural Households	72,000	0.4 GW	7%	24%
Medical Baseline Customers in Heat Counties (50th percentile annual days over 95˚F)	64,000	0.4 GW	7%	24%

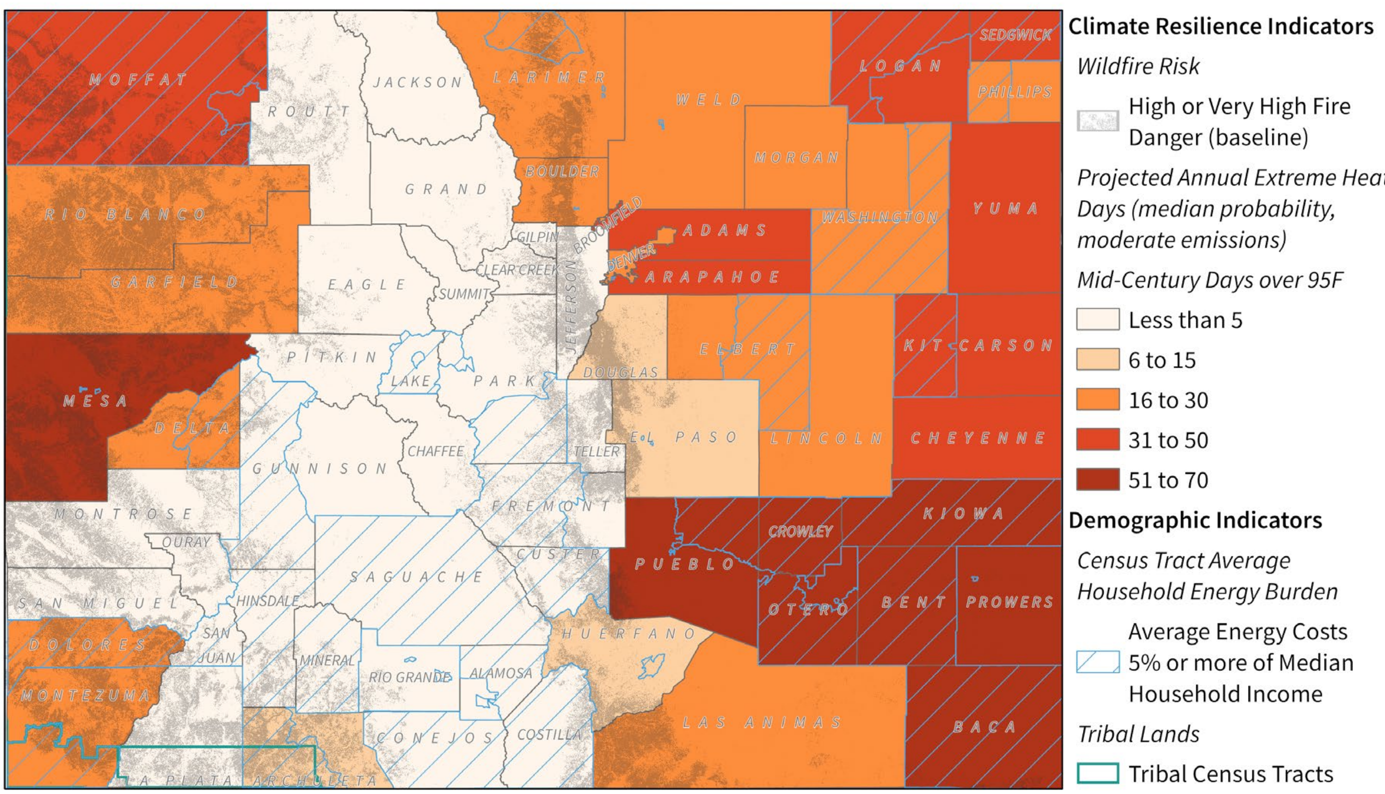
system will be difficult to maintain if: a) costs are passed on to fewer and fewer remaining customers, in which case fuel switching may happen even faster than assumed in our model due to economic pressures on consumers post 2040; or b) if gas utilities have to absorb these costs to keep their remaining customers. Therefore, a managed and geographically targeted phase-out of the gas distribution system from one region to the next (one region entirely phased out at a time), may have to be considered to mitigate some of these potential impacts by gradually reducing fixed maintenance costs.

2.3.4 Climate Resilience and Targeted Deployment of Distributed Energy Resources

Clean energy deployment in certain population subsets may be particularly beneficial to reduce energy cost burdens and provide resilience. Rooftop solar, for example, can provide bill stability and economic savings for low-income households. Approximately 1.5 gigawatts of solar capacity would be required to completely match very low-income households' 2030 energy needs. This number increases to roughly 3.7 gigawatts for low-income households.[85] These same households would likely benefit from energy-saving efficiency measures.

Similar focused deployment strategies are possible to target different populations in a way that maximizes economic, public health, and community resilience benefits. The Core decarbonization scenario projects approximately 5.4 gigawatts of total solar capacity across the state by 2030, 1.7 gigawatts of which are rooftop solar. **Table 3** shows approximately what portion of this capacity would be required to completely cover 2030 energy needs for various demographic groups. The groups shown in this table may reap particularly high resilience and economic co-benefits from clean energy measures due to socioeconomic, geographic, and health-based vulnerabilities. Though the population subgroups in this table are approximate and do not

FIGURE 31. Projected extreme heat days, wildfire risk, and average household energy cost burdens. Portions of Colorado, particularly eastern Colorado, may experience frequent heat days by mid-century; and much of western Colorado has high wildfire risk. A warming climate and intensifying wildfires may exacerbate energy cost burdens for Coloradans due to increasing air conditioning and filtration needs.



85 In this analysis, "very low-income" households are households below the federal poverty line. "Low-income" households are households below double the federal poverty line.

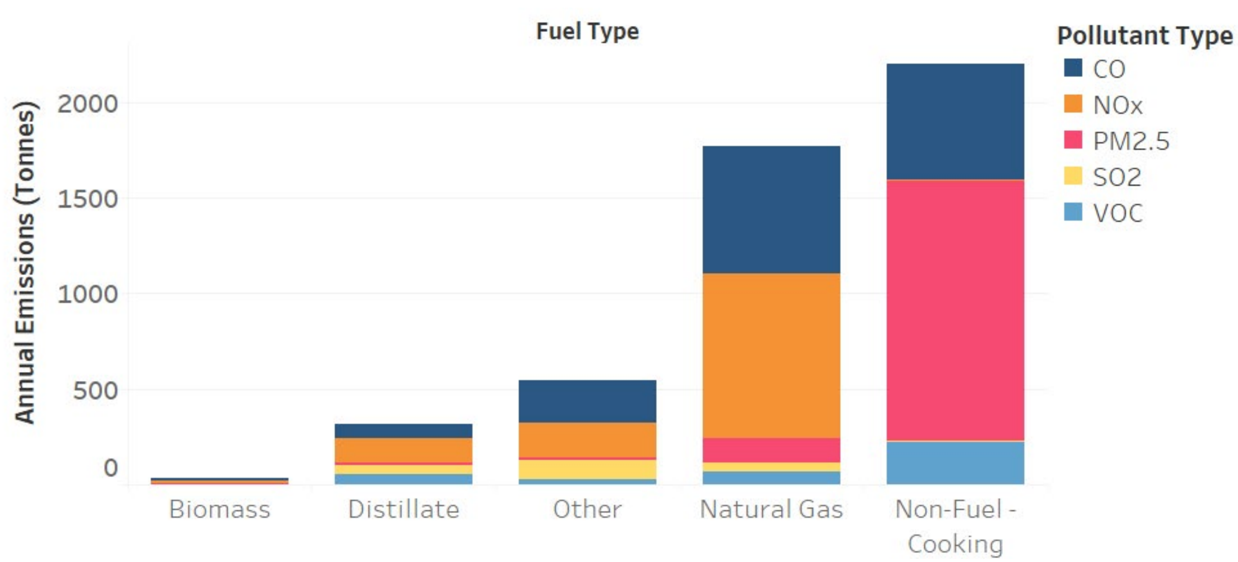
show all groups which may benefit from clean energy deployment, they conceptually illustrate that strategic policies which make solar and other clean energy technologies accessible to these vulnerable populations may maximize the co-benefits of decarbonization. Policymakers may therefore wish to consider co-benefits when balancing deployment of distributed energy resources such as solar + storage, community solar, and efficiency measures versus utility-scale solar projects.

Rural households, for example, and customers who rely on electricity for medical needs may particularly benefit from the resilience and reliability of home solar + storage systems which can provide backup in case of grid outages. Urban households living in apartment buildings might benefit from the fuel savings of efficiency measures and bill stability from community solar programs. Low-income households living in areas with high extreme heat days—projected to increase with climate change (**Figure 31**)—may face trade-offs between affording their electric bills and risking health complications such as heat stroke,[86] acute cardiovascular and respiratory episodes (including premature death),[87] and poor mental health outcomes.[88] Affordable, reliable access to air conditioning and air filtration may help mitigate such outcomes.[89] Low-income households in areas with high fire risk (or downwind from such areas) may similarly benefit from improved access to air filtration and increased electricity reliability during natural disasters. Distributed solar + storage systems and microgrids at facilities such as gyms, schools, and community centers can help these locations serve as resilience hubs and help meet cooling, cell phone charging, air filtration, and even evacuation needs. Distributed solar + storage and microgrids can also provide resilience to key facilities such as clinics and fire stations.

2.4 Commercial Buildings

According to the US Energy Information Administration, the commercial sector accounted for 4.1 megatonnes of CO_2 emissions in Colorado in 2017, or 4.6 percent of the cross-sectoral state total.[90] We were unable to locate or derive commercial emissions data at finer spatial resolution than the county level, which we obtained from the National Emissions Inventory (NEI).[91] Lack of spatially

FIGURE 32. Commercial sector criteria pollutant emissions (2017). "Other" includes gasoline and propane. Data are limited, though commercial use of natural gas, gasoline, propane, and distillate emit criteria air pollutants and precursors. Electrification can reduce fuel use and associated emissions. More data will help develop well-targeted decarbonization strategies for the commercial sector.



86 Wu *et al.* Emergency Department Visits for Heat Stroke in the United States, 2009 and 2010. *Injury Epidemiology* 1.1 (2014): 8.

87 Barnett, A. G., *et al.* Cold and Heat Waves in the United States. *Environmental Research* 112 (2012): 218-224.

88 Basu *et al.* Examining the Association Between Apparent Temperature and Mental Health-Related EMergency Room Visits in California. *American Journal of Epidemiology* 187.4 (2018): 726-735.

89 Ostro *et al.* The Effects of Temperature and Use of Air Conditioning on Hospitalizations. *American Journal of Epidemiology* 172.9 (2010): 1053-1061.

90 US Energy Information Administration. "2017 State Energy-Related Carbon Dioxide Emissions by Sector." May 20, 2020. Available at: https://www.eia.gov/environment/emissions/state/

91 The National Emissions Inventory reports state commercial sector emissions but is incomplete.

granular commercial data does not preclude further decarbonization efforts, but presents difficulties in ensuring decarbonization policy is designed to maximize health, economic, and equity co-benefits where they are most needed. There is accordingly a strong need for more rigorous reporting and characterization of commercial emissions data.

Of the fuels included in the NEI dataset, natural gas produces the most criteria air pollutant emissions statewide (see **Figure 32**). Emissions also result from burning fossil fuels such as gasoline, distillate, propane, and biomass, though to a lesser extent. Without census-tract or facility-level data, it is not feasible to ascertain the distribution of these fuels across geographic space and commercial facility types. The only industry with emissions characterized in the dataset is commercial cooking. However, many of these emissions come from the act of cooking itself,[92] which results in emissions of pollutants such as $PM_{2.5}$ and VOCs due to the chemical processes that occur during cooking, as opposed to fuel burning for the purposes of cooking. Based on the available data, the state should initiate fuel switching initiatives to replace use of natural gas, gasoline, propane, and other emitting fuels with clean electricity in the commercial sector. Moreover, the State may be better able to develop targeted policy initiatives with more detailed information, and data collection efforts are warranted.

2.5 Industrial Sector

Colorado's industrial sector is responsible for a large share of criteria pollutant emissions across the state (see **Figure 1**), although not all of these are from fossil fuel combustion and therefore may not be addressed through decarbonization measures such as electrification. Decarbonization of fuel use in the industrial sector can help to reduce some of these pollutant emissions, but will not eliminate them entirely. The vast majority of industrial NO_x emissions in Colorado is associated specifically with oil and gas production and processing. The oil and gas sector also contributes roughly 10-15 percent of industrial $PM_{2.5}$ and SO_2 emissions statewide,[93] and is also associated with emissions of hazardous air pollutants. The health co-benefits of decarbonizing Colorado's industrial sector, particularly those associated with NO_x emission reductions, are therefore heavily dependent not only on the replacement of fossil fuel use at industrial sites (with measures such as electrification or renewable hydrogen), but even more importantly on the future of oil and gas development across the state.

The data on fuel use and criteria air pollutant emissions across the Colorado industrial sector are limited. Data are available on statewide carbon emissions from industrial fossil fuel use, but available data on criteria pollutant emissions from industrial point sources do not distinguish between combustion and non-combustion emissions. It is therefore difficult to estimate what fraction of criteria air pollutant emissions from industrial point sources can be reduced through decarbonization efforts. Estimates of emissions from distributed industrial sources across the state—such as oil and gas wells and associated infrastructure—are only available at the county level and are likely underestimates.[94] Without sufficient spatial granularity, it is difficult to thoroughly assess the environmental equity and health impacts of these distributed sources, even though they are known to produce criteria air pollutants and other health-damaging air pollutants. Within these data limitations, we analyze the distribution of criteria air pollutant emissions from stationary industrial point sources across population segments, but are limited to a proximity analysis for distributed sources, examining demographic data for populations living near oil and gas wells (as a proxy for oil and gas development operations more generally).[95] We identify broad trends by the source and the location of these emissions. Given the lack of available data on fuel use and without better emissions data for distributed sources, we can only describe potential health and environmental equity impacts of industrial decarbonization in broad strokes.

Figure 33 shows locations and NO_x emissions from point sources (including industrial, power, and transportation point sources) and the Demographic Index across Colorado and in the Denver metropolitan area. These

92 US Environmental Protection Agency. "Commercial Cooking NEMO FINAL_4-2 update." Downloaded Oct. 2020 from: ftp://newftp.epa.gov/air/nei/2017/doc/supporting_data/nonpoint/

93 Oil and gas sector emissions are based on the National Emissions Inventory (NEI) 2017 dataset, and are likely underestimates due to the difficulty of characterizing criteria and hazardous air pollutant emissions from the oil and gas sector.

94 National Emissions Inventory (NEI) emissions estimates for industrial nonpoint sources may be underestimates, as a result of underreporting of pipeline emissions between wellheads and gas processing facilities, as well as the existence of above-average high-emitting oil and gas sites (Grant, John *et al.* "U.S. National Oil and Gas Emission Inventory Improvements." (2017)).

95 Czolowski, Eliza D., *et al.* Towards Consistent Methodology to Quantify Populations in Proximity to Oil and Gas Development: A National Spatial Analysis and Review. *Environmental Health Perspectives* 125.8 (2017): 086004.

FIGURE 33. Pollutant emission point sources and Demographic Index. Point sources are located throughout the state; though certain sources, such as industrial facilities and oil and gas wells, are heavily clustered. Failure to address spatially clustered polluting facilities risks leaving disproportionate residual pollution burdens in pollution-overburdened communities.

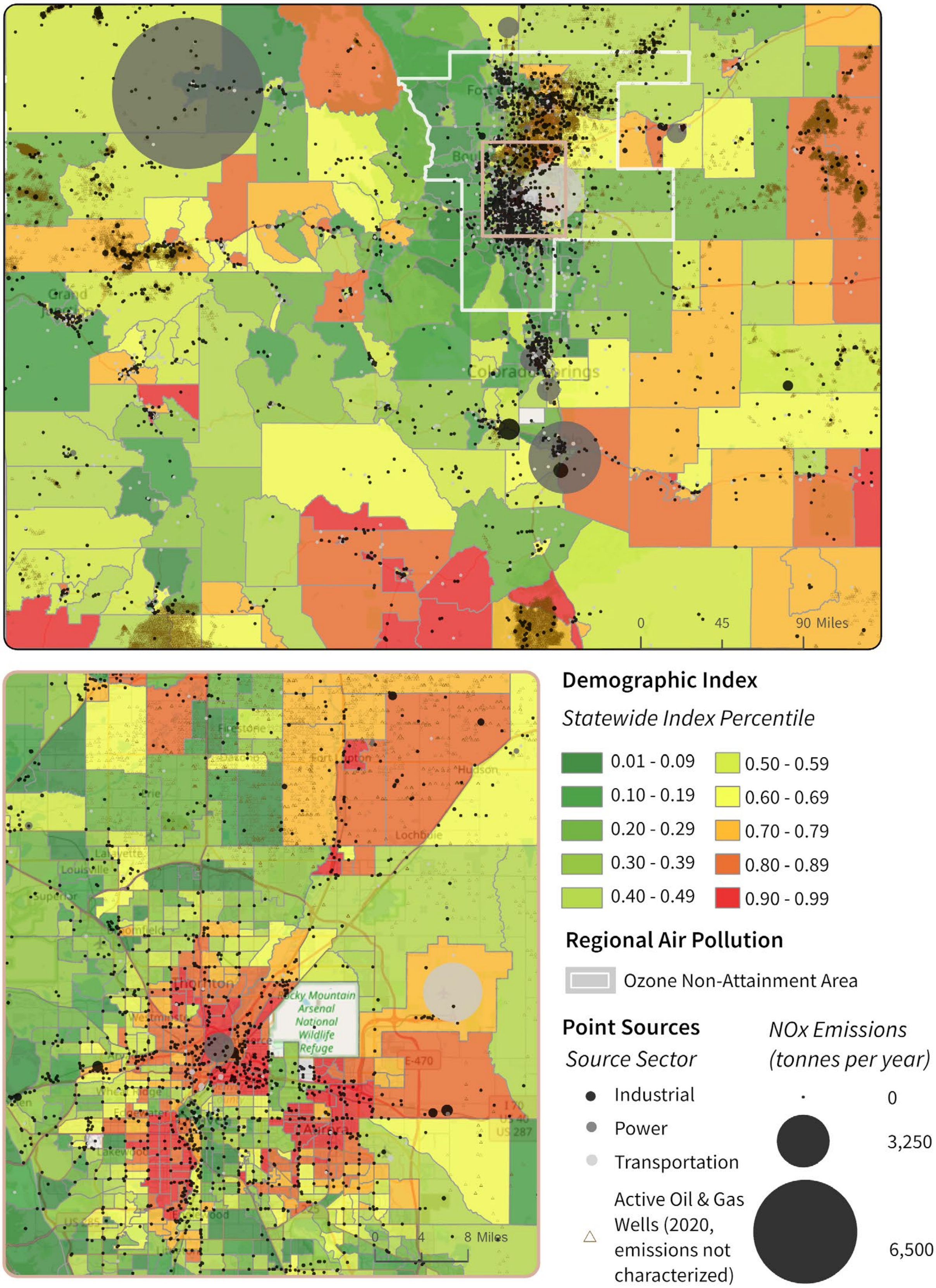
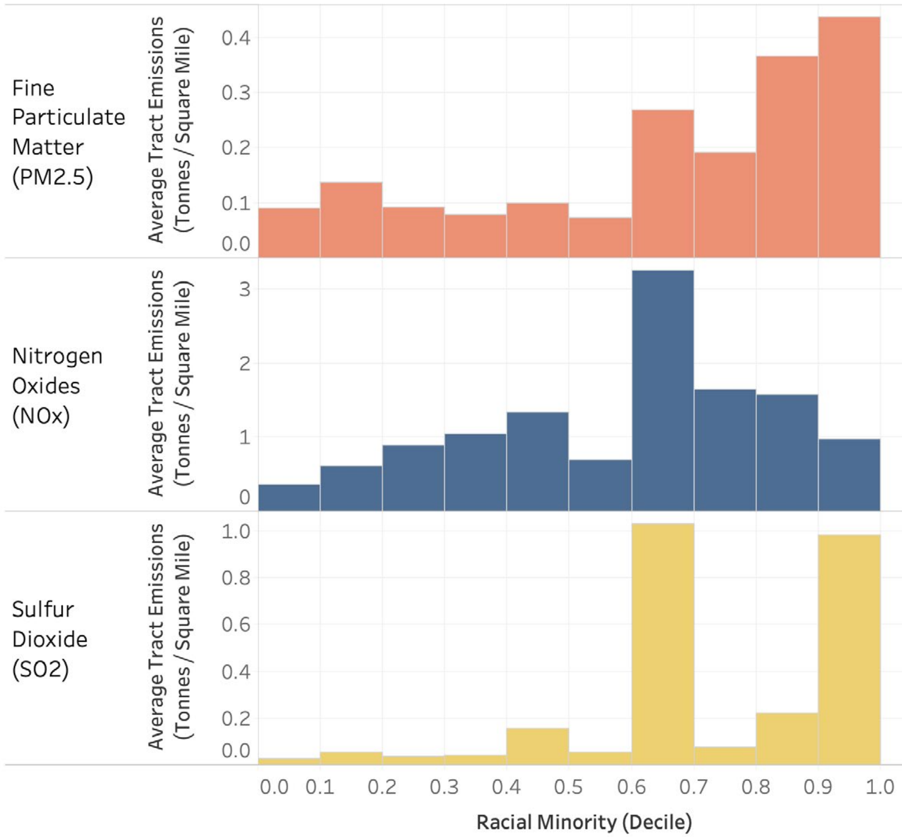


FIGURE 34. Industrial point source emissions (tonnes / square mile) of SO_2, NO_x, and $PM_{2.5}$ in the average tract in each decile bracket of the racial minority demographic indicator. The rightmost bar represents the 10 percent of census tracts with the highest population proportion of racial minorities, and the leftmost bar represents the 10 percent of census tracts with the lowest population proportion of racial minorities. Industrial point source emissions are more dense on average in census tracts with greater proportions of people of color.



show high concentrations of industrial point sources in communities with high Demographic Index rankings, such as Commerce City and parts of the Front Range. Most of these facilities are located in close proximity to the major interstate highways in Colorado (Interstates 76, 25, and 70), contributing to elevated cumulative emissions from multiple sectors.

Analyzing industrial point sources in more detail in **Figure 34**, we find that $PM_{2.5}$, NO_x, and SO_2 emissions from these sources are higher per unit area on average in census tracts with higher proportions of people of color. As stated previously, however, not all of these emissions will be reduced through decarbonization and the phase-out of oil and gas development. Emissions in higher racial minority decile brackets are partly due to oil and gas development facilities that have the potential to reduce hydrocarbon production, processing, and transport under each decarbonization pathway, including natural gas compressor stations in Rifle, and northeast of Denver, as well as the Suncor petroleum refinery in the Denver metropolitan area.

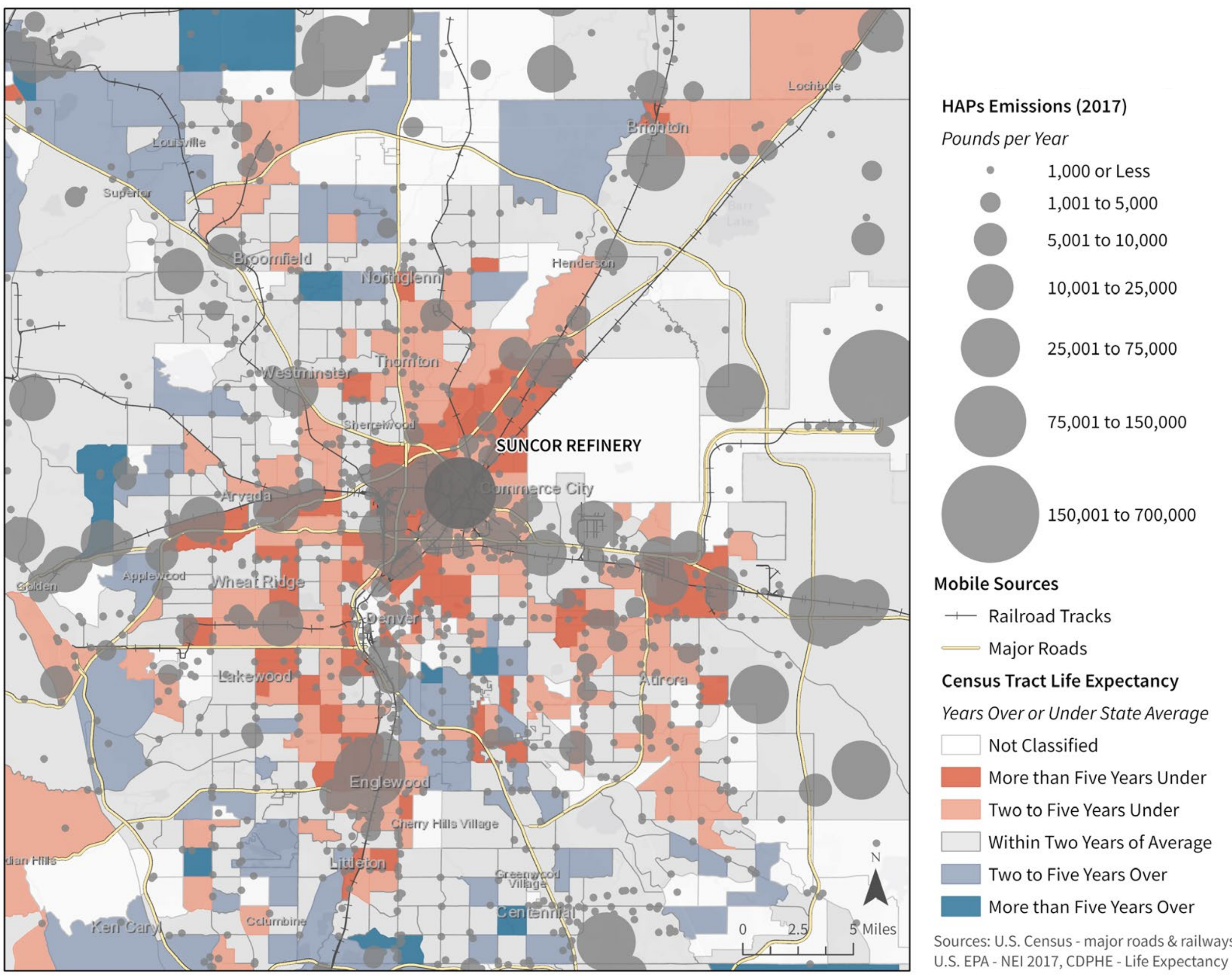
A portion of emissions in these tracts may not be eliminated by decarbonization measures, however, including those from non-combustion processes at high-emitting manufacturing facilities in Denver and Pueblo and solid waste landfills in Denver and Colorado Springs. While decarbonization strategies such as waste-to-energy recovery with air pollution control technologies could reduce some criteria air pollutant emissions from solid waste landfills, other pollution control measures will likely be necessary to reduce emissions from non-energy processes at manufacturing facilities and other point sources that are disproportionately located in communities of color.

Some of these industrial emissions may be reduced through replacement of fossil fuels with hydrogen and electricity, but many are associated with non-energy processes, such as particulate matter generated from mining. Areas with high industrial emissions, no matter the source, may still benefit from decarbonization efforts across all sectors to mitigate cumulative emission burdens.

As noted, many of the industrial NO_x emissions in Colorado are associated with oil and gas production and processing. These sources range from oil and gas wells and natural gas compressor stations to the Suncor Refinery, discussed in **Box 1**. While these emissions are not all from fossil fuel *combustion*, and therefore may not be the primary focus of decarbonization efforts, the phase-out of oil and gas production will help reduce emissions of the methane, a potent greenhouse gas with 87-times the global warming potential of CO_2, which may be emitted intentionally (e.g., during venting or blowdowns) or unintentionally (e.g., from leaking infrastructure).

Similarly, the phase-out of oil and gas production can also help reduce emissions of various health-damaging air pollutants that are co-produced from oil and gas reservoirs (e.g., benzene, toluene, ethylbenzene, and xylene, together referred to as BTEX). Benzene, for example, is listed by the EPA as a hazardous air pollutant, is a known human carcinogen, and is toxic to human development, the immune system, and blood.[96] This infrastructure is mapped in **Figure 33**. Colorado is the fifth-largest oil-producing state and seventh-largest gas-producing state. Altogether, the state has roughly 43,000 oil and gas wells, six interstate oil pipelines, four interstate natural gas pipelines, 43 gas processing plants, one refinery, and a broad network of support infrastructure including compressor stations and distribution pipelines.[97]

FIGURE 35. Urban Denver industrial point sources and average life expectancy. The Suncor Refinery is located in a community with numerous HAPs point sources and low life expectancies compared to the rest of the state (state average = 80.5 years). Inequities may persist for neighborhoods with high baseline environmental burdens if polluting infrastructure remains in place.



96 OEHHA (Office of Environmental Health Hazard Assessment), California Environmental Protection Agency. OEHHA Acute, 8-hour and Chronic Reference Exposure Level (REL) Summary. Available at: https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary.

97 American Petroleum Institute. "Progress and Opportunity: Colorado Natural Gas and Oil." (2018) Available at: https://www.api.org/~/media/Files/News/2018/18-June/Colorado_NaturalGas_Report-June-2018.pdf#page=11&zoom=auto,38,-269

BOX 1: Suncor Refinery Case Study

Legacy Oil and Gas and Industrial Infrastructure in Pollution-Overburdened Communities

The Suncor Refinery in Commerce City is Colorado's only active petroleum refinery. Up to 98,000 barrels a day are refined into gasoline, diesel, asphalt, and jet fuel, mostly from crude materials extracted from the Alberta Tar Sands of Central Canada and the Denver-Julesburg Basin of the Central US, including eastern Colorado. Many of the refinery's products are consumed in-state, with approximately 35 percent of Colorado's gasoline and diesel demand being met by products from this facility.[98]

The refinery sits in a socioeconomically vulnerable portion of the Denver metro area—all census tracts within one mile of the refinery are majority people of color (range: 50-86 percent, compared to 32 percent people of color in Colorado) and majority low-income (range: 50-67 percent, compared to 28 percent of Colorado). These and other demographic indicators place all refinery-adjacent census tracts in the 87th to the 98th percentile of the statewide Demographic Index. **Figure 35** shows that census tracts near this part of Denver have a lower than average life expectancy compared to other Coloradans (state average = 80.5 years). While life expectancy is driven by multiple factors including genetics, environment, and gene-environment interactions, multiple environmental pollutants emitted by these facilities are well known to be associated with premature mortality including, but not limited to, $PM_{2.5}$, NO_x, and hazardous air pollutants.[99,100,101]

Additionally, communities near the refinery face significant environmental vulnerabilities. This is partially due to the clustering of industrial facilities in Commerce City. There are 25 other facilities with emissions reported in the 2017 National Emissions Inventory within a mile of the refinery, as well as several major roads, and a network of railroad tracks.

Although the density of industrial facilities in Commerce City is at least partially responsible for the area's pollution burden, the refinery itself plays a significant role as one of the state's highest emitters. Of 3,900 facilities reporting VOC emissions in the 2017 NEI in Colorado, Suncor had the second highest emissions, accounting for 1.7 percent of the state's total industrial VOC emissions. Similarly, the refinery was the 9th highest of 2,850 facilities emitting hazardous air pollutants in 2017, accounting for 1.1 percent of statewide industrial hazardous air pollutant emissions. The refinery also produced an outsize proportion of the state's industrial CO_2 (2.1 percent), $PM_{2.5}$ (1.9 percent), NO_x (1.0 percent) and SO_2 (1.1 percent) emissions in the same year and in recent years had a series of severe Clean Air Act violations.[102]

The state's decarbonization goals do not ensure that this refinery will close in 2050. This presents a potential environmental and public health equity issue, particularly in light of the demographics of communities surrounding the refinery and their high cumulative environmental burdens. The refinery is one example of how oil and gas infrastructure across the state will continue to emit health-damaging air pollutants in environmentally vulnerable communities if oil and gas production and processing is maintained, or if facilities are retired without proper dismantling and remediation efforts in the coming decades, even as other sectors decarbonize.

98 Suncor. "Shell and Exxon." (2020) Available at: https://www.suncor.com/en-ca/about-us/products-and-services/shell-and-exxonmobil

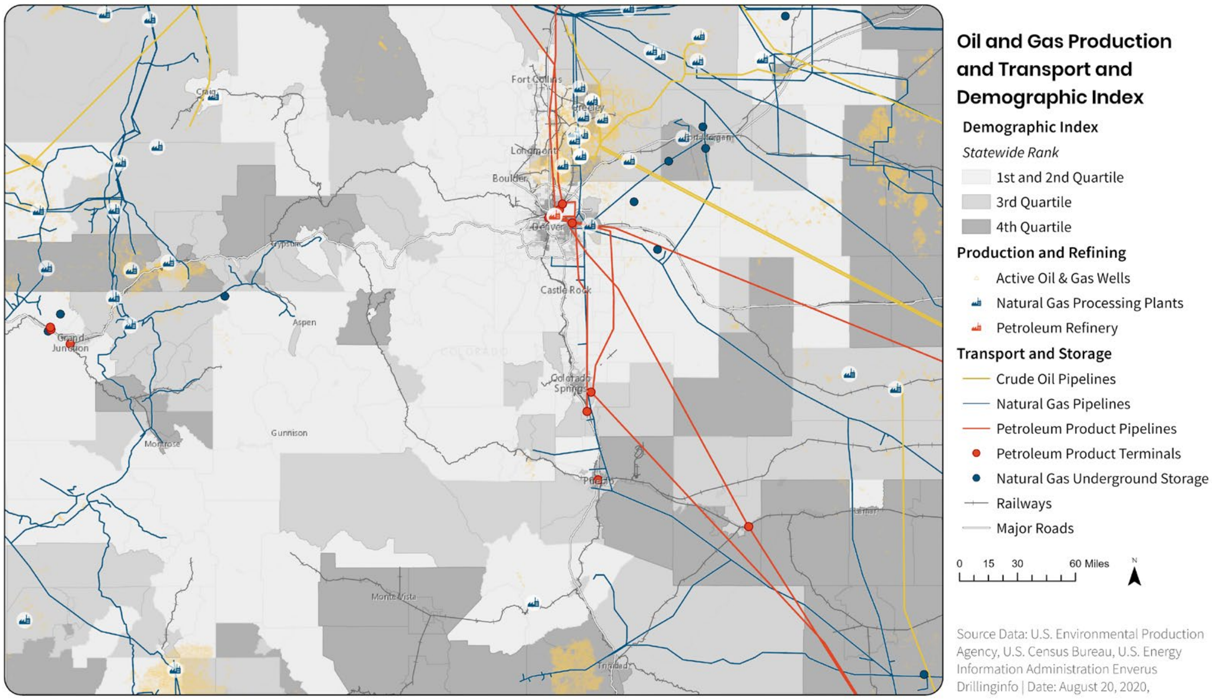
99 Pope III, C. Arden, Majid Ezzati, and Douglas W. Dockery. Fine-Particulate Air Pollution and Life Expectancy in the United States. *New England Journal of Medicine* 360.4 (2009): 376-386.

100 US Environmental Protection Agency. "Health Effects Notebook for Hazardous Air Pollutants". Available at: https://www.epa.gov/haps/health-effects-notebook-hazardous-air-pollutants

101 AirNow. "Your Health". Available at: https://www.airnow.gov/air-quality-and-health/your-health/

102 US Environmental Protection Agency. "Environmental Compliance History Online". Available at: https://echo.epa.gov/detailed-facility-report?fid=110032913024

FIGURE 36. Oil and gas production, transmission, and processing infrastructure across Colorado. Substantial portions of Colorado house some form of oil and gas infrastructure. Extraction and processing often occur in areas with high Demographic Index scores. Infrastructural investments and creation of clean energy jobs in regions with high oil and gas production or processing may help facilitate managed decline and a just transition, and assure communities which economically rely on the fossil fuel industry are included in a post-decarbonization economy.



As the demand for oil is expected to fall due to decarbonization and market forces,[103] however, the state has an opportunity to retire this facility and other fossil fuel infrastructure as it decarbonizes the rest of the economy. Policy strategies, including measures to facilitate the transition of workers in the fossil fuel sector to jobs in other industries, are necessary to support the phase-out of oil and gas production and processing, reduce carbon-equivalent emissions and prevent overburdened communities from shouldering outsized environmental and health burdens.

Analyzing the subset of data on industrial point source emissions associated with oil, gas, and coal infrastructure—excluding distributed sources such as oil and gas wells, for which we have limited emissions data—we found that emissions from these sources and are most dense (tonnes emitted per unit area) in communities with high racial minority population fractions (**Figure 37**). Point sources in this analysis include natural gas compressor stations, the Suncor refinery, coal mines, and other large, stationary sources associated with fossil fuel production, refining, and transport.

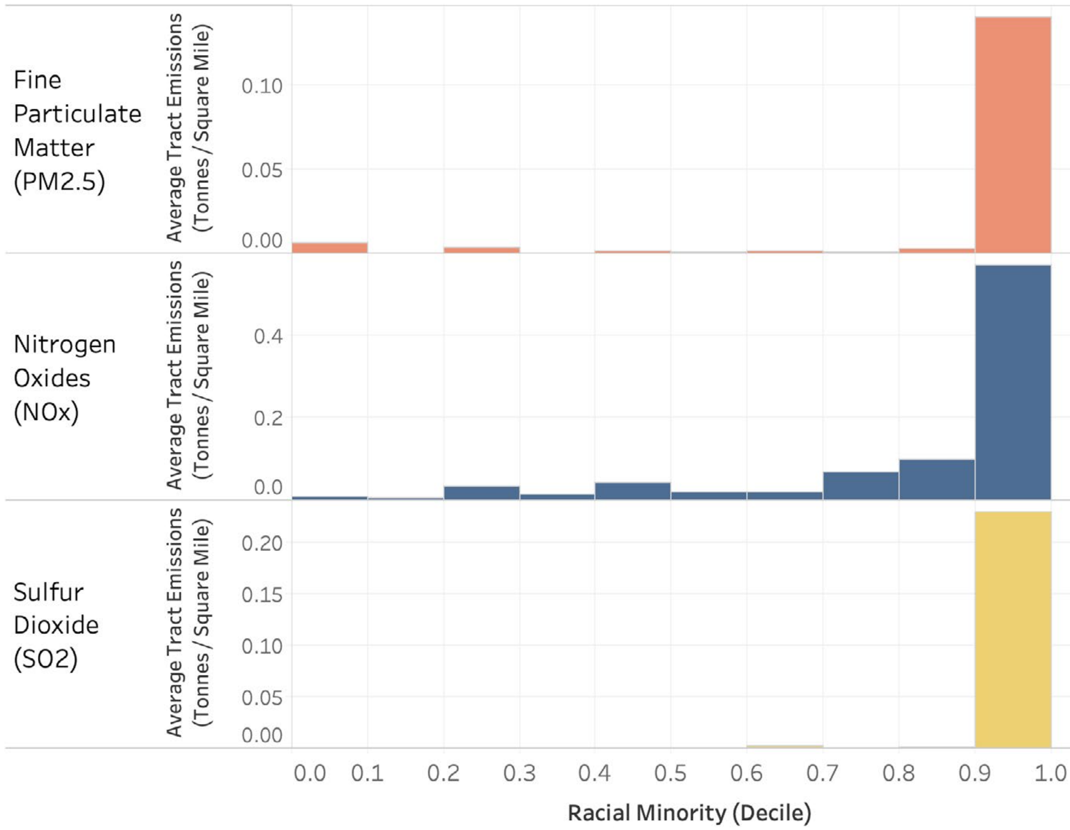
Although robust emissions data are unavailable for oil and gas wells, population proximity analysis serves as a rough proxy for evaluating potential health burdens associated with oil and gas extraction. Previous studies found that population growth near active oil and gas wells was faster than statewide population growth at large, and that between 375,000[104] and 430,000[105] Coloradans lived within a mile of oil and gas wells in the early 2010s. Using more recent population and well data and a smaller search radius (i.e. greater proximity to wells), we found that roughly four percent (250,000) of Coloradans live within a half mile of an active well.

103 Denver Business Journal. "Suncor Cutting Workforce by as much as 15%" (2020). Available at: https://www.bizjournals.com/denver/news/2020/10/05/suncor-workforce-reduction-colorado.html

104 McKenzie, Lisa M., *et al.* Population Size, Growth, and Environmental Justice near Oil and Gas Wells in Colorado. *Environmental Science & Technology* 50.21 (2016): 11471-11480.

105 Czolowski, Eliza D *et al.* Toward Consistent Methodology to Quantify Populations in Proximity to Oil and Gas Development: A National Spatial Analysis and Review. *Environmental health perspectives* vol. 125,8 086004. 23 Aug. 2017, doi:10.1289/EHP1535

FIGURE 37. Fossil fuel industry point source emissions (tonnes / square mile) of SO_2, NO_x, and $PM_{2.5}$ in the average tract in each decile bracket of the racial minority demographic indicator. The high average emissions per unit area of all three pollutants in the 10th (highest) decile bracket is partially due to the Suncor refinery, a highly-polluting facility located in a census tract in Commerce City in which 70 percent of the population are people of color. The refinery's outsized contribution to statewide and local criteria air pollutant emissions underscores the importance of phasing out oil and gas production and processing in environmentally overburdened communities (see **Box 1**).



This is largely driven by several Colorado counties with high population densities near wells—most prominently by Weld, Rio Blanco, and La Plata Counties, shown in **Figure 38**. This suggests that hundreds of thousands of Coloradans, particularly those living in the most heavily impacted regions, may be exposed to oil and gas-associated pollutants in their air and water, some of which are associated with adverse respiratory, reproductive, and hematological health outcomes.[106,107,108,109] Should oil and gas production continue as-is or increase moving forward, these exposures may persist.

The future of industrial greenhouse gas and co-pollutant emissions in Colorado depends in part on whether oil and gas production and processing are phased out. In all modeled scenarios, production declines to 75 percent of current levels by 2030. In the Fossil Free scenario, all production declines to zero in 2050, whereas in the other scenarios production remains at 25 percent of current 2020 levels in 2050. As seen in **Figure 38**, oil and gas wells are concentrated in the Front Range and across rural Colorado, including the Denver-Julesburg, Piceance, and San Juan Basins. If these fields are still producing in 2050, the associated pollution in these regions will remain, even as the rest of the state decarbonizes and reduces pollution from fossil fuel use.

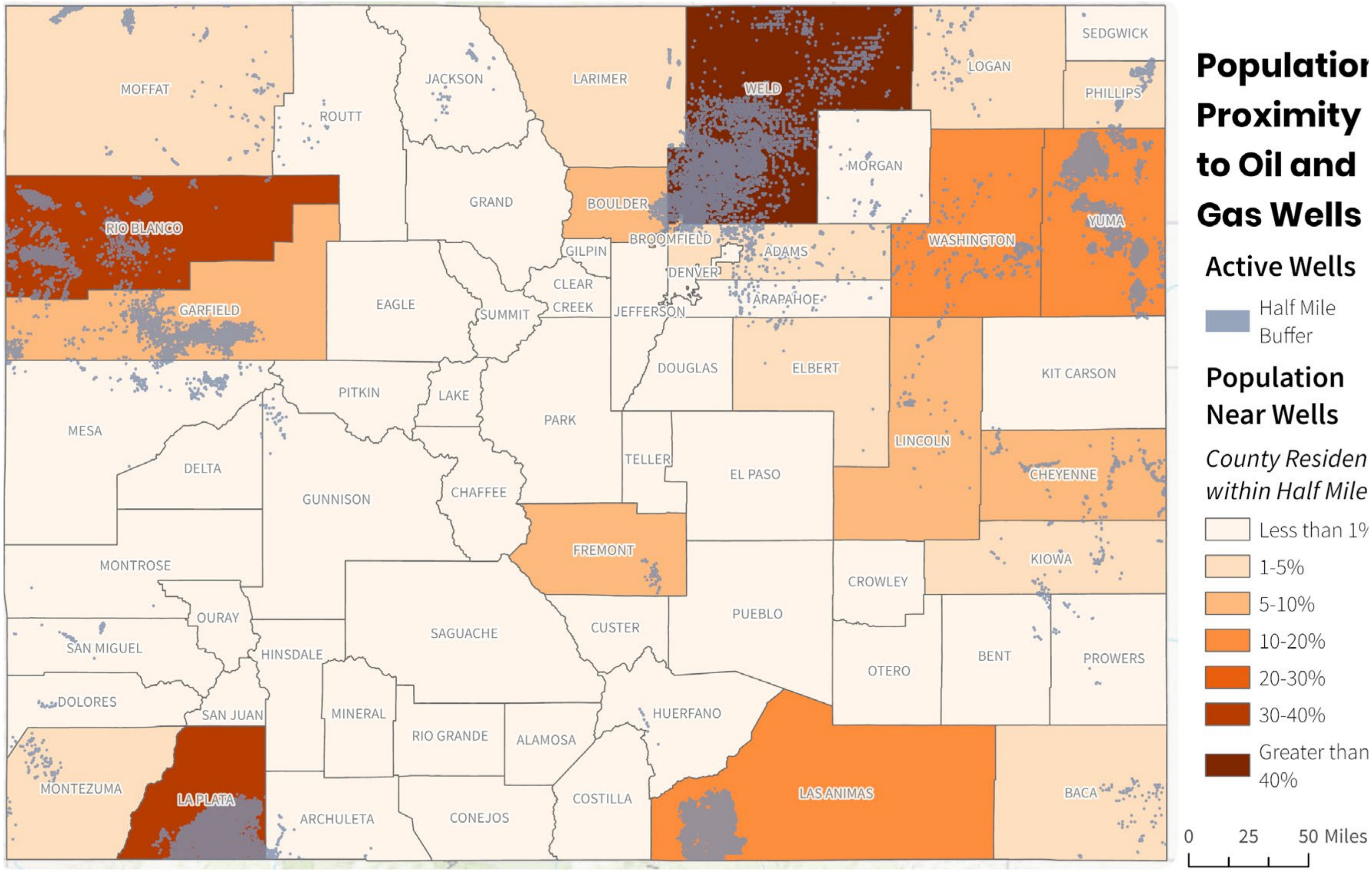
106 Johnston, Jill E *et al.* Impact of Upstream Oil Extraction and Environmental Public Health: A Review of the Evidence. *Science of the Total Environment* 657 (2019): 187-199.

107 Balise, Victoria D., *et al.* Systematic Review of the Association Between Oil and Natural Gas Extraction Processes and Human Reproduction. *Fertility and Sterility* 106.4 (2016): 795-819.

108 American Public Health Association. The Environmental and Occupational Health Impacts of Unconventional Oil and Gas Industry (2018).

109 Willis, Mary, *et al.* Natural Gas Development, Flaring Practices and Paediatric Asthma Hospitalizations in Texas. *International Journal of Epidemiology* (2020).

FIGURE 38. Populations living within half a mile of active oil and gas wells. Portions of Colorado have high population density near active oil and gas wells. Ongoing oil and gas production and/or failure to properly plug wells may lead to continued exposures to health hazards.



ate: August 13, 2020 | Data Source: Drilling Info - Active Oil and Gas Wells, IPUMS NHGIS - American Community Survey 2013-2018 Block Groups

A number of measures can help minimize the health hazards, risks, and impacts of oil and gas development in the coming decades. In the near term, measures such as setback requirements can act as a factor of safety to help reduce population exposures to health-damaging pollutants and other stressors from oil and gas infrastructure. Ongoing regulations to measure and reduce methane leakage, sources of which often emit health-damaging, non-methane VOCs, can help reduce risks of exposures to these pollutants in addition to the climate forcing of methane. Increased monitoring to better characterize methane and methane co-pollutant emissions statewide will enable more focused regulations and enhanced enforcement. As oil and gas development declines, monitoring and upkeep will be required to ensure the safety of aging infrastructure, including the careful monitoring of idle, abandoned, and orphaned wells.[110] Finally, set-aside funds and bonding requirements for remediating fossil fuel brownfields, including proper plugging and abandonment of surface and subsurface oil and gas infrastructure and retired coal mines, can help ensure the safe transition of these areas into new land uses.

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110 Kang, Mary, *et al.* Direct Measurements of Methane Emissions from Abandoned Oil and Gas Wells in Pennsylvania. *Proceedings of the National Academy of Sciences* 111.51 (2014): 18173-18177.

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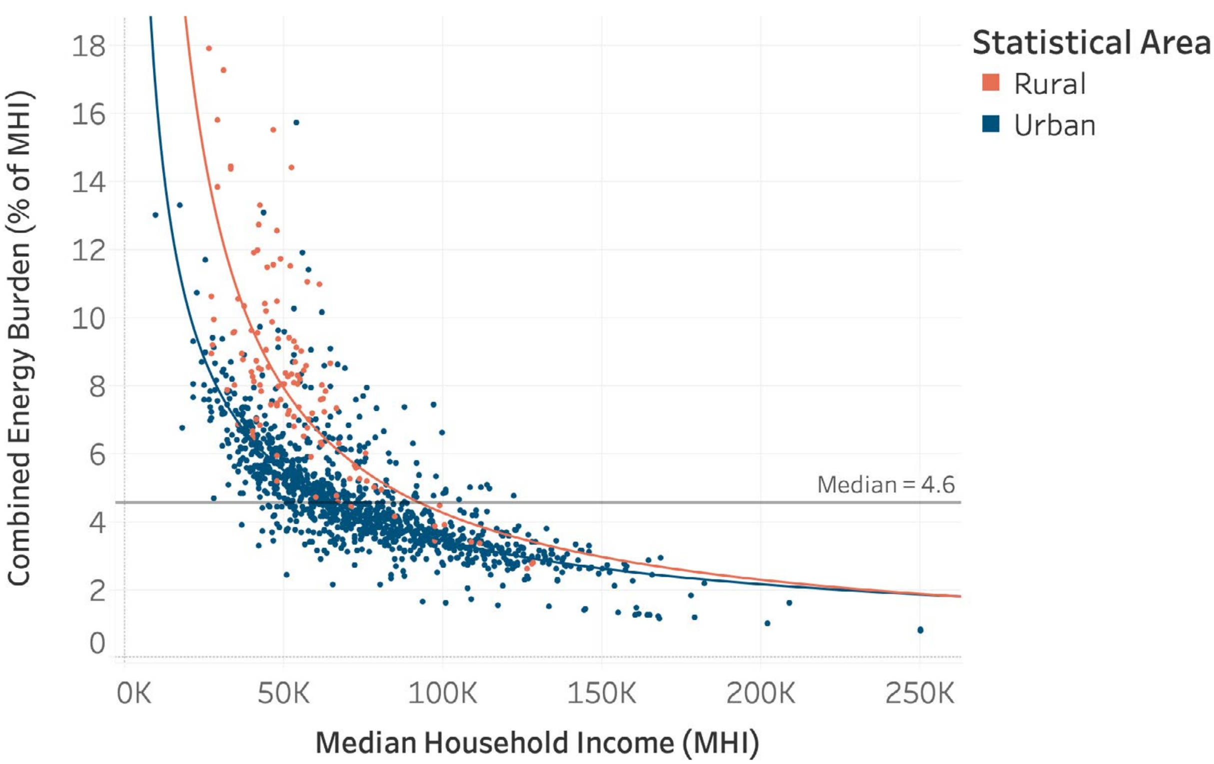
2.6 Cross-Sectoral Themes

In the previous sections, we analyze existing pollution, energy cost burdens, and decarbonization pathways on a sectoral basis. Below, we address the intersection of these sectors: combined energy cost, environmental, and socioeconomic burdens, opportunities to reduce cumulative pollution from multiple sources, and the trade-offs between each pathway that result from prioritizing decarbonization in some sectors before others.

2.6.1 Combined Energy Cost Burdens

While household CO_2 emissions tend to be higher for census tracts with higher median incomes, energy cost burdens are highest for households in census tracts with the lowest median incomes. These energy bills are even more burdensome when considered in combination across sectors. **Figure 39** shows combined utility bill and vehicle fuel burdens for average households in each census tract as compared to median household income. While the median combined household energy cost

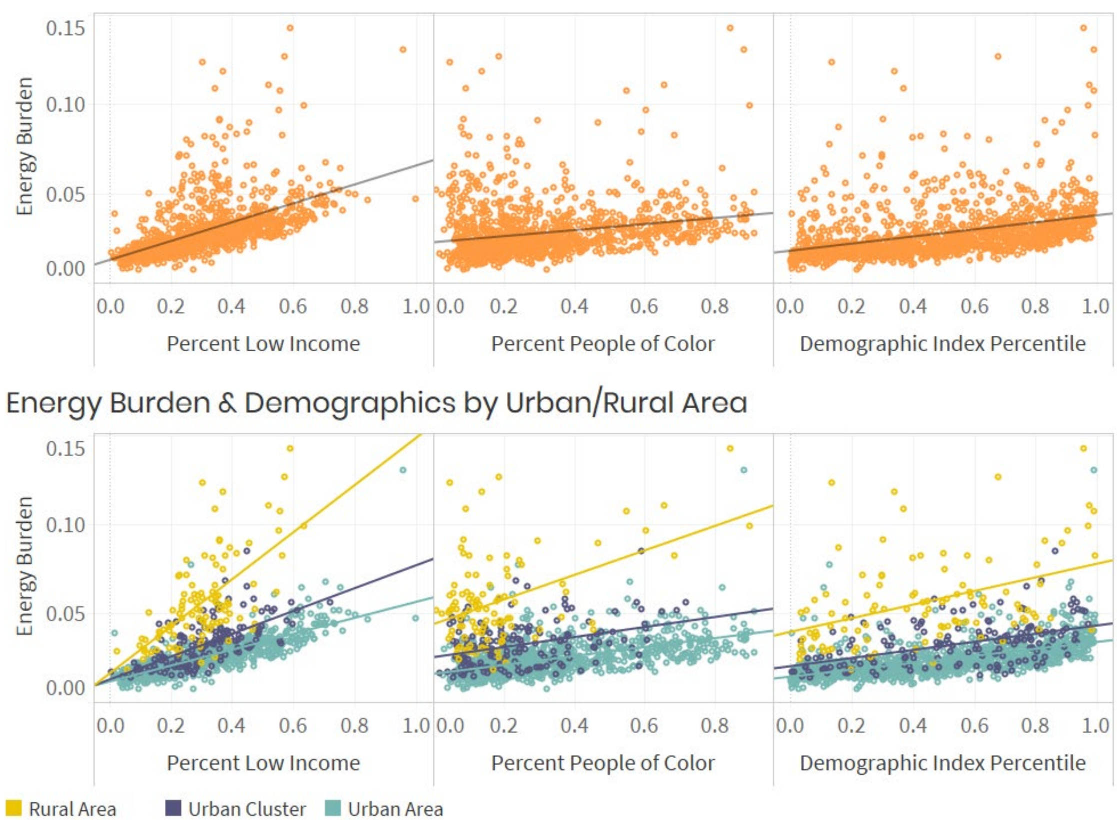
FIGURE 39: Average combined transportation and residential energy cost burden and median household income by census tract. On average, low-income households spend a greater fraction of their annual income on residential heating, household appliances, and transportation fuel. Rural households tend to have higher combined energy cost burdens than urban households, in part due to longer average driving distances, more expensive residential fuels, and factors like housing age and climate.



burden is 4.6 percent of household income, some census tracts have combined average energy cost burdens as high as 18 percent. On average, rural households face higher energy cost burdens than urban households, in part due to longer driving distances and more expensive residential heating fuels,[111] as well as housing age and harsher climates. Individual households within each census tract, of course, may spend an even greater fraction of their annual income on transportation fuel, heating their homes, and powering their appliances.

Our analysis suggests that energy cost burdens are most prominent for low-income households. An initial analysis into other demographic indicators suggests that burdens are not disproportionately high among populations of color on a statewide level *per se*; except insofar as populations of color in Colorado tend to be lower income than White populations. Additionally, we generally found many rural areas with high energy cost burdens, some of which are predominately White while others have a high concentration of people of color. This includes rural tribal lands in southwestern Colorado, particularly the Ute Mountain Reservation, where average energy burdens and the regions' Demographic Index score are both high. Although rural burdens tended to be high, we identified portions of the Denver Metro Area where Demographic Index scores and energy burdens are both high as well. These findings together show the range of low-income, rural, and racial minority communities that may be impacted by bill burdens (**Figure 40**), highlighting the importance of residential clean energy policies tailored to specific populations through community consultation and other targeting strategies.

Figure 40. Energy Cost Burden by Demographic Indicators and Urban/Rural Residence. Sociodemographic indicators' correlation with energy burden varies depending on urban and rural context. For example, percent people of color is more strongly correlated with energy burden in rural than in urban areas. This illustrates the importance of developing geographically and demographically targeted decarbonization policies which benefit a wide range of Coloradans.



111 US Energy Information Administration. "Colorado: State Profile and Energy Estimates." Available at: https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_prices/res/pr_res_CO.html&sid=CO

Figure 41. Industrial and transportation hotspots. Industrial facilities and oil and gas wells tend to be clustered near major roadways and railroad rights-of-way; and interstate routes tend to experience the most truck traffic. Though treated separately in this analysis, industrial activity may influence transportation and associated emissions.

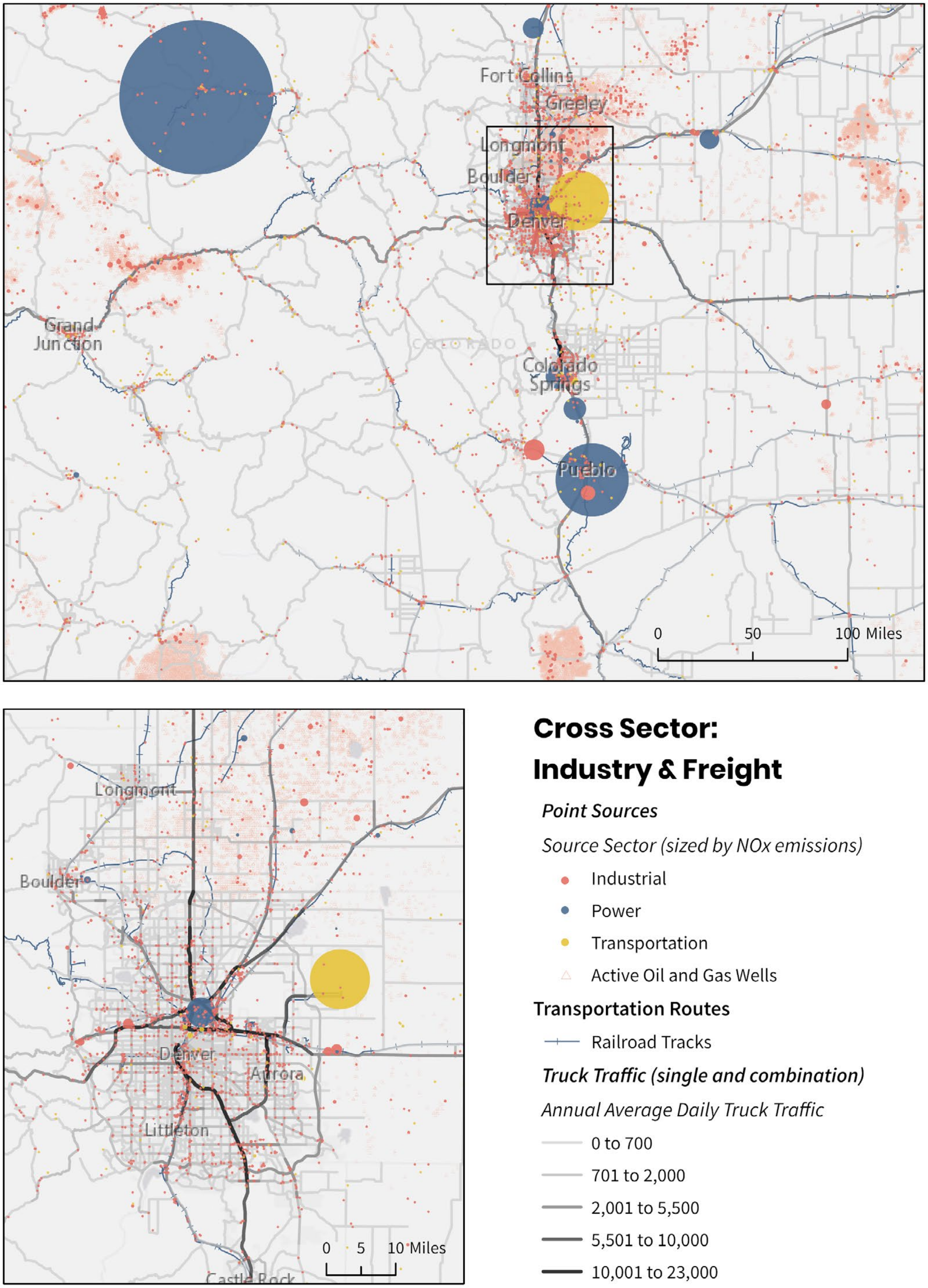
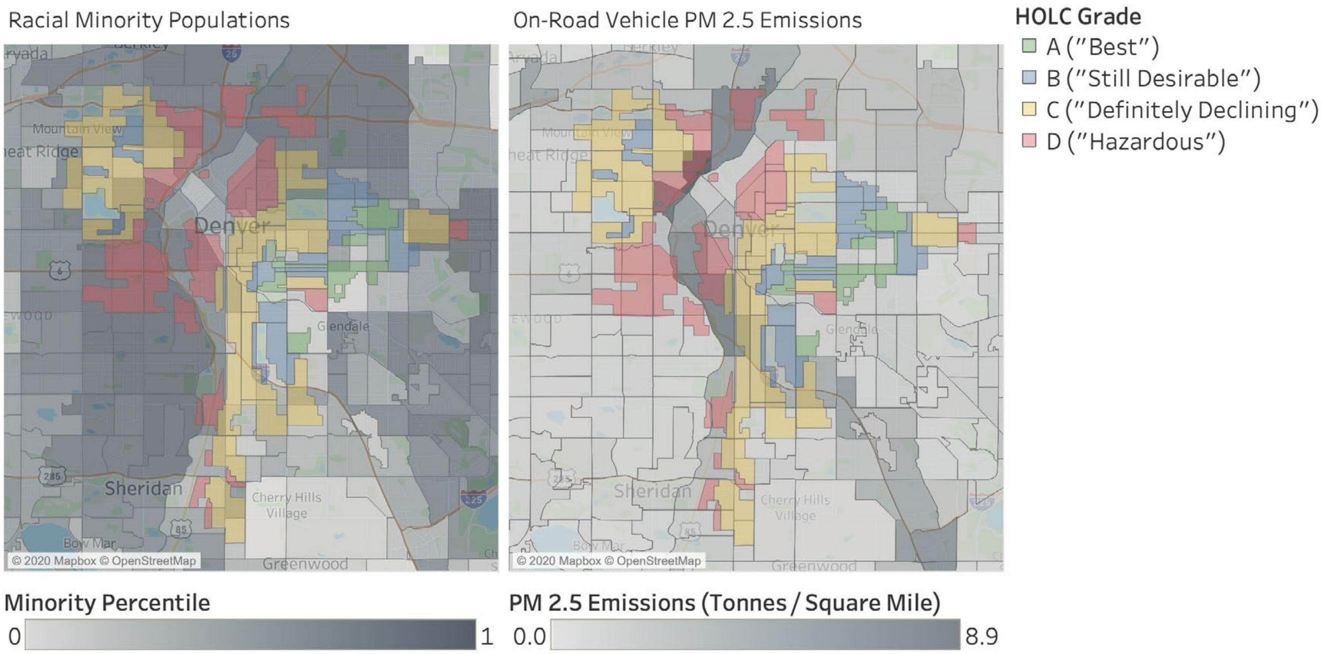


FIGURE 42. Historically redlined districts in Denver overlaying racial minority populations (left) and 2017 $PM_{2.5}$ emissions density from on-road vehicles (right). Red and yellow areas on the map correspond to districts assigned a "D" or "C" rating ("hazardous" or "definitely declining", respectively) by the government-sponsored Home Owners' Loan Corporation (HOLC) in the 1930s. Typically assigned to districts with high population fractions of people of color, "D" and "C" ratings prevented households in these areas from receiving federal home loans. Historically redlined neighborhoods in the map above are bisected by Interstate 25, which contribute to their comparably high $PM_{2.5}$ emissions density.



2.6.2 Cumulative Cross-Sector Emissions

Cumulative emissions across sectors can contribute to both regional air pollution—such as high ozone levels across Denver—and localized pollution hotspots. **Figure 4** illustrates cumulative NO_x emissions across the state, which are most highly concentrated in Colorado's ozone nonattainment area. Decarbonization, as we have seen, can help eliminate some emissions, but may not do so evenly. Most of the decarbonization scenarios—with the exception of Slow Coal Retirement—eliminate the majority of power sector emissions by 2030. Fossil fuel combustion in residential and commercial buildings is of particular concern in terms of indoor air pollution, but the highest emissions from buildings are related to wood burning, particularly in rural areas, and are less likely to be major contributors to cumulative cross-sector emissions. Instead, the two sectors likely to have the highest combined emissions in many locations in the coming years are transportation and industry.

In **Figure 41**, we show combined transportation and industrial sources in the Denver area. These maps illustrate the likelihood of pollution hotspots in certain neighborhoods, such as near the Suncor refinery discussed in **Box 1**. Many of these neighborhoods are also home to low-income communities and communities of color. To reduce these high cumulative emissions, a number of targeted measures may be valuable.

The observed association between minority population fraction and emissions density in urban neighborhoods is geographically associated with historic and contemporary discriminatory land use and economic policies. Redlining, a racially discriminatory home lending policy implemented by the Federal government in the 1930s, is an example of one such policy.[112] In **Figure 42**, we show transportation $PM_{2.5}$ emissions density overlaid with historic districts that were redlined in downtown Denver. These areas overlap, in particular, along Interstate 25, consistent with findings that the National Interstate Highway System was disproportionately constructed through minority

112 University of Richmond. "Mapping Inequality." Retrieved Oct. 6, 2020 from https://dsl.richmond.edu/panorama/redlining/#loc=4/41.212/-93.12&text=intro

TABLE 4. Unique outcomes from each decarbonization scenario.

Scenario	Unique outcomes
Reference	• Energy demand is projected to increase with population growth across all sectors, along with greenhouse gas and health-damaging air pollutant emissions in most sectors. • Coal emissions decline only moderately as economics force some coal plant retirements.
Core	• Rapid greenhouse gas and criteria air pollutant emission reductions from the power sector, as well as sustained emission reductions in all other sectors. • Slight increase in residential criteria air pollutant emissions in some rural communities due to continued use of wood in home heating.
Slow Coal Retirement	• Significant persistent emissions from coal power plants through 2030, notably SO_2 • Slightly greater near-term criteria air pollutant reductions in other sectors. • Higher average residential energy bills.
Low Demand	• Greatest near-term criteria air pollutant emission reductions. • Increased access to public transit. • Greatest overall reduction in energy cost burdens. • Lowest overall utility energy bills. • Greatest overall reductions of particulate matter emissions from the transportation sector
Fossil Free	• Greatest long-term greenhouse gas and criteria air pollutant emission reductions. • Phase-out of oil and gas production; opportunity to eliminate all fossil fuel infrastructure and associated health hazards. • Higher average residential energy bills (though these bills do not include the social benefits associated with greater reductions in carbon dioxide and criteria air pollutants).

neighborhoods in various American cities.[113] In Denver, the use of eminent domain to expand Interstate 70, predominantly through communities of color, has been met with legal resistance from community activists and environmental groups in recent years.[114]

A recent study found that redlined Denver neighborhoods are nearly 5˚F warmer than the rest of the city on summer days, due in part to lack of greentree cover such as trees and other vegetation, which helps mitigate the urban heat island effect.[115,116] Green cover, green spaces, and trees can also play a valuable role in removing pollutants such as ozone and particulate matter from urban environments,[117] and have been associated with improved mental and physical health outcomes. Unfortunately, there is a lack of high-density air monitoring to capture neighborhood-to-neighborhood variations in atmospheric pollutant concentrations. Redlined areas may benefit from a set of cross-sectoral intervention policies, from tree planting to the re-routing of heavy-duty trucks away from this area. High-density air monitoring at the community level could also help guide and evaluate the effectiveness of such policies.

2.6.3 Comparing Decarbonization Pathways

Along with clear climate benefits, all statewide decarbonization strategies explored in this report yield some similar air quality and human health co-benefits, such as overall reductions in criteria pollutant emissions. These findings are outlined in each section above. However, the underlying strategies in each decarbonization scenario also lead to certain unique outcomes. In **Table 4**, we summarize some of the unique impacts and benefits of each decarbonization pathway.

The trade-offs between scenarios tend to fall into two main categories: (1) impacts on bills and energy cost burdens, and (2) impacts on type and location of pollutant emission reductions. Three key decisions emerge:

How quickly is coal retired? In 2030, the largest impact on overall emissions is whether coal is largely retired or stays online, as it does in the Slow Coal Retirement scenario. Outside of the industrial sector, most scenarios eliminate most SO_2 emissions by 2030. The Slow Coal Retirement scenario accelerates transitions in the buildings and transportation sectors in order to achieve 2030 economy-wide climate targets, but additional emission reductions of NO_x and primary $PM_{2.5}$ are entirely offset by the greater amount of remaining coal power emissions. We have limited information on whether pollutants from the industrial sector are from fossil fuels, but even if we assume they all are fossil fuel-related and affected by accelerated decarbonization measures, these do not offset the coal left online.

Does oil and gas production decline by 2030 and cease by 2050? In contrast to the other scenarios, the Fossil Free scenario assumes all fossil fuel production is eliminated by 2050. While retired fossil fuel infrastructure will require maintenance, inspections, and remediation, this is the only scenario in which populations living near oil and gas production and infrastructure have the opportunity to nearly eliminate their risks of exposure to associated health-damaging criteria air pollutants, non-methane VOCs, and hazardous air pollutants. This scenario also requires greater investments in renewable energy facilities and other technologies (e.g., electric hydrogen and synthetic fuels) to ensure that fossil fuels can be fully replaced.

Are broad efforts taken to reduce energy demand? The Low Demand scenario has the greatest emissions reductions by 2030 and lowest utility bills, as well as increasing public transit and active transit options, which can particularly benefit low-income households and increase public health co-benefits. However, this scenario hinges on widespread efforts to increase building efficiency and build out public transportation. These actions require multi-agency coordination, significant municipal planning with community feedback mechanisms, and sufficient up-front capital expenditures, but yield longer term economic and environmental health benefits.

113 Karas, David. Highway to Inequity: The Disparate Impact of the Interstate Highway System on Poor and Minority Communities in American Cities." *New Visions for Public Affairs* 7.April (2015): 9-21.

114 Murray, Jon. Two New Lawsuits Challenge I-70 Project Ahead of Legal Deadline. *The Denver Post*. July 11 2017.

115 Plumer, Brad and Nadja Popvich. How Decades of Racist Housing Policy Left Neighborhoods Sweltering. *The New York Times*, Aug. 24, 2020.

116 Gage, Edward A., and David J. Cooper. Relationships Between Landscape Pattern Metrics, Vertical Structure and Surface Urban Heat Island Formation in a Colorado Suburb. *Urban Ecosystems* 20.6 (2017): 1229-1238.

117 Nowak, David J., Daniel E. Crane, and Jack C. Stevens. Air Pollution Removal by Urban Trees and Shrubs in the United States. *Urban Forestry & Urban Greening* 4.3-4 (2006): 115-123.

3 Policy Discussion

Our analysis highlights the need to integrate health, environment, and energy equity considerations into Colorado's deep decarbonization planning. A wide portfolio of policy options is available to support such a combined approach to achieving climate and energy equity goals. Below, we first review existing equity-focused climate and energy policies in Colorado. We then discuss the policy implications of our analysis for each sector. Finally, we describe additional data collection and research needs that can enable the state to create data-driven energy equity policies and measure their effectiveness moving forward.[118]

3.1 Energy and Environmental Equity Policy: Review of the Landscape

Below, we briefly review several of Colorado's existing policies to elucidate the broader landscape for policies at the intersection of public health, climate justice, and energy equity. This review yields some initiatives that aim to address inequities across multiple sectors, with a variety of approaches. The state is beginning to incorporate measures that reduce burdens to disproportionately impacted communities into its policies, but the enforcement components of these policies are limited. For instance, a number of bills introduced in 2019 and 2020 incorporated more explicit community-participatory language, but much of this language was eliminated in final form.

3.1.1 Existing Environmental Equity Policies

Existing environmental public health policies in Colorado may include broad advisory committees, but are limited in their integration of social equity and justice. For example, in 2019, SB-181,[119] the Oil and Gas Conservation Act, prioritized public health and environment by (1) removing cost considerations and technical feasibility for oil and gas operations approval and (2) reorganizing commission committee membership to require at least five of the nine members be from expertise fields of environmental protection, wildlife protection, soil conservation or reclamation, agricultural production, or public health. The presumed benefits of requiring oil and gas operations to seek approval from a commission with broader focus is a step in the right direction, but may greatly benefit from community member participation and consideration of social equity, which is not directly taken into account.

Taking one step further, HB 19-1261[120] defines the state greenhouse gas reduction target of 90 percent of 2005 levels by 2050, and requires the Air Quality Control Commission to identify and consider input from "disproportionately impacted communities." These communities are identified by the Commission, and will consider "minority, low-income, tribal, or indigenous populations...that potentially experience disproportionate environmental harms and risks... and socio-economic stressors…[which] may act cumulatively...and contribute to persistent environmental health disparities." HB 19-1261 requires the Air Quality Control Commission to develop measures to meet the statewide goals by considering the importance of "equitably distribut[ing] the benefits of compliance" and the "opportunities to incentivize renewable energy resources and pollution abatement opportunities in disproportionately impacted communities." The statute also requires the Commission to "provide for ongoing tracking of emission sources that adversely affect disproportionately impacted communities" and the rules to meet the statewide goals "must include strategies designed to achieve reductions in harmful air pollution affecting those communities." However, there is no requirement to evaluate the impact of greenhouse gas targets on energy equity or environmental equity, nor are there any measurable and enforceable energy equity outcomes or required community input mechanisms the Commission must follow. Community involvement may still be limited,

118 The State of Colorado has numerous policies related to environmental public health, but here we focus specifically on the intersection with energy equity and climate justice.

119 Colorado General Assembly. Senate Bill 19-181 (2019). Last accessed Oct. 2020

120 Colorado General Assembly. House Bill 19-1261 (2019). Last accessed Oct. 2020.

as the Commission maintains discretion as to how those "disproportionately impacted" communities are decided, and who from those communities is able to participate, leaving open room for more equitable participation mechanisms to be adopted by the Commission.

In 2020, two more bills were passed by the House that had the potential to be environmental- and social-equity focused: Environmental Justice and Projects Increase Environmental Fines, 2020 HB-1143,[121] and Increase Public Protection Air Toxics Emissions, 2020 HB-1265.[122] The introduced HB-1143 would use an increase in air and water permitting fees to further environmental justice (EJ) by (1) allocating the increased fines to a new "community impact cash fund" for environmental mitigation projects; (2) creating an EJ ombudsperson position; and (3) creating an EJ Advisory Board with required community representation. Despite the bill's provisions at the time of its introduction, the law that passed completely omits all of the EJ-related efforts and purpose.

Similarly, HB-1265 as originally introduced would have created a new emissions program for four toxins (hydrogen cyanide, hydrogen fluoride, hydrogen sulfide, and benzene) which would have included measures to identify "disproportionately impacted communities," allow permitting based on limiting cumulative burdens for those identified as disproportionately impacted communities, and require public notice and creation of an emergency notification system for local communities with consideration for local, popular languages, among other public health-specific requirements. The final Act only created a program focused on three toxins, omitting hydrogen fluoride, and created an emergency notification system; all other provisions were omitted.

3.1.2 Existing Energy Equity Policies

The State of Colorado has a number of initiatives currently directed towards energy-improvement measures for low-income households, in part on behalf of federal programs. Federal policies direct states to implement financial assistance programs to help meet the basic energy needs of low-income populations. The US Department of Energy's financially subsidized Weatherization Assistance Program, which supports both homeowners and renters,[123] has been in operation in Colorado for 40 years and is administered by the Colorado Energy Office (CEO). Similarly, the US Department of Health and Human Services directs states to administer the Low-Income Home Energy Assistance Program (LIHEAP) to help in part with residential utility bill affordability, and the Colorado Department of Human Services provides this program to Colorado residents with incomes up to 60 percent of the state's median annual income.[124] Additionally, the CEO offers a renewable energy access program focused on community and rooftop solar, reducing household energy cost burden while making renewable energy more affordable to low-income households and accessible for those who cannot put solar on their rooftops.[125,126]

The technical findings of our report highlight the need for social, economic, and environmental realities to be considered when making energy policy decisions, and several of our energy equity-focused recommendations overlap with the introduced texts of HB-1143 and HB-1265. However, with the 2020 legislative session limited due to the COVID-19 pandemic and other setbacks, policy bills that required fiscal notes unrelated to the pandemic were not successful. The introduced texts for HB-1143 and HB-1265 showcase that the legislature is receptive to these equity considerations; and our findings may be used to further guide those discussions.

3.2 Key Themes and Policy Implications by Sector

Our environmental, public health, and energy equity findings across economic sectors reveal multiple opportunities for deep decarbonization in Colorado to simultaneously address environmental socioeconomic and racial disparities. Building upon these key themes, we use our findings to inform and shape our policy recommendations through an energy and environmental

121 Colorado General Assembly. House Bill 20-1143 (2020).
122 Colorado General Assembly. House Bill 20-1265 (2020).
123 Colorado Energy Office. "Weatherization Assistance Program." Available at: https://energyoffice.colorado.gov/weatherization-assistance-program
124 Colorado Department of Human Services. Low-income Energy Assistance Program. Last accessed Oct. 2020.
125 Colorado Energy Office. Insights from the Colorado Energy Office Low-Income Community Solar Demonstration Project (2018).
126 Colorado Energy Office. Community Solar. Last accessed Oct. 2020.

equity lens, by sector and cross-sector below. We do not address the full scope of potential climate policies here, nor impacts—positive and negative—on the energy workforce, and instead focus on energy equity- and health-related climate policies.

Through all sectors evaluated in this study, a recurring and vital theme emerged that warrants direct action in every decision towards any deep decarbonization plan, and that is the full engagement (i.e. representative and enforceable decision-making power) of the local and impacted community. Current legislative and regulatory processes could improve stakeholder participation through genuine, meaningful community engagement and participation, including but not limited to outreach during the design and planning stages of policy development, and community feedback mechanisms that directly impact how further programmatic decisions are made and implementation is pursued. Improvement to community engagement should include:

1. Outreach to local residents and businesses near sources of high pollutant emissions, including (a) transportation hubs with high pollution rates, such as interstate corridors and bus yards, (b) oil and gas production and processing facilities, and (c) other industrial point source pollution emitters;
2. The provision of educational materials in local languages that explain the benefits of electrification and decarbonization for all Coloradans;
3. Increased opportunities for binding community feedback as decarbonization efforts are developed, particularly in moderate- to low-income neighborhoods and communities of color; and
4. Community involvement in the ownership of decision-making processes through working groups or committees focused on how decarbonization efforts are rolled out, which communities should be prioritized, and how the benefits and costs of decarbonization should be allocated.[127]

3.2.1 Electricity Generation

Our power sector analysis yields three key findings from a climate and environmental health and equity perspective: the need to rapidly retire coal generation; the importance of policy mechanisms to ensure remaining gas plants are phased out responsibly without adding undue burden to pollution-overburdened vulnerable communities; and the value of ensuring that renewable energy adoption more equitably benefits communities across socioeconomic strata. New policy initiatives should prioritize communities that are already disproportionately burdened by environmental pollution and health and socioeconomic inequities. Below, we provide the key policy recommendations that have emerged from the technical findings and conclusions in this report.

Recommendation 1. Prioritize rapid coal retirement in decarbonization plans.

Rapidly retiring coal plants has the greatest potential to reduce criteria air pollutants, particularly SO_2, as compared to any other decarbonization strategy. In the Slow Coal Retirement scenario, the pollutant emissions reductions achieved through electrification and energy efficiency gains in other sectors do not offset the total criteria air pollutants from leaving coal generation online.[128] Currently, a number of the state's coal plants have firm retirement dates between 2022 and 2030. However, three facilities—all owned by Xcel—are still expected to have some or all units running after 2030 unless additional policies are set. Potential policy levers to accelerate coal retirement include very high renewable portfolio standards (over 90 percent) and standards limiting criteria air pollutant emissions from the power sector (e.g. maximum allowable NO_x or SO_2 per MWh generated). It is also worth noting that Colorado does not currently include imported electricity in its greenhouse gas footprint calculations, but imported electricity from coal plants in neighboring states still has health impacts in Colorado (and on communities in other states). Including the carbon footprint of imported electricity in the state's greenhouse gas targets will not only limit carbon leakage in the power sector but also reduce demand for these polluting facilities outside the state.

127 These considerations also include workforce development, such as job retraining for workers in the fossil fuel industry, which will be addressed in a forthcoming partner report.

128 It is possible that rapid decarbonization of transportation instead of coal, for example, might help reduce local transit pollution hotspots, but such benefits can be achieved through other mechanisms. Colorado's coal plants are typically located in rural areas but their health impacts can extend across many states.

Recommendation 2: Ensure that power plants left online for reliability are not disproportionately those in socioeconomically disadvantaged communities with high cumulative environmental burdens.

Colorado's power plants are disproportionately located in low-income communities and communities of color and many are within the urban Denver area in an ozone nonattainment region. In the Core scenario some natural gas plants will remain online for reliability for decades, a strategy which risks leaving facilities operational in urban areas with high concentrations of populations of color and low-income residents. While rapid renewable energy adoption, coupled with energy efficiency measures, will reduce the vast majority of power sector air pollution, these plants still run a risk of continuing to operate to meet peak demand on hot summer days when ozone concentrations are already elevated.

As an alternative, Colorado can prioritize replacing these plants by incentivizing energy storage and other clean alternatives to meet local reliability and peak demand needs in urban load pockets. Even in the Fossil Free scenario, these plants may burn biogas in lieu of natural gas, and similar precautions must be taken to limit criteria air pollutant emissions from these facilities. To address these risks, agencies with jurisdiction could limit the annual capacity factor or limit the annual and/or seasonal mass of criteria air pollutants allowed to be emitted, as these facilities are operationally phased out. In addition, infrequent use or retirement of these facilities poses a risk they will become stranded assets abandoned by their owners, which could pose environmental and health hazards to nearby communities, with uncertainty regarding who will bear the financial costs of decommissioning and remediating these sites. Once retired, facility dismantling and soil and water remediation should be funded by the utility companies with oversight by the government, and not left to the local communities. Additionally, local communities should be consulted on how and when to dismantle the facilities in order to minimize personal and work disruption.

Recommendation 3: Ensure equitable economic benefits from utility-scale and distributed renewable energy and efficiency adoption.

In addition to pollution reduction, renewable energy growth can provide benefits in the form of tax revenues and job creation. Furthermore, distributed energy resources such as rooftop solar and efficiency can contribute to resilience and economic benefits, which we discuss in the residential buildings section below. On the utility and community scale, the State of Colorado should work with marginalized communities to develop strategies to build new renewable generation technologies to provide tax revenue and workforce development opportunities.[129] Community-owned, investor-owned, government-owned, and individually-owned assets all inherently benefit different communities, which may or may not financially benefit the local community the technology is sited in, suggesting the need for multiple ownership and funding mechanisms for renewable generation with preference towards an ownership mix. These considerations should play a role in the state's considerations for renewable energy financing and incentives.

Additional community feedback

The equity discussions we held with community organizations highlighted the need for more formal mechanisms for community input into utility programs and decision-making to facilitate electrification. One example of communities pushing for more input in electricity decisions is the relationship between the local government, community organizations, and the utility in Pueblo. In 2018, Pueblo City Council voted to review exiting its contract with investor-owned Pueblo Black Hills Energy due to numerous rate hikes—such as rooftop solar residential surcharges, demand charges to small businesses, and four rate increases for all residential customers—and widespread disconnections and instability in rates. Rate increases and high utility bills can discourage households from adopting electrification measures, so allowing community input for rate stabilization mechanisms and other efforts may be helpful.

A new, additional city council or Public Utilities Commission-sponsored community-committee composed of residential and small business customers of Black Hills would provide a more equitable voice

129 Workforce development is beyond the scope of this report but will be forthcoming in a companion report in 2021.

to contract renewal negotiations and any potential new electricity provider. The community committee should have authority for binding commitments for accountability; there is currently no community committee that Black Hills reports to.[130] An alternative approach to a Black Hills-specific community committee is converting to an electricity model that encourages community input through a non-profit, elected board. Proposition 2A in 2020 would have created a Public Power non-profit, established by Pueblo Board of Water Works (an elected, independent, local governmental entity), to provide power and purchase it through the wholesale market.[131] It was voted down by voters after Black Hills sponsored nearly $1.5 million in ads against the City Council and Board of Water Works.[132, 133] The revival of this proposition, or a similar one, would be useful to provide more community involvement and ownership, which in turn may lead to rate stabilization and expanded electrification adoption.

3.2.2 Transportation

To increase adoption of electric vehicles and expand their health and economic benefits to all populations, policies should be aimed at alleviating barriers to access for underserved communities, largely through expanding community engagement and financing mechanisms. Community input should guide the prioritization of alternative modes of personal transportation, such as public transit, biking or walking, and carpooling as well as electric vehicle charging infrastructure investments. Additional investments in community infrastructure measures that reduce vehicle demand by supporting active transportation options, such as biking or walking, could also help to reduce pollution burdens in urban areas—and improve public health through increased physical activity. Achieving equity and public health benefits across the transportation sector also requires a suite of approaches that address existing pollution—including from heavy-duty vehicles—in addition to providing electric vehicle financing for moderate- and lower-income passenger car and truck owners and supporting the expansion of public transit.

Recommendation 1: Design financial incentives to support low-income adoption of electric passenger vehicles, such as upfront financing, point-of-sale rebates, low-interest loans, and rebates for trading out inefficient vehicles. Incorporate community input to guide electric vehicle charging infrastructure investments which can facilitate electric vehicle adoption among households facing access barriers.

Currently, electric vehicles are disproportionately purchased by higher-income Coloradans. Additionally, a study focused on the California electric vehicle buyers market shows that electric vehicles are disproportionately purchased by non-Hispanic White populations, even when adjusted for income, which may hold true in Colorado as well.[134] Existing incentives, such as tax credits or post-purchase rebates for electric vehicle adoption, benefit those with higher income tax burdens, and do not help alleviate the upfront socioeconomic barriers to vehicle electrification for communities of color or moderate- to lower-income Coloradans. Upfront financing and subsidies for moderate- to lower-income communities are needed to ensure that electrification is more accessible to these populations. Additional financing measures can include point-of-sale rebates, low-interest loans for low- and moderate-income customers to purchase efficienct vehicles, and additional rebates for trading in inefficient older vehicles for cleaner models. It may also be valuable to facilitate the secondary market for electric vehicles. In addition, as vehicles are electrified, the accompanying public charging infrastructure will need to maintain pace, and current access to this infrastructure is limited. Publicly funded charging infrastructure may be particularly valuable in highly polluted communities, rural areas, and dense, urban areas with multifamily buildings to ensure these regions do not lag behind in adoption.

130 Jaffe, Mark. Pueblo and Black Hills Energy Square Off in an Electric War. *The Gazette* (2020).
131 Bring Power Home 2020. Why Vote FOR Proposition 2A (2020).
132 Election Summary Report: Pueblo General Election May 5, 2020 (2020).
133 Beedie, Dan. Pueblo Votes to Keep Black Hills Energy by a Landslide. *KRDO* (2020).
134 Muehlegger, Erich and David Rapson. Understanding the Distributional Impacts of Vehicle Policy: Who Buys New and Used Alternative Vehicles? *National Center for Sustainable Transportation Research Report* (2018).

Recommendation 2: Accelerate medium- and heavy-duty truck electrification and emission reductions by (1) prioritizing the retirement of old medium-duty and heavy-duty trucks (2) providing sufficient financial incentives for small businesses to convert their trucks, (3) rerouting trucks away from dense, urban areas with high cumulative environmental burdens, (4) limiting truck idling, and (5) creating enforceable in-state targets to support interstate trucking electrification goals.

Within the decarbonization modeling scenarios, passenger vehicles are electrified at a faster rate than trucks. Policies are needed to help accelerate the electrification of trucks, most of which are medium-duty and heavy-duty vehicles and trailers, and responsible for a disproportionate fraction of the sector's NO_x and $PM_{2.5}$ emissions. Multi-state initiatives with enforceable in-state targets are key to the facilitation of truck electrification in particular, due to high interstate truck traffic. These initiatives can help reduce pollution along interstate highway corridors. In June 2020, Colorado and 14 other states signed onto a joint Memorandum of Understanding (MOU) which aims to ensure all new medium- and heavy-duty vehicles, such as delivery trucks, buses (school and transit), and other commercial vehicles, are zero-emission by 2050.[135, 136] While this MOU is a first step, neither the 2050 target nor the intermediary 2030 target—that 30 percent of new sales of medium- and heavy-duty vehicles be zero emission—are binding. More aggressive policies, such as California's Advanced Clean Trucks rules, which requires truck manufacturers to produce and make available for sale zero-emission vehicles,[137] may be required to ensure emission reductions are achieved in the near term. As noted in the MOU, strategic deployment of vehicle charging infrastructure, especially along urban interstate corridors, as well as beneficial vehicle charging rate design are needed to facilitate electric vehicle adoption within the trucking industry.

While large fleet owners and operators may be able to absorb the costs of converting their fossil-fueled fleets into electric vehicles, smaller fleets and independent truckers may not be able to do so without additional financial support. Small owner/operator truckers are typically micro enterprises owned or leased by a single person, and access to capital to improve or buy new equipment or vehicles is severely limited. Any effort to electrify the trucking industry will need to incorporate upfront financing mechanisms for these small and micro enterprises. In the decarbonization scenarios, those small and independent fleets that continue to operate non-electrified trucks will be further financially disadvantaged because they will be required to purchase more expensive zero-carbon fuels to meet the 2050 climate goals, unless policy intervention is implemented.

Other efforts to mitigate truck pollution, such as rerouting trucks to less populated areas or limiting idling and wait times in weighing or check-in stations and in residential neighborhoods, could reduce air pollution and be more immediately implemented. Additional measures that replace aging and inefficient trucks should also be considered to address legacy environmental and sociodemographic disparities. However, further investigation is needed to ensure that these measures do not unduly burden small trucking owner/operator or fail to benefit communities with disproportionately high cumulative pollution.

The placement of new charging stations must consider where current and future trucking routes and pollution are located. New infrastructure should not financially overburden those communities already dealing with these existing environmental and socioeconomic disparities, but should instead provide economic incentives to those communities to electrify through local infrastructure ownership, job creation, and revenue generation. This infrastructure build-out needs to be coupled with the safe retirement of fossil fueling stations through government- and fossil fuel company-financed dismantling and soil and water remediation programs.

135 Multi-State Medium- and Heavy-Duty Zero Emissions Vehicle Memorandum of Understanding, June 2020.

136 Northeast States for Coordinated Air Use Management. 15 States and the District of Columbia Join Forces to Accelerate Bus and Truck Electrification. ledge to Develop Action Plan to Eradicate Toxic Diesel Emissions by 2050, July 2020.

137 California Air Resources Board. Advanced Clean Trucks. Last accessed Oct. 2020.

Recommendation 3: Coordinate efforts by local, regional, and state governments—with outreach to local communities—to expand electrified public transit, where appropriate, to reduce overall vehicle travel while improving transit access for mobility-limited households.

Public transit build-out, where appropriate, is a core component of the Low Demand decarbonization scenario, which yields the greatest emission reductions and lowest net cost. In addition to providing these community-wide benefits, affordable and electric public transportation will benefit several populations, including low-income households, that lag in electric vehicle adoption and have the lowest access to any kind of vehicle. Current fossil fuel-reliant public transportation could be phased out and replaced with electric school and transit buses, prioritizing aging fleets and those operating along polluted routes.

Expanded public transit infrastructure, such as mass transit trains or high-speed buses, could help alleviate congestion and pollution burdens in urban areas and increase transit access in underserved communities. However, investments should be informed by community feedback, and should include community-driven solutions for public transit implementation, with accessibility and affordability expanded, while limiting the impacts of displacement and gentrification. A potential initiative Colorado may consider adopting is the Innovative Clean Transit rule from California, which supports transitioning all public buses to zero-emission technology.[138] Additional city planning to support active transit options such as biking or walking can yield additional individual and public health benefits. Many of these efforts will require coordination between state, regional, and local government agencies.

3.2.3 Residential Buildings

Our findings for the residential sector indicate that air pollution from buildings—notably particulate matter and NO_x—is not distributed evenly across the state and can vary dramatically by fuel type and community, including significant contributions from wood in rural areas. In addition, low-income and other socioeconomically vulnerable communities lag, including communities of color, in access to clean energy technologies,[139, 140] leading to the disproportionate distribution of clean energy benefits (e.g. bill savings and reduction of indoor air pollution) away from these communities. Meanwhile, residential energy cost burdens tend to be highest for low-income households, even though carbon footprints tend to be largest for higher-income households. Thus, policies aimed solely at reducing greenhouse gas emissions may not, by themselves, alleviate residential energy cost burdens for Colorado's underserved populations nor reduce building pollutant emissions, particularly from wood fuel. Complementary policies will be needed to ensure that low-income households, communities of color, and rural populations have access to, and benefit equitably from, clean energy technologies.

Recommendation 1: Ensure equitable access to the economic and health benefits of energy efficiency, distributed energy resources, and electrification.

Targeted incentives, financing, and outreach can help reduce barriers to clean energy adoption for underserved households, including those who struggle with high energy cost burdens. Building electrification, which is a core component of building decarbonization, should be combined with (1) easily accessible funding mechanisms for financially disadvantaged communities, including upfront financing, (2) building efficiency measures to reduce overall energy demand, (3) educational outreach to local communities regarding the benefits of electrification, distributed energy resources, and efficiency, and to address any personal or cultural barriers for adoption of clean energy technologies, and (4) further evaluation of the social barriers that low-income communities and communities of color face to adopting these measures. Community feedback can be delivered in numerous forms, including but not limited to forums and workshops, committees for program and project approval, and in advisory capacities throughout program development and implementation. Some initial populations to target may include (1) homes that use alternative fuels such as propane, wood, and fuel oil, (2) those without access to electricity, particularly in rural or

138 California Air Resources Board. Innovative Clean Transit Regulation Fact sheet. Last accessed Oct. 2020.

139 Lukanov, Boris R., and Elena M. Krieger. Distributed Solar and Environmental Justice: Exploring the Demographic and Socio-Economic Trends of Residential PV Adoption in California. Energy Policy 134 (2019): 110935.

140 Sunter, Deborah, Sergio Castellanos, Daniel Kammen. Disparities in Rooftop Photovoltaics Deployment in the United States by Race and Ethnicity. *Nature Sustainability* 2.1 (2019): 71-76.

tribal nation areas, and (3) communities that face higher energy costs due to inefficient electric equipment in drafty or poorly insulated buildings.

To ensure wide participation of households facing multiple market barriers, additional market-oriented mechanisms could be implemented, such as allowing third-party energy service companies to contract with homeowners to take over the costs of their energy bills and guarantee a flat rate for a specified period of time. Third-party participants can thus minimize the upfront costs of efficiency and electrification measures to homeowners while utilizing the benefits of energy savings for the specified time period. In this approach, policy provisions will be needed to protect household interests by mandating rate-stabilizing contracts with the third-party energy service companies during the electrification upgrade payback period, and by providing additional incentives to encourage deep building retrofits and full electrification.

As building efficiency and electrification measures are widely adopted, community engagement should inform the balance between creating financial incentives for private residential property owners to make upgrades and securing housing affordability and stability for tenants. At a minimum, decarbonization policies should be paired with affordable-rent and anti-displacement provisions. Publicly-funded mechanisms, such as grants to landlords of single-family homes, small multi-family properties, and other small businesses should be available to alleviate the need to increase tenant rents while providing capital for the upgrades without undue burden on the landlords. It is important to protect both tenants and small landlords from bearing more than their share of the work to transition to a clean energy economy.

Recommendation 2: Prioritize early electrification of buildings using propane and wood to reduce energy cost burdens and improve health outcomes in rural areas.

Although wood and propane fuels are infrequently used in homes compared to electricity and natural gas, both provide good targets for near-term electrification. Propane is comparatively expensive, and wood is responsible for a large fraction of Colorado's residential criteria air pollutant emissions but is not replaced in carbon-focused decarbonization scenarios. Specifically targeting buildings that burn propane and wood can help reduce high energy cost burdens associated with propane use, and improve ambient and indoor air quality in the case of both propane and wood, leading to potentially better health outcomes in the rural areas where these fuels are more commonly used. While electrification of wood heating is not always the most cost-effective option given the low cost of wood, consideration should be given to strategies for replacing aging conventional and EPA-certified wood stoves with pellet stoves, which have significantly lower particulate matter and VOC emission rates. If energy efficiency and weatherization measures are implemented in buildings with high indoor emissions, proper air ventilation systems should be required to improve indoor air quality, since efficiency measures may limit outdoor and indoor air exchanges and increase indoor air quality risks.

Recommendation 3: Plan for a gradual and geographically targeted phase-out of the natural gas distribution system, with targeted rate-stabilization for non- or late- electrification adopters.

As demonstrated in **Figure 27**, those households which are unable to participate in the adoption of clean energy technologies risk facing escalating utility bills to cover the costs of an aging gas distribution system in transition. As electrification progresses, it may be valuable to strategically target the legacy fossil fuel infrastructure phase-out from one region to the next (i.e. pruning legacy infrastructure) and balance utility bill rates throughout the state. This approach will avoid service disruptions, eliminate long-term maintenance costs, and minimize expensive retrofits and upgrades during the transition. It also provides the additional benefit of removing safety hazards associated with aging natural gas distribution infrastructure. Our findings further underscore the importance of policy interventions that provide bill protections and make clean energy technologies accessible to households with high baseline energy cost burdens during this transition. An equitable approach would require that non-adopters are not left behind shouldering the full cost of stranded assets, and that economically vulnerable and underserved communities are among the first to transition off of the soon-to-be-retired fossil fuel system.

Decarbonization policies that do not further equity through income and racial considerations risk exacerbating existing inequities by accumulating the benefits of electrification and energy efficiency to higher income, and Whiter, households. Policies targeted at reducing indoor air pollution, reducing energy cost burdens, and increasing resilience should be balanced with community empowerment and give historically underserved communities control over their energy sources and end-uses.

Recommendation 4: Consider focused deployment strategies for distributed energy resources to maximize public health and climate resilience benefits, including an expansion of residential solar and storage systems.

Clean energy deployment in certain population subsets can be particularly beneficial for reducing energy cost and pollution burdens, and improving climate resilience. Policymakers should therefore consider climate resilience, reduced energy bills, and improved health outcome co-benefits when weighing the deployment of distributed energy resources such as solar, storage, microgrids, community solar, and energy efficiency measures as compared to utility-scale projects.

Rural households, customers who rely on electricity for medical needs, low-income households or households of color in areas with high wildfire risk or a high number of extreme heat days, may face trade-offs between affording their electric bills and risking climate-related health complications or potentially life-threatening power shut offs during natural disaster events (e.g. wildfires). Such households would particularly benefit from the resilience and reliability of home solar + storage systems or from improved access to affordable air conditioning and air filtration systems. Our calculations in **Table 3** show that the electricity needs of all medical baseline customers in heat-vulnerable counties could be covered by 2030 if 25 percent of all rooftop solar installations were allocated to these medical baseline customers. Similarly, the electricity needs of all low-income rural households could be covered by 2030 if 25 percent of all rooftop solar installations were in these households. Solar + storage and microgrids at community sites such as schools, community centers, cooling centers, and clinics, can also provide resilience hubs where community members can access air conditioning and ventilation, refrigerate medicines, charge cell phones, and otherwise gather in emergencies.

Current incentive structures may have to be amended to reflect future household needs related to climate impacts. As a hypothetical example, replacing an existing natural gas heating system with an air source heat pump might not meet existing incentive cost-effectiveness requirements, but if a household needs to add air conditioning as the summers grow increasingly hot, an air source heat pump might be significantly more cost effective than replacing both an existing heating system and adding a new HVAC system. Similarly, a solar + storage system might be more expensive than the existing grid supply of electricity, but less expensive if a customer is considering the alternative of adding a diesel generator for backup. Current incentive structures and cost-effectiveness provisions may have to be updated to reflect combined decarbonization and climate resilience goals.

Electricity access is not equitably distributed throughout the state, with tribal and rural communities often having more restricted access to electricity. While data for tribal communities is limited for Colorado, consistent, reliable, and accessible energy is not typically ubiquitous in tribal nations in other states,[141] and there is likely a need for the clean energy transition to focus on and correct the historical shortcomings of the current energy infrastructure where it exists in Colorado for these populations. Distributed energy resources such as solar or wind power, coupled with resiliency-focused technologies like battery storage, can provide a powerful and reliable clean energy source for tribal nations and rural communities. Distributed energy resources, in addition to utility-scale and community-scale renewable generation, should be supported by publicly-funded financing mechanisms that tailor solutions for historically underserved and underrepresented communities to have full and reliable access to clean electricity.

Additional community feedback

Based on the discussions we held with community organizations, we also recommend support for electrification of mobile and non-stationary homes and buildings, allowing better utility cost stabilization. Currently, mobile homeowners pay park owners for their utilities in general, as separate metering is uncommon. Given the aging of mobile home parks (many were built or structured during the 1960s-1970s), many park landowners charge maintenance, retrofitting, and upgrade fees to homeowners to bring the homes to more current aesthetic and safety standards, creating a large potential expense for homeowners. Electrification efforts could be encouraged, with cost-sharing, by modification to the Mobile Home Park Act, or by a

141 US Department of Energy Office of Indian Energy Policy and Programs. Strengthening Tribal Communities, Sustaining Future Generations (2017).

committee of homeowners, generally through HOA arrangements. There is not currently a legal requirement for electrification or cost-sharing of utilities.[142] The Colorado Mobile Home Park Act[143] could be further updated and was revamped in HB 19-1309,[144] creating several mobile homeowner key points including: extending time to move or sell a home post-eviction and creating an adjudication process for complaints and dispute resolution. However, there is no climate or energy equity provision in HB 19-1309 as it relates to electrification or decarbonization of a manufactured, mobile home park.[145, 146]

3.2.4 Commercial Buildings

Unlike the residential sector, the commercial sector lacks granular spatial and emissions data and we were unable to conduct a detailed analysis of commercial buildings.

Recommendation 1: Emissions data must be collected and maintained.

City- and county-level emissions data must be collected and maintained by the government in order to analyze current emission level, and analyze best approaches to mitigating potential disparities in emissions. Currently this data is not readily available or easily accessible. We recommend: (1) electrification of commercial operations that utilize alternative fuels such as fuel oil, propane, or wood as a priority, (2) fuel-use emissions reporting requirements categorized by commercial use (e.g. retail, hotels, salons, etc.) and occupancy, and (3) fuel-use emissions reporting requirements based on building type (e.g. Class A, B, or C[147]) and location in accordance with a standards organization such as NAIOP[148] or CoStar.[149] Additionally, as commercial facilities are upgraded for energy efficiency, ventilation systems should also be upgraded to allow for higher quality indoor air, particularly when the space is used for cooking or other particulate-emitting processes.

Recommendation 2: Develop a detailed roadmap to electrify the commercial sector with broad stakeholder engagement.

As with all the other economic sectors, community input, feedback, and representation mechanisms must be considered when prioritizing electrification throughout the commercial sector. This must include commercial real estate stakeholders such as commercial building owners, building management and operators, building tenants (owners, employees, and contractors), and residents that live in or near mixed use commercial spaces. While commercial building tenants may want to electrify their operations based on consumer market preferences, they have limited-to-no control over the commercial building shell and building systems, limiting overall building efficiency and indoor air pollution control. Commercial building owners and investors must also be incentivized to prioritize these upgrades and efficiency measures. Regulatory requirements to increase appliance and building systems efficiency may act in tandem with market forces and financial incentives to upgrade to third-party environmental sustainability standards, such as those promoted through LEED certification.

3.2.5 Industrial Sector

The spatial resolution for industrial point source data is relatively high, but emission and operational data are somewhat limited. These limitations include incomplete data for distributed sources, such as oil and gas wells, and lack of attribution of criteria air pollutant emissions to specific fuel use at facilities, making it difficult to identify energy-specific industrial emissions. Due to these limited data, our recommendations are broad but are a starting point for decarbonization efforts, and we address oil and gas-related emissions independently in addition to industry as a whole.

142 2016 Colorado Revised Statutes §38.12.2 Mobile Home Park Act.

143 *ibid*

144 Colorado General Assembly. House Bill 19-1309 (2019).

145 *ibid*

146 Parked: Half the American Dream. The Colorado Sun (2019).

147 Commercial building classifications vary by organization and other external factors. In general Class A represents the highest grade or quality available, as compared to Class B, C, etc.

148 Originally founded as the National Association for Industrial and Office Parks, this trade and standards organization currently operates as the Commercial Real Estate Development Association. https://www.naiop.org/ Last accessed Oct. 2020.

149 CoStar. CoStar Building Rating System. Last accessed Oct. 2020.

Recommendation 1: Prioritize fuel switching and decarbonization in communities with high cumulative environmental burdens and sensitive populations.

The available emissions data suggest that on average, point source emissions are more heavily concentrated in areas with higher populations of color. Many of these communities also live in proximity to high density emissions from transportation. Industrial decarbonization efforts should therefore include incentives and financing for fuel switching to renewable hydrogen and electrification of industrial equipment and trucks serving these facilities, particularly in areas with high cumulative criteria pollutant emissions and near socioeconomically overburdened communities and sensitive populations. Community feedback mechanisms can help identify regions and facilities of concern to prioritize for fuel switching and other pollution reduction measures, and remediation funds should be set aside for retired facilities.

Recommendation 2: Implement increased setbacks between oil and gas development and places where people live, work, play and learn. Deploy best available emission control and monitoring technologies as soon as possible, and fully phase out in-state oil and gas production, extraction, and processing by 2050 at the latest.

The future trajectory of oil and gas production and processing in Colorado has one of the largest impacts on projected pollution burdens in 2050. While decarbonization across Colorado should eliminate the majority of existing fossil fuel emissions by 2050, ongoing oil and gas production—modeled at 25 percent of current 2020 levels in all but the Fossil Free scenario—will continue to pose health risks to workers and nearby communities. A decarbonization pathway which eliminates oil and gas production by 2050, if not before, would help greatly reduce these risks. In the coming decades, additional measures can help mitigate public health concerns.

First, population exposure to oil- and gas-associated air pollution and non-chemical stressors (e.g., noise and light pollution) can be reduced through the implementation of increased setback distance requirements where populations live, work, play, and learn.[150] Second, ongoing monitoring efforts for methane, VOCs, and other pollutants can help identify unintended emissions in order to quickly stop them.[151] Finally, additional financial reserves, such as bonding requirements put forward by oil and gas operators, should be required to ensure proper plugging and abandoning of oil and gas wells and other surface and subsurface infrastructure when they are no longer being used to avoid climate, health, and environmental damages.

3.2.6 Cross-Sectoral Themes

Our study reveals several cross-cutting themes across sectors and socioeconomic indicators, including cumulative energy cost burdens by income, cumulative emissions, and energy inaccessibility and financing hurdles.

Recommendation 1: Incentivize residential efficiency measures and electric vehicle adoption among households in underserved communities or with high combined energy cost burdens.

Total energy cost burdens—combining residential and transportation energy costs—generally increase as household income decreases, even though higher-income households tend to consume more energy. Socioeconomic status is therefore an important determinant of energy burden, and improved access to bill-reducing clean energy technology such as efficiency measures, community solar, and electric vehicles may help reduce low-income households' energy burdens.

The data most prominently indicate that low-income households should be targeted for clean energy adoption to maximize economic co-benefits; however, demographic predictors of energy burden may vary geographically (**Figure 37**). Additionally, resilience, equity, and public health may be improved by targeting populations vulnerable to natural disasters (e.g. linguistically isolated communities),

150 A rule on setback requirements is currently under consideration in Colorado but the preliminary version includes numerous exceptions which may increase population exposure to oil- and gas-associated health hazards.

151 Although water quality is outside the scope of this report, we note that it may be valuable for water quality testing and transparent reporting to be expanded to cover waste water from point source polluters, and require ground and surface water quality testing around, under, and near waste disposal sites.

historic barriers to reliable and clean energy access (e.g. tribal communities), and populations with high pollution burdens (e.g. communities of color). Policy initiatives such as rebates and subsidies for clean energy adoption, among others, may reduce existing sociodemographic and geographic barriers to access. Residential electricity rates may also have to be restructured to ensure that electrification efforts—both for appliances and vehicles—do not shift consumers into a higher-cost electricity tier and inadvertently cause a disproportionate increase in electricity bills.

Recommendation 2: Prioritize pollution reduction measures—such as electrification, fuel switching, and brownfield remediation—in communities facing high cumulative environmental burdens across sectors; increase environmental data collection efforts to help identify these hotspots.

Energy pollution burdens, shown in Figures 37 and 38, reflect how racialized policy practices and income inequality impact pollution burdens in communities of color and low-income populations. There are several ways to address these pollution burdens in a more equitable way. One measure is to better characterize pollution hotspots by increasing air quality monitoring in regions of concern, and conduct dispersion modeling of pollution reduction measures to identify high-impact emission reduction strategies. A second is to ensure facilities are regularly inspected and pollution emission standards enforced. A third is to prioritize, with community guidance, the replacement of remaining power generation (inclusive of small diesel generators) in these hotspot areas with energy storage and/or renewables. A fourth is to target cross-sector pollutant reduction measures such as electrification of heavy-duty equipment at industrial facilities, electrification of trucks doing short-distance trips in industrial areas, re-routing trucks away from more residential areas, anti-idling truck regulations, and build-out of electric vehicle charging infrastructure.

Additional cross-sector measures may include brownfield remediation and neighborhood greening efforts, such as tree planting. While our initial analysis suggests that many of these target hotspots are in the Denver area, it may be valuable to increase on-the-ground data collection near oil and gas fields to quantify pollution burden in these areas, which is presently poorly characterized, and to determine if additional vehicle, power, and equipment electrification efforts can reduce pollutant burdens in these areas.

Recommendation 3: Consider the distinct characteristics of rural and urban areas when designing decarbonization and energy equity policies.

Policies to address the clean energy transition must consider populations in both urban and rural areas. As our Demographic Index reveals, populations in both regions can have higher shares of traditionally marginalized communities (low-income, people of color, limited educational attainment, linguistically isolated, elderly, and very young populations). In urban cores, moderate- to lower-income households are more racially diverse and have disproportionately higher energy bills and emission burdens, further perpetuating the negative externalities from racially motivated redlining in housing (shown in **Figure 15**) and historic exclusionary practices in employment, education, and job training for minority groups.[152,153,154] We also find that many of these communities face high cumulative environmental burdens from existing fossil fuel infrastructure. Many of these emissions are related to heavy-duty transportation and industry, which are modeled to take longer to electrify than other sectors, suggesting that this pollution may persist in the near term.

Our findings reveal that rural and tribal communities also face multiple challenges, including the persistence of $PM_{2.5}$ pollution due to delayed trucking and equipment electrification, indoor air pollution from higher wood burning, persistent exposure to pollutants associated with oil and gas production, and higher risks of the compounding effects of extreme heat days, wildfire risk, and higher energy cost burdens, as shown in **Figure 27**. Rural and tribal communities that are moderate- to low-income also face burdens of lack of consistent access to energy, or no connectivity at all. Rural areas have high concentrations of White Coloradans compared to urban areas. Even so, there are Hispanic and Latinx households in rural communities, but they are dispersed across the rural parts of the state. Additionally, the Black, Indigenous, and other populations of color

152 Parson, Mateo. Colorado's Racial Wealth Gap: Homeownership & Credit. *The Bell Policy Center* (2019).
153 Jones, Kristin. The Thread that Ties Segregation to Gentrification. *The Colorado Trust* (2018).
154 Hunt, Jerome. A State-by-State Examination of Nondiscrimination Laws and Policies. *Center for American Progress Action Fund*, (2012).

communities in rural areas tend to be in discrete clusters. However, rural cooperative boards and committees are predominantly White, leaving racially diverse rural populations without decision-making authority into how the clean energy transition will occur, over what timeframe, at what financial cost to use services, and what gain for member owners.[155,156,157] State and local policy makers should encourage cooperative boards and committees to be representative of customer communities.

Recommendation 4: Restructure clean energy financing mechanisms to enable equitable access to capital among economically vulnerable and underserved communities.

Lack of access to capital is a large hindrance for clean energy technology adoption among overburdened and underserved racially- and income-disadvantaged populations. To avoid inequitable adoption rates similar to solar, which are heavily skewed towards higher-income populations (and likely skewed towards White populations based on national trends, although we do not have these data for Colorado), assessment should be taken to identify Coloradans who lack access to financial capital or experience non-financial barriers for clean energy conversions. Inequities in clean energy access can be reduced, in part, through renewable energy, efficiency, and electrification financing mechanisms supporting low-income and underserved households—such as point-of-purchase rebates and low-interest loans—rather than relying on tax incentives and post-purchase rebates.

Broader measures to support equitable access to clean energy and benefits from the clean energy economy also include:

- Financing of education for clean energy career advancement for non-graduates, new graduates, and non-energy career professionals to transition;
- Research funding to identify, and address, non-financial barriers to access clean energy for historically marginalized communities, particularly communities of color;
- Community engagement reimbursement and stipend funding for participants, to the extent community members are not adversely affected financially by participating in the engagement process;
- Widespread public infrastructure investments for electric vehicle charging stations, conversion/retrofitting of current fueling stations, and electric grid upgrades to support distributed energy resources;
- Financial incentives for communities of color and underserved populations to access clean energy technologies, encompassing the sector-specific recommendations described earlier;
- Support for businesses repurposing, recycling, or dismantling renewable energy technologies used in the clean energy transition for safe disposal at end-of-life, coupled with financing for transitioning current fossil fuel-focused companies that perform end-of-life services to the new opportunities in the clean energy economy.

Financing mechanisms and related efforts should be accompanied by further workforce development, for which a detailed analysis is beyond the scope of this study. However, a key consideration should include skilled job training in clean energy fields focused on current fossil fuel industry workers.

3.3 Recommendations for Future Research and Data Needs

3.3.1 Data Collection Needs Moving Forward

Much of our analysis is based on models and estimates due to lack of granular pollution, emission, and energy use data. Data collection in the areas below would be very valuable to better identify communities and sectors for energy investments and pollution reduction, set health-protecting regulations, enable better

155 Yanez, Miguel, Liz Veazey, Ric Evans, Nathan Shepherd. Equitable Beneficial Electrification for Rural Electric Cooperatives. *Environmental and Energy Study Institute* (2019).

156 Ross, Lauren, Ariel Drehobl, Brian Stickles. The High Cost of Energy in Rural America: Household Energy Burdens and Opportunities for Energy Efficiency. *Energy Efficiency for All, American Council for an Energy-Efficient Economy* (2018).

157 Labor Neighbor Research and Training Center and ACORN International. The Rural Power Project: A Research & Advocacy Report (2016).

enforcement, and create a baseline upon which to measure success. With the exception of some data that should be aggregated to protect individual privacy, these data should be publicly available, easily accessible, transparent, and regularly updated.

1. Cross-Sector

a. Air quality

i. High-density ambient air monitoring, particularly in potential pollution hotspots.

ii. Fenceline air monitors at power plants and industrial facilities, including for hazardous air pollutants such as benzene, toluene, ethylbenzene, and xylene.

iii. Indoor air monitoring and exposure assessment characterizing concentrations of and exposure to pollutants associated with in-home fossil fuel and biomass use.

b. Electricity access

i. Historical and contemporary electricity accessibility data within the state, by census tract. This should be updated regularly and broken down by sociodemographic indicators, and include community surveys or other self-reporting mechanisms to more broadly capture all populations.

ii. Electricity access data for tribal populations.

2. Transportation

a. Traffic data by road segment with a more granular breakdown by vehicle class. We used Colorado Department of Public Health and the Environment estimates of the vehicle miles traveled breakdown by vehicle class for each functional classification to improve the vehicle class granularity available from the Federal Highway Administration HPMS dataset. Real traffic data with a more granular breakdown by vehicle class would improve the accuracy of emissions estimates.

b. We recommend that Colorado submit traffic data for local roads (HPMS Functional Classification 7) voluntarily to the Federal Highway Administration HPMS, along with required Functional Classifications 1-6.

c. Colorado-specific vehicle age distribution data by vehicle class would improve the accuracy of emissions estimates.

3. Power

a. Primary particulate matter emissions measured hourly (rather than estimated) and covering all facilities.

b. Emission data for small facilities, in particular small diesel generators.

c. Current and regularly updated data on the ownership for fossil fuel facilities and clean energy facilities, along with sociodemographic breakdown of ownership, board, and leadership positions.

4. Residential buildings

a. Household-level energy use and burden data, aggregated at the census tract or block group level to protect privacy while allowing some spatially refined analysis.

b. Energy efficiency and solar adoption rates by household, again summarized for individual household privacy.

c. Gas distribution line data. We identified state[158] and federal[159] data sources on natural gas service territories throughout Colorado which did not match. Given the public safety hazards inherent in natural gas distribution and the potential for these hazards to increase if systems are not retired properly, it is important to know the exact alignment of service areas and distribution systems.

158 Colorado Energy Office. "Natural Gas." Accessed Oct. 2020 from: https://energyoffice.colorado.gov/natural-gas

159 US Department of Homeland Security. "Natural Gas Service Territories." Accessed Oct. 2020 from: https://hifld-geoplatform.opendata.arcgis.com/datasets/natural-gas-service-territories

5. Commercial buildings

a. More granular (census tract level) fuel use and emissions data by commercial subsector (e.g. restaurants, warehouses, etc.).

6. Industry

a. Water impacts from produced water disposal and near oil and gas production.

b. Co-pollutant emission analysis at oil and gas wells.

c. Emissions data by process and fuel at the facility-level (e.g. combustion vs. non-combustion emissions, etc.).

3.3.2 Recommendations for Research

Baseline Environmental Justice Screening Data

We created a Demographic Index, reliant on EJSCREEN indicators, to identify socioeconomically burdened populations across Colorado. However, it may be valuable for the state to design its own environmental justice screening tool using indicators which reflect Colorado's priorities and needs to support vulnerable and environmentally overburdened populations. In addition to identifying a suite of socioeconomic indicators deemed pertinent by Colorado stakeholders, this tool could incorporate additional indicators such as health measures (e.g. asthma rates) and environmental burdens (e.g. pesticide concentrations). Input from a broad range of stakeholders, including scientists, community organizations, and others, can provide valuable insights into the design of such a screening tool. The resulting tool may be useful for designing energy and climate policy and measuring its effectiveness, and also may be applied to policy decisions more broadly.

Health Impacts Analyses

Our analysis here focuses primarily on current pollutant *emissions* and changes in emissions under different decarbonization scenarios in order to determine whether or not there are inequities in pollution burdens and to identify potential strategies to alleviate those burdens. However, we did not model the health *impacts* of these emissions. The trends we have identified suggest there are likely disparities in the health impacts, in addition to the pollutant emissions, of fossil infrastructure and pollution mitigation pathways; these findings highlight the need to model air pollution dispersion and health impacts for any proposed state decarbonization policies in order to achieve greater health benefits for communities across Colorado, particularly those burdened by a disproportionate share of pollution. For example, Fann *et al.* (2011) illustrated strategies to maximize health benefits and reduce inequality in pollution burdens by focusing on multi-pollutant reductions in vulnerable communities.[160] Our initial screen may highlight sectors and regions where a detailed health impact analysis of both the current system and of clean energy policy strategies may be valuable. These include both indoor and outdoor air quality analyses, such as quantitative research on exposures to indoor air pollution from natural gas leakage to better characterize health risks associated with residential natural gas use.

Managed Retirement of Infrastructure

We see a significant risk of inequitable bill impacts moving forward for households that do not electrify. One strategy to limit these impacts would be selective "pruning" of the natural gas infrastructure, effectively electrifying entire neighborhoods at a time and retiring the gas distribution lines to reduce upkeep costs. It would be valuable to analyze the gas loads and strategies that would allow for such a transition to minimize infrastructure upkeep costs. During this transition period, publicly funded financial mechanisms can be used to stabilize ratepayer bills, and reduce them for low-income customers.

Barriers to Clean Energy Adoption

Current trends suggest that solar, storage, efficiency, and vehicles are inequitably distributed across Colorado. To mitigate these inequities moving forward, the state should collect higher-granularity data on existing adoption rates and analyze these in relation to existing demographic distributions in order to set a reliable baseline. The state should conduct a study to identify specific barriers facing these underserved populations, including outreach to these communities, in order to design effective policies. Ongoing data collection will allow for ongoing comparison to the baseline adoption levels and provide opportunities to revise policies as needed.

160 Fann, Neal, *et al.* Maximizing Health Benefits and Minimizing Inequality: Incorporating Local-Scale Data in the Design and Evaluation of Air Quality Policies. *Risk Analysis: An International Journal* 31.6 (2011): 908-922.

4 Technical Appendix: Methods

4.1 Overview of Methods

We used a three-step process to identify priority areas for the State of Colorado to build energy equity and co-pollutant reduction benefits into its decarbonization strategy. First, we approximated sectoral greenhouse gas and criteria pollutant emissions at fine spatial resolution. To do so, we applied emissions factors to energy production and consumption data obtained using processes detailed in the sector-specific methods below. Next, we joined these data with demographic data from the US Census Bureau. This enabled us to characterize the state's existing energy equity landscape—accounting for such considerations as clean energy access, bill burdens, and proximity to pollution, among others. We then integrated our findings from the first two steps with Evolved Energy Research's model results to illustrate how various decarbonization pathways may be implemented in a manner which maximizes social and environmental co-benefits. Throughout this process, we held multiple listening sessions and interviews with Colorado community organizations to understand their energy equity and social equity priorities for their local communities. Methodologies and source data used at each step are discussed in greater detail below.

4.2 Sectoral Energy Equity and Emissions Mapping

4.2.1 Baseline Demographic and Environmental Indicators

We analyzed population characteristics and cumulative environmental burdens across Colorado using a mix of data aggregated from the US Census and from the US Environmental Protection Agency's environmental justice screening tool EJSCREEN.[161] EJSCREEN includes census block group information on a set of demographic indicators, including:[162]

Demographic indicators

1. **Populations of color:** Population fraction that is not non-Hispanic white;
2. **Low-income:** Population in households below double the federal poverty level;
3. **Linguistic isolation:** Population living in households where no one over 14 speaks English as a primary language and all adults speak English less than "very well;"
4. **Educational attainment:** Fraction of adults with less than high school education;
5. **Children:** Population fraction under age five;
6. **Elderly:** Population fraction over 64.

Census tract-level values were calculated for each indicator using the population-weighted average of the block group values in each tract. The indicator value for each census tract was then compared to the remaining census tracts statewide and assigned a percentile value.

To identify populations which are uniquely vulnerable to this pollution due to cumulative socioeconomic burdens, we created a Demographic Index to reflect a combination of demographic indicators. The raw value for the Demographic Index was calculated by averaging the percentiles for each of the above demographic indicators. This raw value was then assigned a statewide percentile by comparing census tracts across the state, and the percentile value used as the Demographic Index score.

This index is necessarily limited by the data available within EJSCREEN. We therefore also assess some of our data in the context of additional environmental and socioeconomic indicators not available in EJSCREEN. These include the following, reflecting additional environmental burdens, climate vulnerabilities, and health vulnerabilities:

161 US Environmental Protection Agency. "EJSCREEN: Environmental Justice Screening and Mapping tool." Available at: www.epa.gov/ejscreen

162 Descriptions and data years for EJSCREEN indicators are provided in the "Technical Documentation for EJSCREEN." Available at: www.epa.gov/ejscreen/technical-documentation-ejscreen

1. **Non attainment areas:** Regions that exceed federal air quality standards (in this case, average 8-hour ozone concentrations) in the US Environmental Protection Agency's Green Book. [163]

2. **Wildfire risk zones:** Regions facing high wildfire risk.[164]

3. **Projected extreme heat days:** Number of days projected to exceed 95˚ F given a moderate carbon emissions scenario in the 2020-2039 timeframe.[165]

4. **Population health:** Census tract average life expectancy relative to the statewide average.[166]

We used these indicators to assess both their combined and individual relationships with energy burdens and cumulative environmental burdens from the fossil fuel industry, as described below. These indicators are meant to help characterize both cumulative burdens and vulnerabilities, but are not necessarily complete, and the state may choose to include additional indicators (e.g. health measures such as low birthweight births and environmental exposure metrics such as proximity to pesticide application) for decision-making purposes.

4.2.2 Power Sector

We aggregated power plants from the US Energy Information Administration's Form 860[167] and selected a subset of 55 facilities burning fossil fuels (including natural gas, petroleum liquids, and coal) and/or biofuels (including landfill gas and wood), seven of which were deemed likely idle or closed. We cross-checked and updated facility locations using satellite view on Google Maps.[168]

We subsequently characterized populations in close proximity to Colorado's power plants by calculating population characteristics within a one-mile and three-mile radius of each plant. We used 2010 Census Block data[169] for population weighting and 2014-2018 Census Block Group data[170] to obtain underlying population characteristics such as population size, percent of residents under two times the Federal poverty line, and percent non-white residents. Our methods are modeled after theUS Environmental Protection Agency's EJSCREEN population weighting methods, which are described in the tool's technical documentation.[171]

We used the US Environmental Protection Agency Air Markets Program Database[172] for 2019 to calculate baseline emission data, including total CO_2, SO_2, and NO_x emissions and rates of emissions per megawatt-hour of electricity generation. This database omits some small and infrequently used power plants. We cross-checked the generation and emissions for these small facilities for 2018, which are estimated by the US Energy Information Administration,[173] and determined they account for roughly 1 percent of in-state fossil fuel and biomass-consuming power generation. The *estimated* emission rates of NO_x and SO_2 from some of these facilities seemed anomalously high. We therefore included these facilities (which may be small but often burn high-emission fuels like diesel) in our analysis of populations near power plants, but only included the data for plants for which we have *measured* emissions in our analysis of electricity transition pathways.

We used the emission rates calculated above to estimate the average emissions of each power sector generation scenario developed by Evolved. We next calculated how much emission benefit could be obtained by prioritizing the retirement of plants with the highest co-pollutant emission rates. We ranked the plants by emission rates, and assumed that the highest-emission plants would be retired first (including the highest SO_2 emission rates for coal plants and the highest NO_x emission rates for natural gas plants). Using this prioritization, we compared end-point (e.g. 2030) and cumulative emissions from each scenario with and without prioritizing retirement of higher polluting facilities.

163 US Environmental Protection Agency. "Colorado 8-hour Ozone Nonattainment Areas (2015 Standard)." Available at: www3.epa.gov/airquality/greenbook/co8_2015.html

164 Colorado State Forest Service. "Wildfire risk viewer." Available at: https://coloradoforestatlas.org/

165 Kopp and Rhodium Group. "Probability-weighted ensembles of U.S. county-level climate projections for climate risk analysis: Table directory." 2016. Accessed 2020. Available at: https://rucore.libraries.rutgers.edu/rutgers-lib/51860/#related

166 Colorado Department of Public Health and Environment. "Colorado Life Expectancy by Census Tract Published by NAPHSIS-USALEEP (2010-2015). Available at: https://data-cdphe.opendata.arcgis.com/datasets/colorado-life-expectancy-by-census-tract-published-by-naphsis-usaleep-2010-2015

167 US Energy Information Administration. "Form EIA-860 (2018)." 2020. Available at: www.eia.gov/electricity/data/eia860

168 Google. "Maps." 2020. Available at: www.google.com/maps

169 US Census Bureau. "TIGER/Line FTP Archive: TIGER2010BLKPOPHU." June 2011. Available at: www2.census.gov/geo/tiger/TIGER2010BLKPOPHU/

170 US Census Bureau. "TIGER/Line FTP Archive: 2018 ACS." April 2020. Available at: www2.census.gov/geo/tiger/TIGER_DP/2018ACS/

171 US Environmental Protection Agency. "EJSCREEN Technical Documentation." September 2019. Available at: www.epa.gov/sites/production/files/2017-09/documents/2017_ejscreen_technical_document.pdf

172 US Environmental Protection Agency. "Air Markets Program Data." 2020. Available at: https://ampd.epa.gov/ampd/

173 US Energy Information Administration. "Emissions by plant and by region." 2020. Available at: www.eia.gov/electricity/data/emissions/

4.2.3 Transportation

On-Road Mobile Source Emissions

Using the Federal Highway Administration's 2018 Highway Performance Monitoring System (HPMS) dataset, we multiplied annual average daily traffic by road segment length to obtain daily vehicle miles traveled for each road segment. The HPMS dataset provides annual average daily traffic data for three categories: (1) all vehicle categories, (2) single-unit heavy-duty trucks, and (3) combination-unit heavy-duty trucks.

To obtain a more granular breakdown of vehicle miles traveled, we used estimates from the Colorado Department of Public Health and the Environment (CDPHE) on the vehicle miles traveled breakdown for six HPMS vehicle categories for each road type in Colorado (based on functional classification and urban/rural designation). We applied the vehicle miles traveled breakdown from CDPHE to the HPMS road segment vehicle miles traveled data in order to obtain a breakdown of vehicle miles traveled by the following HPMS vehicle categories: (1) motorcycles, (2) light-duty passenger cars, (3) light-duty trucks, (4) buses, (5) single-unit heavy-duty trucks, and (6) combination-unit heavy-duty trucks.

We created a 250-foot buffer around each road segment in the HPMS dataset and proportionally allocated vehicle miles traveled to overlapping census tracts based on area of overlap. We subsequently aggregated vehicle miles traveled across road segments within each census tract to estimate total vehicle miles traveled for each census tract. This procedure was carried out for each HPMS vehicle category to enable later application of emissions factors.

To estimate criteria air pollutant emissions in each census tract, we used EPA MOVES 2014a state-specific emission factors for carbon monoxide, NO_x, $PM_{2.5}$, PM_{10}, and VOCs, which are provided for each vehicle model year. We used Evolved's assumed allocation of VMT by vehicle vintage for each analysis year to calculate a fleet-average emission factor for each MOVES vehicle source type and fuel type (gasoline and diesel). For alternative fuel vehicle types used in Evolved's model, we used emission factors from Argonne National Laboratory's 2019 AFLEET tool.

We applied our estimated fleet-average emission factors (grams/mile) to statewide vehicle miles traveled for each vehicle category, mapping the MOVES vehicle source types to HPMS vehicle categories. When multiple MOVES vehicle source types mapped to one HPMS vehicle category (e.g. buses), we averaged the emission factors across MOVES vehicle source types within the corresponding HPMS vehicle category.

We assigned a weight to each census tract based on its fraction of statewide vehicle miles traveled for each vehicle category. We then allocated emissions by pollutant and HPMS vehicle category to each census tract by multiplying the tract's weight by the statewide emissions from that vehicle category.

To analyze criteria air pollutant emissions over time for each decarbonization scenario, we used the Evolved model's projected changes in vehicle miles traveled and fuel switching for each vehicle category. We assumed the relative contribution of each census tract to statewide vehicle miles traveled per vehicle category remained the same from 2017-2050 despite changes to overall statewide vehicle miles traveled. We also assumed that fuel switching occurred uniformly across the vehicle fleet for each vehicle category.

Transportation Fuel Burden

To estimate the fraction of vehicle miles traveled that is household-generated (i.e. not from commerce), we took the national sum of household travel from the 2017 National Household Travel Survey and divided it by the national sum of light-duty vehicle miles traveled from the 2017 Federal Highway Administration HPMS dataset. We applied the resulting household travel fraction of light-duty vehicle miles traveled of approximately 73 percent to Evolved Energy's projected statewide light-duty vehicle miles traveled for every year from 2017-2050 to project annual household-generated vehicle miles traveled. We attributed this resulting statewide estimate solely to passenger cars and light-duty passenger trucks, excluding light-duty commercial trucks. We excluded motorcycles, as Evolved did not estimate vehicle miles traveled for this vehicle class. We then derived the fuel use for household-generated light-duty vehicle travel, using Evolved's fuel use estimates for passenger cars and light passenger trucks.

To allocate household travel fuel use to each census tract, we used the Bureau of Transportation Statistics 2017 Local Area Transportation Characteristics for Households data on average household weekday travel by census tract. We multiplied the average household weekday travel by the count of households with vehicles in each census tract to estimate aggregated household weekday travel for each census tract. We then assigned a weight to each census tract based on its proportional contribution to total statewide household weekday travel. We then multiplied each census tract's weight by the statewide household travel light-duty vehicle fuel use estimated above to estimate household travel fuel use for each census tract.

To estimate household fuel costs associated with vehicle travel, we multiplied tract-level aggregated household fuel use by Evolved's baseline and projected fuel costs by fuel type. We used Evolved's 2020 fuel costs for the baseline 2017 transportation fuel burden estimates. We then divided the total tract-level fuel costs by the number of households in each census tract to estimate transportation fuel cost for the average household in each census tract. We divided this by median household income from the American Community Survey 5-year 2014-2018 dataset to estimate annual transportation fuel burden as a fraction of income for the average household in each census tract.

Electric Vehicle Adoption

We used 2020 data provided by the Colorado Energy Office and Atlas Public Policy on electric vehicle registrations by ZIP Code (current DMV registrations as of Oct. 1, 2020). To analyze electric vehicle adoption by income level, we used household counts and median household income data by ZIP Code Tabulation Area (ZCTA) from the US Census Bureau American Community Survey 5-year 2014-2018 dataset. We summed the number of EV registrations by ZCTA and divided by the number of households in each ZCTA. We used the median household income by ZCTA to analyze electric vehicle adoption rate by income level.

4.2.4 Residential Buildings

Residential energy consumption data are not readily available at geographic scales conducive to spatial or demographic analysis—though reliable statewide estimates by fuel type are available from the Energy Information Administration.[174] We accordingly built a regression model to develop weights which apportion statewide residential energy consumption to individual census tracts based on a variety of geographic, climatic, housing-related and demographic variables.

Our model uses previously developed methods,[175,176] to estimate each tract's relative contribution to statewide residential electricity, natural gas, propane, and wood consumption. Predictive variables for each census tract were extracted from the 2015 Residential Energy Consumption Survey[177] and the 2014-2018 American Community Survey[178] to estimate fuel-specific energy consumption for the average household in each census tract. We used this output, supplemented with additional electricity and natural gas data (provided by the authors of Min *et al.* 2010 and updated with more current predictors),[179] and the number of households in each tract to develop a weighting factor for each tract's share of statewide energy consumption.

We then applied this weighting factor to the Energy Information Administration's statewide consumption estimates to approximate each tract's residential energy consumption by fuel. These weighted values were used as baseline census tract energy consumption estimates. Similarly, we applied these weighting factors to projected consumption estimates under each decarbonization scenario to estimate future census tract-level residential energy consumption along each modeled decarbonization pathway. This methodology assumes the distribution of energy consumption amongst census tracts stays constant, and does not account for any changes to its spatial distribution between different scenarios. We subsequently multiplied all tract-level energy consumption estimates by emission factors[180] to identify priority areas for greenhouse gas reductions, populations and geographic regions likely to use more heavily polluting fuels, and possible changes in the distribution of residential emissions for different decarbonization pathways.

174 US Energy Information Administration. "State Energy Data System." Available at: https://www.eia.gov/state/seds/

175 Min, Jihoon, Zeke Hausfather, and Qi Feng Lin. A High-Resolution Statistical Model of Residential Energy End Use Characteristics for the United States. *Journal of Industrial Ecology* 14.5 (2010): 791-807.

176 Jones, Christopher, and Daniel M. Kammen. Spatial Distribution of US Household Carbon Footprints Reveals Suburbanization Undermines Greenhouse Gas Benefits of Urban Population Density *Environmental Science & Technology* 48.2 (2014): 895-902.

177 US Energy Information Administration. "Residential Energy Consumption Survey 2015." Available at: https://www.eia.gov/consumption/residential/data/2015/

178 US Census Bureau. "TIGER/Line FTP Archive: 2018 ACS." April 2020. *Ibid*.

179 Min, Jihoon, Zeke Hausfather, and Qi Feng Lin. A High-Resolution Statistical Model of Residential Energy End Use Characteristics for the United States. *Journal of Industrial Ecology* 14.5 (2010): 791-807.

180 California Air Resources Board, "Residential Emissions Factors". Available at: https://ww2.arb.ca.gov/carb-miscellaneous-process-methodologies-residential-fuel-combustion; Environmental Protection Agency "Residential Emission Factors". Available at: https://www3.epa.gov/ttn/chief/ap42/ch01/index.htm

Residential Energy Cost Burden

To characterize baseline residential energy cost burdens, we multiplied our census tract-level energy consumption estimates by 2018 Energy Information Administration Colorado prices by fuel.[181] We used the same methodology to project energy cost burdens with 2030 tract-level consumption estimates and scenario price projections from the Evolved model. Average household energy cost burden was then calculated for each census tract by dividing estimated energy expenditures by household income.

Residential Bill Impacts

To illustrate the impacts of fuel switching and energy efficiency measures on household energy bills, we used Evolved projections for residential fuel consumption, residential fuel prices, and residential clean energy adoption rates to calculate the average increase in household electricity use under each decarbonization scenario relative to the Reference case. We then attributed the electricity use increase to the fraction of adopting households only, resulting in higher electricity bills for those households but eliminating their natural gas bills. Conversely, non-electrifying households were assumed to have the same average electricity and natural gas consumption as in the Reference scenario.

The Evolved model assumes different electrification rates for different residential end-uses. We used the projected electrification rates for space heating as a proxy for all electrification measures with the assumption that they happen simultaneously to simplify our calculations. Because the Low Demand, Core, and Fossil Free scenarios all have identical residential end-use electrification rates in the Evolved model, we also incorporated the rate of residential building shell retrofits to distinguish the Low Demand scenario, which has higher rates of energy efficiency upgrades, from the other scenarios. The goal of the outlined approach to calculating residential bill impacts was to provide an illustrative apples-to-apples comparison between clean-energy-adopter and non-adopter bills, and between the different scenarios based on projected fuel consumption, fuel prices, and adoption rates, all other things being equal.

Residential Solar Deployment

We applied the weights calculated as described in **Section 4.2.4** to statewide 2030 residential energy consumption estimates for the Core scenario. We additionally developed census tract population weights by dividing each tract's baseline number of people and households by statewide totals. We multiplied these weights by 2030 values from the Evolved model to get tract-level demographic projections.

We joined our tract-level energy and population projections with data describing potential high-priority populations for residential solar deployment. Populations identified as high-priority include those who may derive additional resilience, economic, and/or health benefits from rooftop solar deployment, such as residents of counties with a high number of projected mid-century heat days,[182] households with income below the Federal poverty line,[183] rural households,[184] and households with at least one person dependent on electricity for medical reasons.[185]

We used our demographic and consumption projections and a 0.18 average capacity factor for distributed solar in Colorado to estimate the solar capacity needed to match target populations' residential energy needs by 2030. We compared these numbers to the 2030 total solar and rooftop solar projections underlying Evolved's model outputs to gauge whether additional solar deployment or redistribution of solar resources (i.e. residential instead of commercial) might be considered to maximize co-benefits.

181 US Energy Information Administration. "Residential Sector Energy Price and Expenditure Estimates, 1970-2018, Colorado." (2020). Available at: https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_prices/res/pr_res_CO.html&sid=CO

182 Rasmussen, D. J.; Meinshausen, Malte; Kopp, Robert E. "Probability-Weighted Ensembles of U.S. County-Level Climate Projections for Climate Risk Analysis." Rutgers University Libraries. 2016. Available at: https://rucore.libraries.rutgers.edu/rutgers-lib/51860/#package

183 US Census Bureau. "TIGER/Line FTP Archive: 2018 ACS." *Ibid*.

184 US Census Bureau. "TIGER/Line FTP Archive: 2018 ACS." *Ibid*.

185 US Department of Health and Human Services. "HHS emPOWER Map 3.0." Accessed September 2020. Available at: https://empowermap.hhs.gov/

4.2.5 Commercial Buildings

To our knowledge, the most spatially granular commercial emissions data available to the public are delivered at the county level in the NEI.[186] Methods to derive more spatially detailed emissions data are not readily available for the commercial sector due to a lack of geographic and descriptive data such as those used to derive weighting factors for the transportation and residential sectors. As such, our analysis of the commercial sector and cross-sectoral analyses integrating commercial data are limited to the county level. Furthermore, our commercial analyses are limited due to data quality issues in the National Emissions Inventory commercial dataset which lead us to conclude that these data are incomplete.

4.2.6 Industrial Sector

To evaluate current industrial criteria air pollutant emissions, we drew from the NEI 2017 point source dataset, excluding power plants and transportation-related point sources (airports, railyards), and the NEI industrial nonpoint source dataset, including only those distributed sources associated with the oil and gas sector. While the NEI nonpoint source dataset specifies which nonpoint sources are associated with oil and gas production, emissions are estimated at the county level and the locations of distributed sources are not provided.

While the NEI point source dataset provides criteria air pollutant emissions by industrial facility, it does not provide emission factors or EPA source classification codes for these facilities. Without emission factors, we were unable to project criteria air pollutant emissions over time based on Evolved's projected changes in fuel consumption and production quantities for various industrial subsectors.

We analyzed the demographic characteristics of communities near industrial point source emissions in the baseline year by assigning facilities to census tracts based on their latitude and longitude in the NEI dataset. We then used demographic data from the EPA EJSCREEN dataset to analyze trends in industrial point source emissions alongside demographic indicators such as low-income population fraction, people of color population fraction, and overall demographic index.

Despite the potential for significant emissions and associations with adverse health outcomes,[187,188,189] oil and gas wells are only included at the county-level in the NEI nonpoint dataset, and are likely underestimates.[190] To our knowledge, no comprehensive datasets characterizing these emissions are available. A growing body of research has worked around this data gap by using where people live as a proxy for population exposure to oil and gas production-related health hazards.[191] We accordingly used spatial data from Enverus' DrillingInfo database for all active wells in Colorado[192] and 2014-2018 Census block group data[193] to calculate the number of Coloradans living near oil and gas wells in 2020. We allocated residents based on the area-based proportion of overlap between each block group and a half-mile buffer around wells. Though this methodology does not characterize oil and gas production-related emissions, it provides a rough assessment of baseline health hazards—which enables discussion of the potential for ongoing hazards under various decarbonization pathways.

Suncor Refinery Case Study

A dedicated case study on one industrial facility enables focused assessment of the potential community health and equity implications of leaving fossil fuel infrastructure online. We selected the Suncor Refinery in Commerce City (Denver metro area) for such a case study based on consultation with community stakeholders. We used the EPA Enforcement and Compliance

186 US Environmental Protection Agency. "National Emissions Inventory 2017 - Nonpoint Sources." Available at: https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei

187 McKenzie et al. Childhood Hematologic Cancer and Residential Proximity to Oil and Gas Development. *PloS one* 12.2 (2017): e0170423.

188 Tran, Kathy V., *et al*. Residential Proximity to Oil and Gas Development and Birth Outcomes in California: A Retrospective Cohort Study of 2006–2015 Births. *Environmental Health Perspectives* 128.6 (2020): 067001.

189 Hays, Jake, Michael McCawley, and Seth BC Shonkoff. Public Health Implications of Environmental Noise Associated with Unconventional Oil and Gas Development. *Science of the Total Environment* 580 (2017): 448-456.

190 Grant, John *et al*. U.S. National Oil and Gas Emission Inventory Improvements. (2017)

191 Czolowski, Eliza D., *et al*.Towards Consistent Methodology to Quantify Populations in Proximity to Oil and Gas Development: A National Spatial Analysis and Review. *Environmental Health Perspectives* 125.8 (2017): 086004.

192 Enverus. "Active Oil and Gas Wells." Retrieved July 2020 from: https://www.enverus.com/

193 Manson *et al*. "IPUMS National Historical Geographic Information System: Version 15.0 [dataset]." 2020. Available at: https://data2.nhgis.org/main

History Online database[194] to characterize the facility's regulatory compliance history and the EPA NEI[195] to evaluate the refinery's relative contribution to criteria and hazardous air pollutant emissions.

4.2.7 Cross-Sectoral Data

In addition to analyzing the health, equity, and environmental implications of decarbonizing each individual sector, we sought to characterize economy-wide patterns by conducting cross-sectoral analyses. We joined the commercial, industrial, power, residential, and transportation data discussed in sections 2.3.2 to 2.3.6 above at the county level. Analyses at finer spatial resolution such as the census tract level was considered but omitted due to the lack of readily available commercial data below the county level and due to the complex nature of pollutant dispersion from point sources such as power plants and industrial facilities, which is outside the scope of this report.

Aggregate, cross-sector datasets were used to analyze patterns such as overall baseline pollution distribution and household energy (residential) and fuel (transportation) burdens. Additional datasets pertinent to pollution and demographics were integrated into these analyses to provide further context. These include data characterizing such health metrics as asthma prevalence and average life expectancy[196] and spatial data detailing the distribution of ambient air pollutant non-attainment areas.[197]

4.3 Community and Stakeholder Organization Outreach for Equity Considerations

We conducted multiple virtual listening and interview sessions with various Colorado organizations throughout 2020 in order to understand their policy, energy equity, and social equity concerns and priorities. Some covered topics included local community priorities regarding:

- Public health and policy priorities related to energy
- Pollution sources and nearby communities
- Economic impacts and job creation, stagnation, or decline
- Local, community input and accountability of projects to communities
- Access and funding to demand-side energy use reduction efforts, such as appliance efficiency
- Access and funding to electrification efforts in transportation and housing

From these discussions, we compiled a list of focus areas and case studies that were incorporated into the technical analysis performed in this study.

194 US Environmental Protection Agency. "Enforcement and Compliance History Online." Accessed July 2020. Available at: https://echo.epa.gov/

195 US Environmental Protection Agency. "National Emissions Inventory 2017." April 2020. Available at: https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei

196 Colorado Department of Public Health and Environment. "Colorado Health Information Dataset." Accessed Sept. 2020, Available at: https://cohealthviz.dphe.state.co.us/t/HealthInformaticsPublic/views/CoHIDLandingPage/LandingPage?iframeSizedToWindow=true&:embed=y&:showAppBanner=false&:display_count=no&:showVizHome=no

197 US Environmental Protection Agency. "Green Book GIS Download." May 30, 2020. Available at: https://www.epa.gov/green-book/green-book-gis-download