GREEN FOR ALL

Integrating Air Quality and Environmental Justice into the Clean Energy Transition

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EXECUTIVE SUMMARY

Decarbonization is coming — or it had better be if we are to avoid truly dire consequences for human and ecosystem well-being. As the start date for serious decarbonization is delayed, to some the urgent need to accelerate it may overshadow the social issues of equity and environmental justice. But ignoring these dimensions of climate policy can undermine the basic goal of expanding and protecting human well being — and also may jeopardize the broad-based public support that will be required to implement effective climate-protective policies.

There are encouraging signs that the new administration recognizes this. During the campaign President Biden pledged to deliver 40% of the overall benefits from a clean energy revolution to disadvantaged communities. Clean air and environmental justice criteria could be included, for example, in the formulation of Clean Energy Standards (CES) to mandate that electricity companies not only increase the share of clean and renewable power but also meet explicit standards for reducing co-pollutant emissions and their disparate impacts on Environmental Justice communities. Such provisions would ensure that as the contribution of fossil fuels to the nation's electricity supply is phased out, reductions in their use occur where the resulting public health and environmental justice benefits are greatest.

In January 2021, shortly after taking office, President Biden signed an executive order establishing an office of health and climate equity at the Department of Health and Human Services and establishing a White House interagency council on environmental justice. A central aim is to improve conditions in communities that have borne disproportionate burdens from power plants, incinerators, and other sources of pollution.

> *Very large improvements in public health and environmental justice can be achieved at very low cost.*

This study provides further encouragement: based on an analysis of alternative decarbonization pathways in the electric power sector, we find that very large improvements in public health and environmental justice can be achieved at very low cost. To do so, however, will require explicit incorporation of these goals in to the design of climate policies.

Decarbonization of electric power generation is a crucial part of response to climate change. The transition to clean and renewable electricity will not only bring long-term benefits worldwide by helping stabilize the Earth's climate, but also bring large, localized and near-term benefits by reducing emissions of hazardous co-pollutants that are released by fossil fuel combustion. These more local and more immediate payoffs can help to strengthen and consolidate support for policies to accelerate the clean energy transition.

Because people of color and low-income communities often suffer disproportionate exposure to air pollution, including emissions from power plants, improvements in local air quality also create valuable opportunities to advance the goal of environmental justice.

The explicit incorporation of air quality and environmental justice objectives into the design decarbonization policies can greatly enhance these co-

Photo by Eric Kayne, for Earth Justice benefits. In contrast, decarbonization policies that focus narrowly on carbon reduction alone could not only leave potential health gains on the table but also may worsen air quality in pollution "hot spots" in predominantly minority and low-income communities. These issues are particularly relevant in the electric power sector.

The principles that co-benefits should count in policy design, and that policy makers should seek to remedy disproportionate harms borne by people of color and low-income communities, are both well-established in environmental policy in the U.S. The same principles, we believe, could and should be adopted by private-sector entities, including the hundreds of firms that have subscribed to Science-Based Targets for reducing their own carbon footprints.

This study demonstrates that it is eminently feasible to adhere to these principles in formulating climate policy, and that this can be done at reasonable cost. This will require moving beyond a narrow focus on carbon reduction alone, however, to embrace clean air and environmental justice as additional policy goals that merit a prominent place in decarbonization strategies.

In this study we examine how the incorporation of air quality and environmental justice objectives would affect the course of decarbonization in the U.S. electric power sector. We compare three alternative decarbonation scenarios to a "baseline" that simply minimizes the cost of producing electricity (subject to the constraint of meeting existing demand in each of 26 subregions in the United States) without decarbonization.

Scenario 1
Carbon-alone

Policy narrowly focused on the goal of a **20% reduction of carbon dioxide emissions.**

Scenario 2
Carbon plus air quality

Policy that targets the dirtiest power plants by **imposing an added constraint of reducing the damages from co-pollutants by 50%.**

Scenario 3
Carbon and air quality plus environmental justice

Scenario that additionally requires attainment of the same **50% reduction in co-pollutant damages for Black, Hispanic, and low-income populations.**

Our results reveal substantial differences between policies in the carbon-alone scenario versus the latter two scenarios. The most notable difference arises from the fact that natural gas-fired power plants often are located in more densely populated areas than coal-fired plants and in greater proximity to minority neighborhoods. In the carbon-alone scenario, the health damages to these communities increase relative to others, and in some regions — notably California — they even increase in absolute terms. That is, the carbon-alone strategy can have the perverse results not only of exacerbating environmental disparities but also actually worsening pollution exposure in minority communities in some places.

When decarbonization policy instead explicitly incorporates the objectives of improving air quality and advancing environmental justice, however, the result is a substantial reduction in the co-pollutant damages. This is achieved in part by greater reliance on renewable energy sources, and in part by damage-sensitive changes in the locations where additional gas-fired power is being generated.

Turning to the cost side of the picture, our results show that the addition of the clean air and environmental justice criteria does not greatly increase the price tag for decarbonization. The cost of the carbon-reduction scenarios depends on the ambition of their targets, with greater cost for more complete decarbonization. With the goal of a 20% reduction of carbon dioxide emissions, the additional co-benefits of meeting air quality and environmental justice targets are more than twice as large as the additional cost. Overall, meeting the clean air and environmental justice targets as well increases costs over the carbon-alone scenario by no more than 5%, and this difference diminishes as the decarbonization target becomes more ambitious.

Our results show that is feasible to include air quality and environmental justice criteria into a broad decarbonization policy for the U.S. electric power sector at a reasonable cost, one which is greatly overshadowed by the potential human health benefits. However, our results also show that an explicit focus on air quality and environmental justice criteria is necessary to achieve these benefits, and a decarbonization policy that does not explicitly include these criteria could worsen human health damages and environmental inequality.

INTRODUCTION

In response to the climate crisis, decarbonization over the coming decades is likely — and necessary — with a trajectory towards net-zero emissions by 2050. Electric power comprises approximately 30% of U.S. greenhouse gas emissions, so the reduction of the greenhouse gas emissions of the sector is a crucial component of a broad decarbonization program.

Many companies have committed to help the world achieve climate goals by adopting Science-Based Targets, reductions in the company's carbon footprint needed for the company to do its fair share on the way to global carbon reduction. These companies can reduce carbon in their own operations, in their upstream suppliers, or in the downstream use of their products. A particularly salient component is typically the firm's own energy inputs, of which electricity is often the largest.

Decarbonization of electricity emissions will also reduce emissions of hazardous co-pollutants generated by fossil fuel combustion, such as sulfur dioxide, nitrogen oxides, and particulate matter, leading to air quality improvements and public health co-benefits in communities impacted by power plants. The extent of these co-benefits will vary across facilities, depending among other things on fuel type, pollution abatement technologies, and location.

In the U.S., it is well established that people of color and low-income communities tend to bear disproportionate exposure to air pollution, including co-pollutant emissions from electrical power plants (Ash et al., 2009; Boyce & Pastor, 2013; Richmond-Bryant et al., 2020).

Coal, which today accounts for just under one-quarter of U.S. electricity generation (U.S. Energy Information Administration, 2020), is less efficient in terms of carbon release than are other fossil fuels, and also exceptionally dirty in terms of hazardous co-pollutants (U.S. Environmental Protection Agency, 2016).

People of color are especially at risk. Coal Blooded, a 2012 report published by the NAACP and environmental justice organizations (Wilson et al., 2012) and a 2020 study published in the *American Journal of Public Health* (Richmond-Bryant et al., 2020) have documented the deadly impact of coal on Blacks, Hispanics, and Indigenous People in the United States.

Decarbonization creates valuable opportunities to improve public health by reducing emissions of hazardous co-pollutants and to advance environmental justice. But these gains will not result automatically from decarbonization; instead they must be pursued deliberately. Policies narrowly focused solely on the objective of reducing carbon emissions will fail to take full advantage of opportunities to improve public health and advance environmental justice in the process. Worse, in some instances decarbonization policies that are blind to co-pollutants and their inequitable distribution may perversely increase exposures in specific localities and exacerbate environmental injustice. Indeed there is evidence that this has already occurred in California (see text box on page 10), which has pursued one of the most ambitious decarbonization policies in the country (Cushing et al., 2018; and Boyce & Ash, 2018).

This study examines how decarbonization policies can be designed effectively and efficiently to pursue the goals of improved air quality and environmental justice by targeting emissions reductions across electric power plants to achieve these goals.

Policies narrowly focused solely on the objective of reducing carbon emissions will fail to take full advantage of opportunities to improve public health and to advance environmental justice in the process.


BALTIMORE
PATAPSCO ST
STOP

DECARBONIZING THE ELECTRICAL ENERGY SECTOR

An opportunity for improving health and advancing environmental justice — As a type of pollution that threatens the entire planet, greenhouse gases (GHGs) are a global public bad. It does not matter where carbon dioxide, methane, or other GHGs are emitted: the consequences for Earth's climate are the same. The reduction of GHG emissions is a global public good, of equal value in mitigating climate change whether the reduction occurs in Johannesburg, Beijing, or Youngstown.

In contrast to the distinctive global impact of GHGs, the impacts from emissions of hazardous co-pollutants are localized. For example, coal combustion releases mercury and sulfur compounds. The combustion of fossil fuels, including natural gas, generates primary and secondary particulate matter, nitrogen oxides, and ozone precursors. These are termed "co-pollutants" in the literature on climate policy. Unlike the global harm from carbon dioxide, co-pollutants mostly have local and regional effects, harming populations and ecosystems within miles, tens of miles, or hundreds of miles of the pollution source.

Public health

Human harms from co-pollutants are enormous. Ambient (outdoor) air pollution is estimated to kill almost 9 million people per year worldwide, making it one of the world's greatest killers (Lelieveld et al., 2020). In the U.S., the average loss of life expectancy from air pollution is 1.6 years (*ibid*., Supplementary Data). Roughly two-thirds of the worldwide toll, and as much as 80% in high-income countries like the U.S., can be attributed to fossil fuels. Reductions in the quality of life, including aggravation of asthma, emphysema, other chronic obstructive pulmonary diseases (COPD), and cardiovascular disease from exposure to air pollution add to the human cost.

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A reduction in co-pollutants associated with reduced GHG emissions will relieve the impacted local and regional populations at the same time that the entire Earth benefits from the GHG reduction. Unlike the benefits of mitigating the climate crisis, which will become most substantial later in the 21st century, the air quality co-benefits of decarbonization are immediately felt here and now.

Estimates of the value of air quality co-benefits place them in the same order of magnitude as the benefit of GHG reduction according to the valuation procedures used by official agencies such as the U.S. Environmental Protection Agency (Dedoussi et al., 2019). Comparisons of the two sorts of benefits are complicated by the fact that the estimated benefit of GHG reduction depends greatly on what discount rate is used to convert future benefits into present-value terms. But a reasonable case can be made that the benefits of GHG reduction and co-pollutant reduction are in the same ballpark. Moreover, the air quality co-benefits may be of even greater political salience by virtue of their spatial and temporal proximity to pollution sources.

That is, because the air quality co-benefits of reduced fossil fuel combustion improve the health and quality of life of local populations now, emphasizing these benefits may provide more political traction for decarbonization efforts.

The Yellow Vest protests in France were sparked by anger over a fuel tax intended to generate revenue and reduce fuel consumption. One protester explained, "President Macron is worried about the end of the world. I'm worried about the end of the month." The here-and-now character of co-benefits can significantly change the politics of climate policy, reducing conflict over how to weigh the future benefits of decarbonization against present-day concerns over cost and inconvenience.

The localized nature of the co-benefits can also mitigate the public-good problem inherent in policies that incur local costs to achieve more widely dispersed global benefits. For both reasons, taking co-benefits into account can do much to solve the problem of who bells the cat.

Photo by Paul Orr,
Louisiana Environmental Action Network

This approach to climate policy is consistent with the widespread adoption of multi-pollutant strategies for air-quality management (McCarthy et al., 2010; National Research Council, 2004). The authoritative U.S. government guidance on regulatory impact analysis, Office of Management and Budget (OMB) Circular A-4, explicitly directs agencies to consider co-benefits (also known as "ancillary benefits") in federal rulemaking (Office of Management and Budget, 2003, p. 26).

In June 2020, under the cover of the emergency circumstances of the Covid-19 pandemic, the Trump administration proposed eliminating co-benefits from cost-benefit analysis of regulations, a move welcomed by the fossil fuel industry and immediately denounced by environmental law experts and former EPA officials. "The Trump administration is going to put in place some analytical techniques that will make it easier for them to kill more Americans," said Richard Revesz, the director of the American Law Institute at New York University (Davenport & Friedman, 2020). To safeguard public health, it is vital that this cynical move be blocked.

Environmental justice

The localized character of co-benefits poses critical issues of distributive justice in climate policy that can be overlooked in an exclusive focus on GHG emissions. Where and how decarbonization occurs will profoundly affect the distribution of co-benefits as well as their magnitude. Some shifts in the location of activities that emit GHGs — for example, shifting more electric power generation to facilities that generate less carbon per kilowatt hour — may exacerbate co-pollutant hotspots and harm populations living near sites of increased activity.

The long and painful history of unequal distribution of environmental goods and bads has been thoroughly established by activists and researchers in the environmental justice movement. Since the publication of the landmark study *Toxic Wastes and Race in the United States* (Commission for Racial Justice, 1987), research and public attention to environmental justice has grown dramatically. A substantial body of literature has documented environmental disparities in which minorities and low-income communities face greater hazards (for reviews, Mohai and Bryant, 1992; Ringquist, 2005; Bullard et al., 2007; Pastor, 2007; Boyce, 2007; and Mohai and Saha, 2015).

Discriminatory social, economic, and political processes have systematically sited polluting activities, including industrial plants and waste disposal facilities as well as combustion-based electricity generation, near communities of color and low-income people. Similar processes have systematically denied people of color and low-income people access to housing in less exposed locations.

Researchers have established that these effects of race and ethnicity persist even when controlling for income — and that income effects persist even when controlling for race and ethnicity (see, for example, Bullard et al. 2007; Mohai and Bryant, 1992; Mohai and Saha, 2006; Mohai et al. 2009, AJPH; Morello-Frosch et al., 2002; Bouwes, Hassur, and Shapiro, 2003; Ash and Fetter, 2004; Downey and Hawkins, 2008; and Zwickl et al. 2014).

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The first National People of Color Summit on the Environment in 1991 initiated a new understanding of the environment not only as nature to be protected but as the place where people live, work, and play. Environmental justice, defined in terms of race, ethnicity, and income, became an explicit objective in federal government policy making in 1994 when President Clinton signed Executive Order 12898 directing every government agency to take steps to identify and rectify "disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations."

Owing to the global and national delays in taking the steps needed to address the climate crisis, the eventual pace of decarbonization to meet climate goals must be rapid. When political circumstances allow serious climate action, the push to reduce carbon emissions by any means necessary may be accompanied by a single-minded focus on carbon reduction. There is a real risk that such a narrow focus will lead not only to a failure to capitalize fully on air quality co-benefits but also to a more inequitable distribution of co-pollution burdens.

Reduced fossil fuel consumption unquestionably will have positive impacts on public health both in the short run as a result of reductions in co-pollutants and in the long run as a result of mitigation of the climate crisis.

But as we demonstrate in this study, appropriate policy design can, at little extra cost, substantially enhance the short-run benefits and ensure that these are shared by communities that have been subject to disproportionate environmental burdens.

In sum, then, the co-benefits of greenhouse gas reduction will deliver air quality co-benefits that are immediate, local, and highly significant in terms of both public health and political impact. Well-designed policy is needed to ensure that these co-benefits are fully realized and fairly distributed.

RISKS OF A NARROW FOCUS ON CARBON ALONE

An old and insightful adage in public policy is, "what you measure and what you reward are what you get." This maxim helps to explain the perverse effects of a single-minded focus on standardized test scores in schools, which can twist education in many ways, from "teaching to the test" to outright cheating by school administrators; on weight maintenance guidelines in nursing homes, which has led to overuse of dangerous sugary supplements; and on stop-and-frisk statistics in policing, which has contributed to the tragedy of racial profiling. The lesson is clear: reliance on a reductive, one-dimensional metric to address complex problems with high stakes seldom yields broadly beneficial results.

Decarbonization is likely to dominate metrics and rewards in environmental policy in the years ahead. Companies, many acting in the best faith, have signed onto agendas committing themselves to achieving carbon neutrality. But a narrow focus on decarbonization alone runs the risk of overlooking, or even aggravating, other environmental harms and environmental injustice.

The accelerating exit from coal in the electricity section in the U.S. has had substantial health and climate benefits, but the shift to natural gas has also entailed new social, health, and environmental costs and has shifted their distribution (Burney 2020). For example, increased levels of ozone within a 25-50 kilometer radius of power plants is associated with the addition of new natural-gas fired units.

A particular concern in efforts to reduce pollution is the problem of "hot spots." For example, while carbon prices, implemented through taxes or permit systems, can reduce total emissions, some areas may have higher emissions after their introduction. Similarly, clean energy standards that require a certain overall level of emissions reductions (or a certain percentage of renewables in the energy mix) may lead to higher emissions in specific areas. The attainment of emissions reduction goals in aggregate does not necessarily mean that they will be achieved everywhere.

In a study of California's relatively ambitious carbon-reduction program, Cushing et al. (2018) find that exposure to co-pollutants from electricity generation actually increased in some communities, even as the state as a whole achieved net reductions in emissions of both GHGs and co-pollutants (see page 11). Compared to neighborhoods that experienced decreases, those neighborhoods that experienced increases in exposure typically had higher proportions of people of color and higher proportions of poor, less educated, and linguistically isolated residents. This experience demonstrates that the pitfalls associated with an exclusive focus on carbon emissions are not merely hypothetical.

A CAUTIONARY TALE FROM CALIFORNIA: THE PERVERSE IMPACT OF DECARBONIZATION ALONE

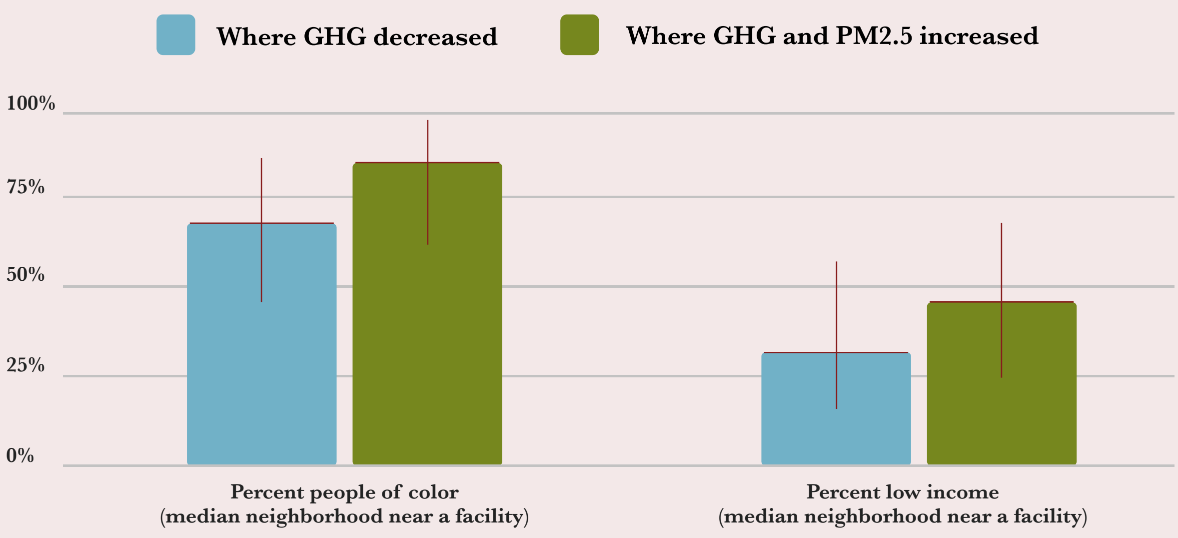
California has been a leader in decarbonization in the U.S. The state's Global Warming Solutions Act of 2006 mandated substantial reductions in greenhouse gas emissions, a goal achieved by a mix of regulatory measures and a cap-and-trade system for carbon emissions. The cap-and-trade system for power plants and other high-GHG facilities, which began in 2012, was not designed with specific attention to impacts on local co-pollutants or environmental justice. Instead the focus was on decarbonization alone.

In the analysis presented in this report we find considerable regional variations in the air quality and environmental justice impacts of a decarbonization-only policy (see Tables S-10 and S-11). The most dramatic adverse effects are found in California (corresponding to the CAMX electricity region in Tables S-10 and S-11), where co-pollutant damages not only fail to decline but increase absolutely. The impacts are especially large for people of color and low-income communities. **The modeled 20% reduction in carbon is predicted to more than double overall co-pollutant damages, and more than triple them for Blacks.**

At the core of these perverse impacts from a decarbonization-alone program is the role of natural gas in California's electric power supply and the environmental injustice in the location of California's electrical generation sector. A number of California gas-fired power plants exhibit high co-pollutant damages per unit electricity generated and high impact on environmental justice communities.

Demographics of neighborhoods in California near polluting facilities

By pollution change after implementation of cap and trade



Notes: The percent people of color and percent low income are reported for the median among neighborhoods within 2.5 miles of a facility. Low income is defined as household income below 200% of the Federal Poverty Line. For comparsion, people of color and low-income people comprise 63% and 28% in California's population as whole.

Sources: Cushing et al (2018); and US Bureau of the Census.

Consistent with the results of our model are the conclusions of a peer-reviewed study authored by Dr. Lara Cushing and her colleagues on what actually happened in the first three years of California's cap-and-trade system. Their study was published in the prestigious journal *PLoS Medicine* in 2018.[a]

Cushing et al. find that facilities regulated under California's cap and trade program were already overwhelmingly located in disadvantaged neighborhoods. Over the three years following the implementation of the cap-and-trade program, a number of neighborhoods across the state experienced increases in annual average greenhouse gas and co-pollutant emissions from regulated facilities located nearby. These were disproportionately inhabited by people of color and by poor, less educated, and more linguistically isolated residents. The figure shows that neighborhoods within 2.5 miles of facilities are disproportionately inhabited by people of color and low-income people, and facilities with pollutant increases were even more disproportionately inhabited by people of color and low-income people.

Cushing et al. observe that the cap-and-trade system in California brought a substantial shift from out-of-state generation, which was more likely to be coal-fired, to in-state generation, which was more likely to be gas-fired. While this shift entails a global carbon reduction and the phase-out of coal reduces the gross load of regional pollutants, the shift towards gas close to population centers and especially close to EJ communities, points up the need for more careful design and regulation.

A recent working paper that has been widely reported but not yet peer-reviewed examined the impact of California's cap-and-trade program on average emissions from the regulated facilities. The authors assumed that the same average percent impact applies to all facilities regardless of location. Unlike the study by Cushing et al., this sheds no light on whether the program had disparate effects across regulated facilities.[b]

The lessons from California demonstrate the importance of including local air quality and environmental justice concerns in the design of decarbonization policies. As our report shows, this is both necessary and feasible.

[a] Cushing L, Blaustein-Rejto D, Wander M, Pastor M, Sadd J, Zhu A, Morello-Frosch R. (2018) Carbon trading, co-pollutants, and environmental equity: Evidence from California's cap-and-trade program (2011–2015). PLoS Medicine 15(7): e1002604. Available at https://doi.org/10.1371/journal.pmed.1002604.
[b] Hernandez-Cortes, Danae, and Kyle C. Meng. Do environmental markets cause environmental injustice? Evidence from California's carbon market. Working Paper No. w27205. National Bureau of Economic Research, 2020.

SCIENCE-BASED TARGETS FOR GREENHOUSE GAS REDUCTION

Science-Based Targets (SBTs) are GHG emission targets adopted by companies that, if widely adopted, would achieve decarbonization on a level required to hold the global temperature increase to 2°C above pre-industrial temperatures, a crucial mitigation target established in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Some 1,100 firms have committed to SBTs, pledging to effect reductions in GHG emissions from their own facilities and activities, in their supply chains, and from the lifecycle of their products (Science Based Targets, 2020).

The Science-Based Target movement is a partnership of the World Business Council for Sustainable Development, the World Resources Institute, the UN Global Compact, and the CDP (formerly the Carbon Disclosure Project). It designates three "scopes" for company interventions to reduce GHG emissions: "Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy. Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions" (World Resources Institute, 2004).

Scope 2 emissions are especially relevant for the hundreds of firms that have adopted SBTs to date, many of which have rather modest Scope 1 emissions. Decarbonizing the energy supply is an important site of intervention because purchased electricity is often highly carbon-intensive, and because in most cases the switch to renewable electric sources will not disrupt or require other changes to firms' production systems because electricity is fungible as long as the supply is adequate.

Electricity generating facilities and the companies that own them are among the top greenhouse gas emitters in the United States. The Greenhouse 100, an index developed by the Political Economy Research Institute at the University of Massachusetts Amherst (Ash & Boyce, 2019), ranks companies by their GHG emissions using data from the US EPA's Greenhouse Gas Reporting Program (US EPA, 2014). The top ten companies on the Greenhouse 100 list are electric power producers. The top three alone, Vistra Energy, Southern Company, and Duke Energy, account for 5% of all GHG emissions in the United States from all sources combined, including energy, industry, agriculture, transportation, and households. The reason to focus on electricity generation is that is where the emissions are.

For the electric power companies, their own activity (i.e., Scope 1 emissions) would be the most relevant arena for carbon reduction. To date, however, no fossil-fuel based power companies in the United States have adopted SBTs. But the current SBT adopters, which for the most part have relatively modest direct (Scope 1) emissions, are likely to focus on their electricity purchases (Scope 2 emissions) to meet the climate targets they have set for themselves.

The SBTs, as conceptualized and operationalized to date, focus exclusively on carbon reduction. Hence there is the potential — so far untapped — to integrate public health and environmental justice into corporate SBT policies, as well as into the climate policies of federal, state, and local governments.

The analysis presented here can help current SBT adopters who want to include health and environmental justice impacts in their Scope 2 GHG emission reduction strategies. Our analysis can also assist electric utilities, if and when they adopt SBTs, to increase immediate public health benefits and reduce the pollution exposure of vulnerable and overburdened populations.

MEASURING LOCAL POLLUTANTS AND ENVIRONMENTAL JUSTICE IMPACTS

The carbon efficiency and carbon footprint of different electric generating units are relatively straightforward to calculate. Fuel is the key determinant of carbon efficiency. Coal produces roughly 2.21 pounds of CO_2 per kWh, compared to 0.92 pounds/kWh for natural gas (U.S. Energy Information Administration, 2020). Oil is similar to coal in this respect. Renewable electricity sources produce essentially zero CO_2/kWh. Apart from the carbon content of the fuel, other factors affecting the carbon efficiency of fossil-fuel based electrical generation units are facility-specific: the capacity, activity level, temperature, and technology of the unit. In addition, individual facilities may use more than one fuel source to generate electricity. For example, some facilities that rely primarily on natural gas also use fuel oil at times of unusually high electricity demand or when natural gas is unavailable.

For analyzing climate policy co-benefits, a key feature of electric power plants is how much of each co-pollutant is released per unit of GHG and per unit of electricity generated. Measuring the local human-health impact of power plants depends on the fuel type, scale, specific technical features such as stack height and pollution control equipment, and also on local population density and topographic and weather conditions. The pollutants released include sulfur and heavy metals, NO_x, particulate matter, ozone precursors and a variety of hazardous organic compounds.

We use data from the US EPA and the US EIA that collates information on fuel types, electrical generation, GHG emissions, and the emissions of the co-pollutants SO_2, NO_x, and PM2.5, "criteria pollutants" regulated under the Clean Air Act that are significantly implicated in the negative health impacts of air pollution.

We use a peer-reviewed integrated assessment model called Air Pollution Emission Experiments and Policy (APEEP) to assess the impacts of these co-pollutants.[1] Integrative assessment includes information on the fate and transport of the pollutants released, the toxicity of the various pollutants, and exposed populations and other ecological receptors. APEEP has been used by the National Academy of Sciences for its 2010 report *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* (NAS 2010). The damage estimates from APEEP are estimated in dollars using a variety of standard EPA and other peer-reviewed valuation methodologies, including the EPA Valuation of a Statistical Life (VSL). We apportion these estimated impacts to environmental-justice populations on the basis of population shares within 5 km or 15 km of the generating facility.

[1] In addition to adverse effects on human health, APEEP assesses damage done by each ton of SO2, NOx, and PM2.5 emissions in reduced yields of agricultural crops and timber, reductions in visibility, enhanced depreciation of man-made materials, and damages due to lost recreation services. For the purposes of the present analysis, we assume that the demographic distribution of non-health damages mirrors that of health damages. Details about APEEP appear in Annex B.

DIFFERENCES AMONG ELECTRICAL GENERATION FACILITIES

Decarbonization policies will result in a shift of activity to facilities that produce less CO_2 per unit of electricity produced.

Rankings by total emissions of CO_2 and co-pollutant damages

To examine differences among facilities that rely on fossil fuels, we first ranked them in terms of both total CO_2 emissions and the damages attributable to their emissions of hazardous co-pollutants. Online appendix tables S1-S4 identify the top 20 facilities ranked by these measures, first for the entire universe of both gas and coal power plants and then for natural gas-fired plants alone. A searchable, sortable online table of Gas and Coal Electrical Generation Plants gives a wider set of variables for the full set of coal and natural gas plants so that users can pursue their own assessments.

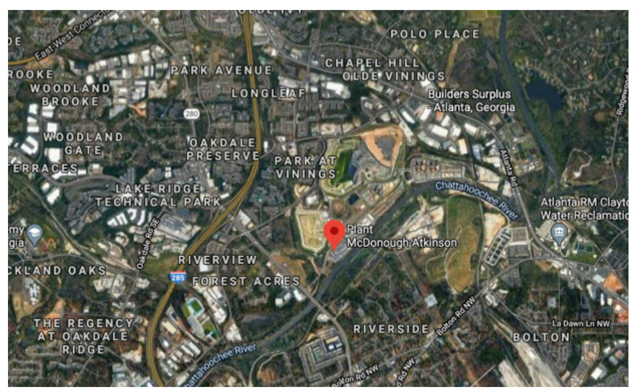
Table S-1 lists the 20 electrical generation facilities nationwide that produce the largest carbon emissions. All of them are coal-burning plants. This is because of both the large scale of coal plants and their relatively high carbon emissions per unit electricity.

Although these are all high CO_2-emission plants with roughly the same rate of CO_2 emission per unit electricity, there is substantial variation among these facilities in the estimated damages from airborne toxics borne by the surrounding population. Differences in the damages per unit of electricity reflect the population densities in the surrounding area, regional variations in coal quality, and possibly differences in the effectiveness of pollution control equipment. Among the top 20 CO_2 emitters, the highest co-pollutant damage in dollars per unit of CO_2 is generated by the W.A. Parish facility in Fort Bend County, Texas.

Table S-2 lists the 20 natural-gas electrical-generation facilities with the highest total carbon emissions. The rate of CO_2 emission per unit of electricity ranges roughly from 300 to 500 kg of CO_2 per MWh of electricity, roughly one-third to one-half that of the coal-fired plants in Table S-1. Again, there are wide variations in co-pollutant damages per unit of CO_2.

Tables S-3 and S-4 show the electrical generation facilities that produce the largest co-pollutant damages for the surrounding population, with Table S-4 again limited to natural-gas facilities.

Some have advocated for natural gas as a so-called "bridge fuel" in the transition from fossil fuels to renewable energy (Weissman, 2016). The rationale is that while coal is carbon-intensive and laden with hazardous co-pollutants, natural gas is cleaner in terms of both carbon emissions and co-pollutants.



A tale of two fuels: highly toxic coal-burning electrical generation units have historically been situated in lower density areas; natural gas-burning plants, still toxic, tend to be located closer to urban and suburban populations.

On the left, the nation's highest-CO_2 coal plant, Scherer (Monroe Co., Georgia), is surrounded by a population of 2,324 people, of whom 20% are Black, 13% are Hispanic, and 48% are low income.

On the right, the second highest CO_2-emitting natural gas plant, McDonough-Atkinson (Cobb Co., Georgia), is surrounded by 60,340 people of whom 40% are Black, 8% are Hispanic, and 25% are low income.

However, natural gas remains a potent source of GHG emissions more broadly. It is now widely recognized that leakages in natural gas production and transmission are a major source of emissions of methane, a potent GHG that is the second most important contributor to global climate destabilization after CO_2.

Moreover, gas-fired power plants are often located closer to population centers, in contrast to coal plants which are often sited in more sparsely populated locations. This spatial difference exacerbates the scale of health impacts from their co-pollutant emissions, and also their environmental justice impacts insofar as the communities in which they are sited have disproportionately proportions of people of color and low-income residents. The plants listed in Table S-4 and others like them will become the backbone of a natural-gas based electrical system if the bridge-fuel model is adopted.

Environmental justice: Demographic correlates of power plant characteristics

To shed light on the environmental justice (EJ) dimensions of choices in power generation, Tables 1, 2, and 3 summarize demographic correlates of fuel type and CO_2 efficiency.

Table 1 shows the percent EJ population living within 15 kilometers of fossil-fuel electricity plants by fuel type. The population around the average coal plant is 8.1% Black, compared to 13.4% for gas plants (and 13.1% for oil-burning plants, which are relatively few in number). For comparison, the Black share of population in the average U.S. county is 9.1% and the the U.S. population is 12.7% Black (the regional and urban concentration of Blacks makes the average county substantially less Black than the nation as a whole).

Table 1. Percent EJ Population near electrical-generation facilities, by fuel type

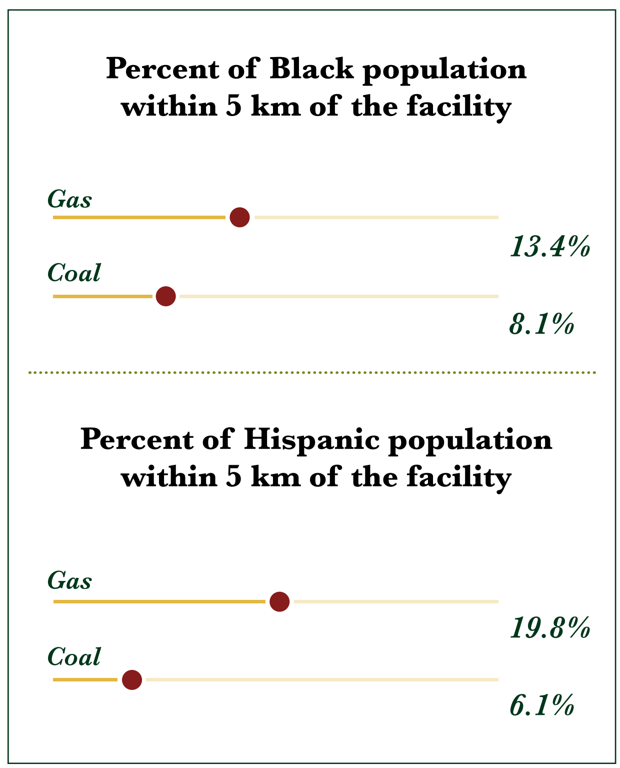
	Black share within 5 km		Hispanic share within 5 km	
Fuel	Mean	95th percentile	Mean	95th percentile
Coal	8.1%	34.9%	6.1%	22.4%
Gas	13.4%	53.4%	19.8%	64.3%

The relatively high concentration of Blacks around natural gas plants is even more striking when we compare not average plants but those in areas that are most disproportionately Black. At the 95th percentile of the percentage-Black distribution for coal-burning plants, 34.9% of the surrounding population is Black. For natural gas plants the corresponding share is 53.4%.

The pattern for Hispanics is similar. The mean percentage Hispanic around natural gas plants is 19.8% compared to 6.1% around coal plants and 11.4% in the average U.S. county. At the 95th percentile the Hispanic share for natural gas plants is 64.3%, compared to 22.4% for coal and 53% for all counties.

For low-income Americans (here defined as those with incomes below 200% of the Federal Poverty Line), the pattern is different: the average shares are similar around coal and gas plants and similar to the national average.

These findings indicate the potential for substantial environmental justice concerns in the shift from coal to natural gas. A decarbonization policy that is based exclusively on carbon-efficiency may result in more electricity generation and co-pollutant emissions in proximity to Black and Hispanic population concentrations.



This does not mean that shifting from coal to natural gas is a bad idea from the standpoints of reducing carbon emissions and improving air quality. What it does mean, however, is that it is important to consider the specific locations where increased electricity generation from natural gas takes place.

Table 2 provides further evidence on the differential damages by fuel type. Coal is unquestionably more locally toxic in total and for EJ populations than is natural gas. But while for the population as a whole and for low-income people, the impact of coal is on the order of 8 times greater than that of natural gas, for Blacks, the impact of coal is less than 4 times larger than that of natural gas and for Hispanics the impact of coal is less than 3 times larger than that of natural gas. While everyone should welcome the demise of coal, if the replacement is natural gas, then not all will benefit proportionately.[2]

Table 2. Co-pollutant damages

	Black	Hispanic	Low Income	All
Fuel	**Total ($ billion)**			
Gas	1.1	1.4	2.2	6.6
Coal	4.0	3.6	17.5	55.3
Oil	0.3	0.1	0.4	1.2

Table 3 divides all fossil-fuel power plants into three groups, each comprising one-third of the nation's total electricity generation capacity, based on their CO_2-efficiency (how much CO_2 is emitted per unit electricity), and compares the least efficient one-third to the most efficient one-third. The least CO_2-efficient plants are disproportionately coal (and oil), whereas the most CO_2-efficient plants are overwhelmingly (94.5%) natural gas. The latter will produce more electricity in the quest for greater CO_2-efficiency.

It is instructive to look at the demographics around these facilities. The most efficient plants are located in more densely populated areas: the total population living within 5 km and 15 km is 80% greater than that around

Table 3. Plant Characteristics and Demographics by CO_2 efficiency

Fuel	Least CO_2-efficient	Most CO_2-efficient
Gas	30.2%	97.6%
Coal	69.8%	2.4%
Population within 5 kilometers		
Mean percent Black	8.2%	13.7%
Mean percent Hispanic	9.5%	20.1%

the least efficient plants. For the least efficient plants the average percentages of Black and Hispanic people in the surrounding areas are comparable to their shares in the average U.S. county. But for the most efficient plants the surrounding population has considerably higher percentages of Black and Hispanic people. In other words, a shift towards greater CO_2-efficiency is likely to impose disproportionate co-pollutant burdens on Black and Hispanic populations.

Summing up, a purely carbon-centric shift from lower CO_2-efficiency to higher CO_2-efficiency power plants will increase the relative exposure of environmental justice populations and has the potential to increase the total population exposure to the co-pollutants.

[2] The Black share in nearby populations is also exceptionally high for biomass and other non-traditional combustibles such as the incineration of plastics, tires and other waste material with high toxic loads per unit of energy. The situation is similar but less extreme for Hispanics.

EVIDENCE FROM SIMULATED DECARBONIZATION SCENARIOS

The question we have laid out — how to incorporate co-pollutant emissions and their distribution into decarbonization strategies — can be modeled as a multi-criteria optimization problem, a method applying linear programming to assess better or worse solutions in the presence of potential tradeoffs.

It is not always possible to achieve the best result in every dimension of a multi-criterion problem. We want to achieve the level of carbon reduction needed to ensure long-term human well-being by limiting the increase in global temperatures to the level set forth in the Paris Agreement. We also want to ensure substantial local air quality co-benefits, and do this in an equitable way that ensures that socially vulnerable and marginalized populations are fully included in these benefits. Finally, we must be attentive to the technological feasibility and cost of emissions reductions at specific locations.

To do this, we impose a set of constraints intended to capture realistically regional requirements for electrical generation capacity. Electricity has limited scope for long-distance transmission, so generation has to be reasonably close to the point of use. For example, wind farms in the Great Plains cannot effectively be used to power California or the eastern seaboard. We therefore use a regional demand constraint to ensure that all of the scenarios reported here meet electricity needs at a regional level. For this purpose, we use the 26 eGRID subregions in the contiguous United States. In effect, we treat these as separate power markets, each of which must be adequately supplied with electricity.

Some of the new renewable energy technologies face the challenge of intermittency. Solar power can only be generated during the daylight hours. Wind power depends on variable wind conditions. Demand management, energy storage, and reliance on other energy sources when wind and solar are not available are among the solutions, but each of these poses challenges. So as not to overestimate the scope for rapid replacement of combustion-based electrical generating capacity with clean and renewable systems, we applied strong constraints on their supply in the model (see Annex A).

Taking the above considerations into account, we first calculate a scenario that simply minimizes the cost of producing enough electricity to meet existing demand in each of 26 subregions with no decarbonization constraint. This resulting mix of electricity generation output across power plants differs somewhat from the actual present-day mix since the latter reflects a range of other factors that are not captured in the model. But this provides a reasonable baseline against which to assess the results of alternative decarbonization policies, analyzed with the same simplifying assumptions.

We then compare three different decarbonization scenarios:

1. **Carbon alone:** The first is a "carbon-alone" policy, focused exclusively on achieving a 20% reduction of CO_2-equivalent emissions (that is, emissions of CO_2 and other greenhouse gases, like methane, which are converted in the EPA data into units equivalent to CO_2 based on their climate impacts). In this scenario, the goal is simply to decarbonize at the lowest possible cost.

2. **Carbon plus air quality:** The second is a "carbon plus air quality" policy that targets emissions reductions at power plants that cause the greatest damages from co-pollutant emissions. For this purpose, we impose the added constraint of reducing co-pollutant damages by 50% compared to the baseline.

3. **Carbon and air quality plus environmental justice:** The final policy scenario, "carbon and air quality plus environmental justice," additionally requires that the 50% reduction in co-pollutant damages is also achieved specifically for Black, Hispanic, and low-income populations nationwide.[3]

Table S-8 provides an overview of the results under these alternative scenarios in terms of nationwide fossil fuel use, CO_2 emissions, and co-pollutant damages for different populations. Our focus here is on the relative contributions of coal and natural gas to each of these in the different scenarios.

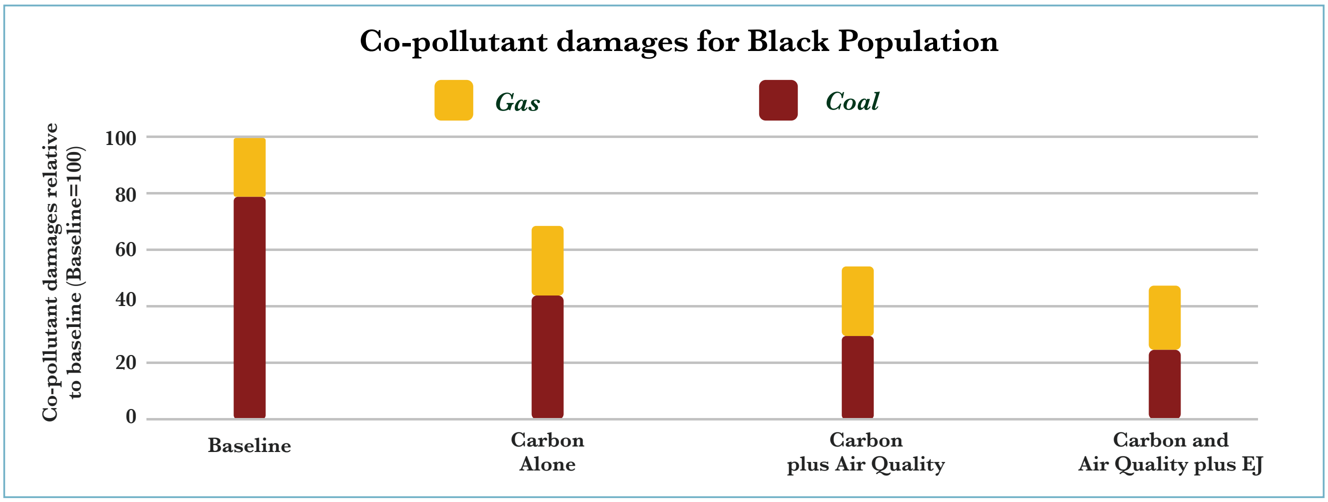
[3] We define low income as people living in households with income below 200% of the Federal Poverty Line. In 2018, 31.5% of all US households were low income by this definition.

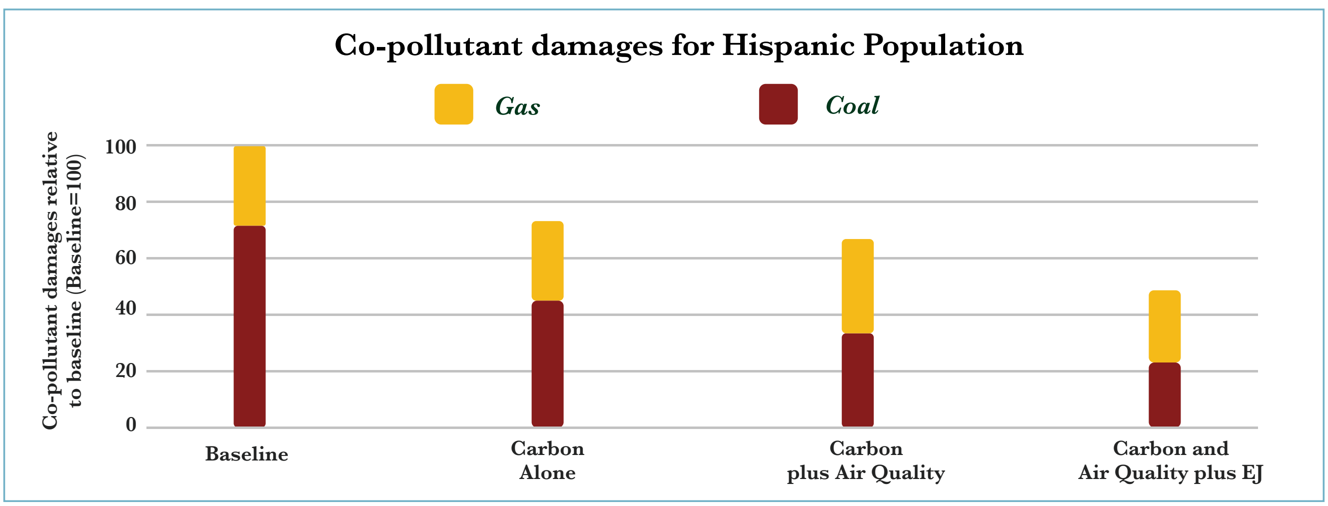
A decarbonization program that is focused on carbon alone leads to a major shift away from coal in favor of natural gas. Coal-fired plants fall from 25.6% of electrical generation to 15%, while natural gas plants increase from 31.3% to 41.9%. Renewables do not grow substantially in this model because much of the 20% decrease in CO_2 can be accomplished simply by means of this shift among fossil fuels.

The shift from coal to natural gas reduces co-pollutant damages overall by one-third. But in the carbon-alone scenario there is an increase in co-pollutant damages from natural gas electricity generating units, which rise by around 30% along with the roughly 30% increase in the share of natural gas in the electricity generation mix. As a result Hispanics, many of whom live near gas-fired plants, see a smaller decrease in total co-pollutant damages than other groups. Moreover, as discussed below, our results indicate that some regions of the country, including the state of California, would actually experience *increased* co-pollutant damages in the wake of a carbon-alone policy.

The other decarbonization scenarios, which incorporate the additional constraints of achieving 50% reductions in co-pollutant damages overall (in the second scenario) and also in EJ communities (in the third), have little further effect on the shares of coal and gas in the electricity mix.[4] But by reshaping decisions as to *which* gas-fired plants are tapped for more power generation, they have major effects on the magnitude and distribution of air quality co-benefits.

In the second (carbon plus air quality) scenario, the 50% reduction in co-pollutant damages overall is almost matched for low-income households, but the reductions for Blacks and Hispanics fall short of that mark. Incorporating the EJ constraint as well (the third scenario) results in further changes in where gas-fired generation is ramped up, again with little impact on the overall mix of coal and gas in the nation's electricity supply.





[4] The co-pollutant constraints here result in only a modest increase in the share of clean renewables, reflecting our conservative assumptions as to the scope for increasing their output and reducing their cost. With more optimistic assumptions, this effect would be stronger.

COST OF INCORPORATING AIR QUALITY AND ENVIRONMENTAL JUSTICE

Decarbonization will have costs as well as benefits. A key question from the standpoint of air quality and environmental justice is what will be the additional cost of doing decarbonization "right" by including these objectives in policy design. The answer is that it is quite inexpensive to incorporate these objectives. What is more, the more ambitious the decarbonization program in terms of its carbon reduction goals, the lower the additional cost of including them.

> *With a 50% decarbonization - a substantially more ambitious and somewhat more expensive decarbonization goal - the additional cost of a 50% reduction in co-pollutant damages is essentially nil, and the additional cost of reducing the burden for EJ communities is on the order of 1%.*

In the scenarios considered here, all based on a 20% reduction in carbon, adding the additional objective of a 50% reduction in co-pollutant damages raises the cost by only 5%. Adding the further objective of reducing the co-pollutant damages by 50% specifically for EJ communities results in virtually no extra cost beyond the 5%. With a 50% decarbonization, i.e., a substantially more ambitious and somewhat more expensive decarbonization goal, the additional cost of a 50% reduction in co-pollutant damages is essentially nil, and the additional cost of reducing the burden for EJ communities is on the order of 1%.

Table 4 compares the additional co-benefits and additional costs of simulated co-pollutant sensitive carbon reduction programs to a 20% decarbonization alone program. The additional co-benefits are more than twice as large as the additional costs, resulting in a total net benefit of $4.75 billion per year when including the air quality target and a total net benefit of $5.77 billion per year when including the environmental justice target as well.

In other words, the inclusion of serious co-pollutant reduction goals that will make a substantial contribution to improvements in public health, especially for vulnerable communities, is a fairly low-cost modification of the decarbonization program.

Table 4. Annual Benefits and Costs of Including Air Quality and Environmental Justice in Decarbonization Program

	Adding Air Quality	Adding Air Quality and EJ
Benefit	$9.56 bn	$10.61 bn
Cost	$4.81 bn	$4.84 bn
Net benefit	$4.75 bn	$5.77 bn

REGIONAL VARIATIONS

Although a carbon-alone policy would reduce overall co-pollutant damages (albeit not as much as in the scenarios that incorporate air quality and environmental justice as policy goals), there are pronounced variations in its effects at regional level. These are shown in Table S-10; the regions are defined by the US EPA's Emissions & Generation Resource Integrated Database (eGRID) and shown in the accompanying map.

> *In a number of other regions, including much of the Midwest and the Carolinas and Virginia, the 20% reduction in carbon is not accompanied by an equivalent reduction in co-pollutant damages.*

Most striking is the perverse impact in the state of California (roughly corresponding to the CAMX region), where co-pollutant damages increase by a whopping 156%, or in other words, by a factor of more than 2.5 (a 100% increase would mean that damages double). The increase is even larger for EJ communities, and the co-pollutant damages for Blacks in California more than triple. A relatively small increase in co-pollutant damages is also found in the MROE region, which includes Milwaukee and other cities in eastern Wisconsin.

This finding is consistent with the study of the impact of California's cap-and-trade by Cushing et al. (2018), which found that co-pollutant emissions increased in some locations, and that these increases were concentrated in communities with higher percentages of people of color.

In a number of other regions, including much of the Midwest and the Carolinas and Virginia, the 20% reduction in carbon is not accompanied by an equivalent reduction in co-pollutant damages.

Table S-11 reports the regional impacts of the carbon-alone scenario specifically for co-pollutants from natural gas power plants. As expected, these largely explain the overall co-pollutant findings for California. But increased co-pollutant damages from this source occur across much of the country.

The regional results underscore the perils of relying on a carbon-alone strategy, and further strengthen the case for incorporating explicit air quality and environmental justice goals into climate policy design.

IMPLICATIONS FOR COMPANIES ADOPTING SCIENCE-BASED TARGETS

In addition to its relevance for public policy, this report carries important implications for the companies that have adopted Science-Based Targets (SBTs) and are seeking to address their "scope 2" emissions in the form of energy purchases as part of their supply chains.

The firms adopting SBTs may be able to incorporate improvements in air quality and environmental justice into their environmental strategies. Again, realizing these potential co-benefits requires deliberate attention to co-pollutants in developing decarbonization plans.

As of December 2020, 1,106 companies have adopted SBTs, pledging to reduce GHG emissions in ways consistent with meeting the 1.5-2 degree C target needed to prevent catastrophic climate changes. In most cases, these companies have pledged to meet these targets with reductions in their direct (scope 1) emissions, and some have gone further and pledged to address supply chain (scope 2) and product life-cycle (scope 3) emissions as well.

While the reduction of GHG emissions reduction is an urgent priority, it need not be the only environmental priority. Companies also have environmental impacts based on their emissions of toxic chemicals. Furthermore these may have disproportionate effects on socially vulnerable populations.

Of the 1,106 companies that have adopted SBTs, nearly 200 operate one or more facilities in the United States that report air or water releases to the US EPA's Toxics Release Inventory (TRI). Using a peer-reviewed method for assessing company performance in terms of toxic releases and environmental justice (Ash and Boyce, 2011), we assessed the performance of each of these companies. The method is described in more detail in Annex C. The assessment rests on the total potential chronic human health risk captured by the US EPA's Risk Screening Environmental Indicators RSEI Score for air releases and the US EPA's RSEI Hazard for water releases.

Table 5 reports the EJ toxics performance of SBT-adopting companies that appear in the top 100 of US EPA RSEI companies for either RSEI Air Risk or RSEI Water Hazard. The air and water ranks show the company's rank among the 5,902 companies that report air releases and 3,296 companies that report water releases to the TRI.

Ten of the SBT-adopting companies have air releases large enough to qualify them for the Air Toxic 100, the list of 100 companies with the highest human health risk from airborne toxic releases in the United States. Thirteen of the SBT-adopting companies have water releases large enough to qualify them for the Water Toxic 100, the list of 100 companies with the highest hazard from waterborne toxic releases in the United States. One company (Clariant AG) appears in both the Air Toxic 100 and Water Toxic 100. (See http://toxic100.org/ for details on these and other companies. A full list of Companies Adopting Science-Based Targets with US Toxics Release Inventory Reports is available at https://www.peri.umass.edu/GreenforAll/sbt-table.)

Each company is also assessed on the basis of the share of the US airborne human health risk from its facilities that is borne by people of color and by low-income people (households with income below 200% of the Federal Poverty Line). For water releases, Table 5 reports the share of the population living within 10 miles of the company's facilities who are people of color or low-income people. In many cases, these shares exceed the percentages of people of color and low-income people in the U.S. population (37.2% and 28.9%, respectively).

TABLE 5: COMPANIES ADOPTING SCIENCE BASED TARGETS WITH TOP 100 US EPA RSEI AIR RISK OR WATER HAZARD

Top Air Polluters Based on US EPA RSEI Air Score

Rank in the PERI Toxic 100 Air Polluters	*Company Adopting Science-Based Target*	*Nonwhite share (US EPA RSEI Toxic Score)*
8	CLARIANT	**58.2**
11	CRODA	**49.7**
14	TERUMO	**32.4**
17	ECOLAB	**78.7**
35	klöckner & co	**59.2**
50	AkzoNobel	**70.3**
62	ArdaghGroup	**43.1**
74	Linde	**47.6**
77	SOLVAY	**57.2**
97	Kingspan	**18.1**

Top Water Polluters Based on US EPA RSEI Water Hazard

Rank in the PERI Toxic 100 Water Polluters	*Company Adopting Science-Based Target*	*Nonwhite Share (Population within 10 miles of facilities)*
7	CLARIANT	**56.6**
19	nemak	**42.9**
69	Cargill	**27.0**
95	TATE & LYLE	**19.8**
63	MITSUBISHI ELECTRIC	**27.4**
63	MITSUBISHI ESTATE	**27.4**
63	NYK LINE NIPPON YUSEN KAISHA	**27.4**
35	AES Tietê	**9.8**
60	sappi	**9.5**
15	suez	**26.5**
71	SUMITOMO CHEMICAL	**14.9**
71	SUMITOMO ELECTRIC	**14.9**
71	SUMITOMO FORESTRY	**14.9**

CONCLUSIONS

Decarbonization of electric power generation will be a key part of any serious effort to address the climate crisis. The transition to clean and renewable electric power will not only bring long-term global benefits by helping to stabilize the Earth's climate, but also will bring more localized and near-term benefits by reducing emissions of the hazardous co-pollutants released by fossil fuel combustion. These air quality co-benefits can strengthen public support for policies to accelerate the clean energy transition.

Low-income communities and people of color are disproportionately exposed to hazardous air pollution, including power plant emissions. Improvements in air quality therefore create important opportunities to reduce this disparity and advance the goal of environmental justice.

The principles that co-benefits should count in policy design, and that policy makers should strive to remedy disproportionate harms inflicted on people of color and low-income communities, are well-established in U.S environmental policy and in the policies of many state governments. Similar policies could — and, we believe, should — be adopted in policies of private-sector entities, including the hundreds of firms that have subscribed to Science-Based Targets for reducing their own carbon footprints.

The explicit incorporation of local air quality and environmental justice goals into decarbonization policy design can enhance these co-benefits, further advancing human health and further consolidating public support for the policy. Indeed, a decarbonization policy focused narrowly on carbon reduction alone could have perverse results, not only of leaving potential health gains on the table but even worsening local air quality in some "hot spots" and exacerbating environmental injustice.

This study has examined how incorporation of these objectives would affect the course of decarbonization in the U.S. electric power sector. To do so, we implemented a linear programming simulation that meets electricity requirements (disaggregated to a subregional level) at lowest cost. We then compared the baseline scenario of zero carbon reduction to three scenarios: first, a policy narrowly focused on the goal of a 20% reduction of carbon emissions from the sector; second, a policy with the additional goal of targeting the dirtiest facilities so as to achieve a 50% reduction of co-pollutant damages; and third, a policy with the additional goal of ensuring the same 50% reduction for Black, Hispanic, and low income populations.

The results show substantial differences in the pattern of decarbonization between the carbon-alone scenario and the two scenarios that incorporate co-pollutant reduction objectives. Overall, the damages from hazardous co-pollutants decrease in the carbon-alone scenario thanks to the phasing out of coal. The results vary substantially across regions, however, and California in particular sees substantially increased damage for the entire population and even more so for Blacks and Hispanics. When decarbonization policy explicitly incorporates air quality and environmental justice objectives into its design, the result is a very substantial reduction in the co-pollutant damages from gas-fired power plants compared to the carbon-alone scenario.

The most notable difference lies in the co-pollutant damages from natural gas-fired power plants. In the first scenario, these damages increase substantially as coal is phased out in favor of natural gas without regard to the extent of health impacts generated by the latter. Gas-fired plants often are located in more densely populated locations than coal-fired plants, and in greater proximity to low-income and predominantly minority neighborhoods.

Comparing the latter two scenarios (carbon plus air quality versus carbon and air quality plus environmental justice), the overall reductions in co-pollutant damages are similar, but substantial differences show up in a fine-grained examination of facility-by-facility results.

Turning to the cost implications of these alternative scenarios, we find that the fulfillment of the clean air and environmental justice goals does not radically change the cost of decarbonization. The cost of meeting these clean air and EJ goals is on the order of 5% more than the cost of a decarbonization focused exclusively on carbon alone. Moreover, the additional cost in meeting these goals declines as the decarbonization target is tightened.

Environmental policy in the United States has long accepted the principle that co-benefits, such as the clean air improvements brought about by decarbonization, ought to be included in cost-benefit analyses. The federal government has also accepted the principle that its policies should aim to remedy the disproportionate exposure of people of color and low-income communities to environmental harms.

President Joe Biden has committed his administration to incorporating air quality and environmental justice into its clean energy plans. During the presidential campaign Biden said he would "prioritize strategies and technologies that reduce traditional air pollution in disadvantaged communities." Specifically, he pledged to deliver 40% of the overall benefits from a clean energy revolution, including "reduction of legacy pollution," to disadvantaged communities, using a Climate and Economic Justice Screening Tool to help identify them.[5]

There can be no excuse for failure to act upon and achieve these important goals. The analysis presented in this report can help to inform the design of policies to this end. It would be feasible and desirable, for example, to include explicit clean air and environmental justice criteria alongside decarbonization in formulating Clean Energy Standards (CES), to mandate that electricity providers not only increase the share of clean and renewable energy in power generation but also meet standards for reducing co-pollutant emissions overall and specifically impacting EJ communities.[6] Doing so would ensure that the contribution of fossil fuels to our electricity supply is phased out and that reductions are prioritized where the public health and environmental justice benefits are greatest.

There can be no excuse for failure to act upon and achieve these important goals.

It is eminently feasible to adhere to these principles in designing climate policy, and our analysis indicates that it can be done at a reasonable cost. This will require moving beyond a narrow focus on carbon alone, however, to embrace clean air and environmental justice as policy objectives that play a prominent and complementary role in the design of decarbonization strategies.

[5] *The Biden Plan to Secure Environmental Justice and Equitable Economic Opportunity*, July 2020, https://joebiden.com/environmental-justice-plan/
[6] This is similar to, but distinct from, a policy mandating that a specific share of green energy investments be targeted into EJ communities, another goal set in the Biden-Harris plan. For discussion of the latter, see Stokes et al. (2021).

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ANNEX A
ALTERNATIVE SCENARIOS FOR DECARBONIZATION: LINEAR PROGRAMS FOR EQUITABLE CARBON REDUCTION

Our goal is to assess different programs for energy generation and emissions reduction in the electrical generation sector that will meet electrical demand, minimize cost, meet greenhouse-gas reduction targets, and reduce co-pollutant exposure.

A program is a choice of electrical generation for every available electrical facility that meets the electricity demand of customers and meets all of the pollution reduction goals specified by public or private decision makers. The cost of a program for a single plant is the operation and maintenance cost, including fuel, for all of the electricity generated by the plant. The total cost of a program sums the cost for each plant based on the amount of electricity that each plant produces. (Anjos and Conejo, 2017).

We assume that the electrical generation sector, which is largely private and profit-making, will choose the least expensive way to meet electricity demand subject to regulatory constraints. This assumption lets us apply a widely used method, linear programming, to model how the sector will respond to new constraints (Anjos and Conejo 2017).

Cost for a generating facility is the energy output of the facility multiplied by the cost per unit energy of the fuel used by the facility. The linear programming system is constrained to meet the actual energy demand of a previous year (2018) on a region-by-region basis. Thus, additional energy produced in, say, California, cannot be used to meet an energy shortfall in New England in the attempt to meet greenhouse gas reduction goals.

For additional realism, we also require that electrical-energy demand be met around the clock, by specifying times of day in which renewable energy sources, i.e., wind and solar, are not available because of intermittency. Solar is not available when the sun is not shining; wind energy is not available when the wind is not blowing. The problems of providing baseload and confronting the intermittency of renewable sources is sometimes managed by modeling hourly energy production on an annual basis. The data we use do not permit year-round hourly modeling, and we instead divide each day into four periods: 16 hours per day when neither solar nor wind is available; 3 hours per day when wind but not solar is available; 2 hours per day when solar but not wind is available, and only 3 hours per day when both solar and wind are available.

These constraints reflect a conservative stance with respect to the intermittency problem and the imperative of meeting electrical energy demand and avoiding blackouts or brownouts. The model also assumes, conservatively, that no GHG reductions will be affected via energy efficiency. Shortfalls in energy production to meet the constraints are made up with backstop technologies with a higher cost per kilowatt-hour.

We use a sequence of four programs that characterize how the electrical generation sector will respond to these multiple constraints. In each case, the sector seeks to minimize its cost of energy production while meeting the constraints of the program.

1. **No decarbonization:** The baseline program is the cost-minimizing solution that does not seek to reduce either CO_2 or co-pollutant emissions, and is constrained only by meeting electrical energy demand on a region-by-region basis. As noted above, the electrical generation has to meet regional demand, reflecting the reality that energy produced, say, by hydro power in upstate New York cannot be feasibly shipped to meet demand in Nashville, Tennessee, or Phoenix, Arizona. The baseline program also requires that electrical generation meet electrical energy demand at all times of day. The point of the baseline program is to describe what energy generators are already doing: producing energy for profit, which is captured by the choice of the least costly production mix, to meet consumer electrical demand.

2. **Carbon alone:** We then introduce an overall CO_2-equivalent reduction target. While keeping the constraint of the baseline to generate enough electricity to meet demand within each region and over the course of the day, the system must also meet a targeted reduction in total GHG emissions. The GHG reduction target is modeled on the Science-Based Targets of We Mean Business, a non-profit alliance of private-sector companies that have committed to meeting GHG reduction targets in their own activity and in their supply chains.

3. **Carbon plus air quality:** We then introduce a target for reducing the human health impact from local pollution. While meeting the electric generation demand and the GHG reduction constraint, the program must also meet a targeted reduction in the local pollutant (expressed in terms of potential chronic human health damage).

4. **Carbon and air quality plus environmental justice:** We then introduce targets for reducing the human health impact from local pollution for specific socially vulnerable environmental-justice populations, for example, defined for the purpose of this exercise as Blacks, Hispanics, and low-income people living below twice the Federal poverty line.

First, we compute the baseline program for the universe of electrical generation facilities that minimizes cost per unit of energy. We then extend the model to minimize cost while achieving a specified reduction in total CO_2-equivalent greenhouse gas emissions from generation activity. We consider a 20% reduction in CO_2-equivalent greenhouse gas emissions, a near-term goal that is consistent with roughly an 80% reduction by 2050. We compute the collateral benefits of this reduction program in terms of reduced chronic human health damages from local pollutants that will be associated with the reduction in greenhouse gas emissions. Because minimizing cost per unit of energy without a constraint on co-pollutant reductions is the guiding objective of this program, there may well be missed opportunities for co-pollutant reduction at low cost.

Then we compute an alternative decarbonization program that, in addition to minimizing cost while achieving a specified reduction in total CO_2-equivalent greenhouse gas emissions from generation activity, adds a constraint for a 50% reduction of co-pollutant impact overall, and then the additional constraint of a 50% reduction of co-pollutant impact for Black, Hispanic, and low-income people, while still achieving a specified reduction in total CO_2-equivalent greenhouse gas emissions from generation activity.

For each facility, indexed by i, c_i is a fuel-specific cost per unit of energy expressed in dollars per MWh.

E_{qis} is total annual net electrical energy generation in MWh at time-of-day q for plant i in subregion s, and E_{is} sums the electrical generation over periods of the day to express the total annual energy generation of facility i. In addition to existing plants 1 to I_s, each region also has the ability to add new renewable capacity, effectively, an additional plant $I + 1_s$ that will, at the relatively high cost of installing and operating the new capacity, meet regional demand. In this way we ensure that the electrical energy plans meet regional demand and do not permit brownouts or blackouts. Regional demand is defined as the 2018 electrical use for the region. This guarantee is, thus, highly conservative in the sense that it assumes no reduction in energy demand from conservation or pricing measures. Every energy plan presented guarantees full provision of electricity to users at historical levels.

M_{qis} is the nameplate capacity in MWh per year of facility i in subregion s at time of day q. No plant can exceed its time-of-day capacity for the amount of energy produced at that time of day throughout the year.

G_i is total plant CO_2-equivalent greenhouse gas emissions in metric tons for facility i, and $g_i = G._i / E._i$ is the plant i average rate of CO_2-equivalent greenhouse gas emissions in kg per 2018 plant unit of electrical energy generation in MWh computed from 2018 totals for CO_2 and electrical generation. We assume that the marginal rate of CO_2-equivalent greenhouse gas emissions per electrical energy generation is equal to the historical average rate of plant-specific CO_2-equivalent greenhouse gas emissions per electrical energy generation.

P_i is the total potential chronic human health damage from local pollution exposure for the facility for the entire population living within 50 km of the facility. $p_i = P_i / E_i$ is the total potential chronic human health damage per unit of electrical energy generation. As with GHG, we assume that the marginal rate of local pollution per electrical energy generation is equal to the historical average rate of plant pollution per unit of electrical energy generation. P_i^j is the total potential chronic human health damage from local pollution exposure for the facility for specific community j.

The fuel-specific cost of generation is compiled from various sources, including Klein and Whalley (2015) and Nock and Baker (2019). In general, we use the operation and maintenance cost per unit electricity to characterize the cost of generation at existing facilities and a levelized cost-of-energy measure to express the cost of generation at newly constructed renewable-energy facilities.

The capacity figures are taken from the U.S. EPA eGRID 2018 database, which in turn draws on data from the Energy Information Administration (EIA). We take hydro and geothermal facilities to be currently operating at maximum potential. Solar and wind can produce at their maximum wattage (power) but their effectiveness varies over the time of day. We constructed a 24 day in which solar and wind are both available for 3 hours per day, solar but not wind is available 2 hours per day, wind but not solar is available for 3 hours per day, and there are 16 hours per day when neither wind nor solar is available. These assignments were based on consultation with experts in the field of energy economics and policy.

Regional demand and average rate of CO_2-equivalent greenhouse gas emissions figures are also taken from the U.S. EPA eGRID 2018 database.

The information on the impacts of local pollutants comes from the Air Pollution Emission Experiments and Policy (APEEP) model. The APEEP model is a peer-reviewed integrative assessment model that provides reliable damage estimates, in dollars, for the electrical generation sector. We use eGRID data on each of three leading pollutants (SO_2, PM2.5, NO_x) released by each facility, multiplied by the APEEP-estimated damage in dollars per ton for that pollutant released, which varies based on which county the facility is located. The rate of damage per unit of CO_2 or per MWh of electricity is the total damage divided by tons of CO_2 or MWh of electricity produced by the facility. We introduce environmental justice by computing the demographic shares within a 15-km radius of facilities. For the purposes of the present analysis, we assume that the demographic distribution of non-health damages mirrors that of health damages. We apportion these estimated impacts to environmental-justice populations on the basis of population shares within 5 km or 15 km of the generating facility.

A.2 Baseline cost-minimization model

As a first step, we will solve the following constrained minimization problem:

$$\min_{E_{qi}} \sum_{i=1}^{I} c_i \cdot E_{qi}$$

Subject to:

$$\sum_{i=1}^{I_{q,s}} E_{qi} \geq E_{q,s}^{2018} \quad \forall\, s,q$$ (Meet 2018 demand for every region by time of day)

$$M_{qi} \geq E_{qi} \geq 0$$ (Facility non-negativity and capacity)

This linear program yields an energy output E^*_{qi} for each facility i (in region s) at each time of day q, with the times of day corresponding to capacity varying because of fuel-specific intermittency. Summing over the four times of day yields E^*_i the optimal energy output for each facility. Every facility can be assessed in terms of its optimal energy output E^*_i, the cost of generation $ci \bullet E^*_i$, the output of greenhouse gases $gi\, E^*_i$, and the population exposure from local pollutants $pi \bullet E^*_i$. The total energy, cost, greenhouse gas emissions, and local pollutant exposure from operating the electrical generation system, stratified by region, fuel, or ownership, is the sum of the facility-level results.

A.3 Carbon emissions reduction

Beginning with the Baseline Cost-Minimization model, we add the greenhouse gas constraint:

$$\min_{E_{qi}} \sum_{i=1}^{I} c_i \cdot E_{qi}$$

Subject to:

$$\sum_{i=1}^{I_{q,s}} E_{qi} \geq E_{q,s}^{2018} \quad \forall\, s,q$$ (Meet 2018 demand for every region by time of day)

$$M_{qi} \geq E_{qi} \geq 0$$ (Facility non-negativity and capacity)

$$\sum_{i=1}^{I} g_i \cdot E^*_i \leq G$$ (Total GHG target)

where G is the Greenhouse Gas Emission Target. We specify the target as a percentage of 2018 emissions, with $G := (1-\tau) \cdot \sum_{i=1}^{I} g_i \cdot E^{2018}{}_i$,where τ is the targeted percent reduction in Greenhouse Gas emissions.

This second linear program will give us a set of generation values for each facility at each time of day q, and again summing over the four periods of the day yields a generation value for each facility.

Multiplying facility energy generation by the cost per kilowatt hour at the facility and summing up over all facilities will give us a total $\sum_{i=1}^{I} c_i \cdot E_i$ cost, of generating electricity to meet demand while reducing CO_2-e emissions.

The linear programming approach finds the most efficient way, in terms of minimizing costs, to meet the full set of constraints. We evaluate the difference in cost between the baseline program and the program that incorporates the baseline and the GHG-reduction constraint. We can also evaluate the difference in terms of benefits of reduced damage from the reduction of co-pollutants.

A.4 Co-pollutant emissions goal

We next add the overall co-pollutant damage reduction goal:

$$\min_{E_{qi}} \sum_{i=1}^{I} c_i \cdot E_{qi}$$

Subject to:

$\sum_{i=1}^{I_{q,s}} E_{qi} \geq E_{q,s}^{2018} \quad \forall s,q$ (Meet 2018 demand for every region by time of day)

$M_{qi} \geq E_{qi} \geq 0$ (Facility non-negativity and capacity)

$\sum_{i=1}^{I} g_i \cdot E^*_i \leq G$ (Total GHG target)

$\sum_{i=1}^{I_s} p_i \cdot E^*_i \leq P_s \; \forall s$ (Co-Pollutant Damage Target for every region)

This will again yield an electrical generation program specifying the electrical output for each facility at each time of day *q*.

Multiplying electricity output by the unit cost and summing over facilities will give us a total cost of production which expresses the cost of meeting electrical demand, achieving the GHG reduction target and adding the constraint of reducing co-pollutant damage. We can then evaluate the difference in cost between this, the baseline program, and the CO_2 reduction program. We can also evaluate the difference in terms of benefits of reduced human health damage from reduction of co-pollutants.

A.5 Environmental justice goal

APEEP can be an expression for the potential chronic human health damage for the entire population living within 50 km of the facility, and we create a related measure to express the impact on specific socially vulnerable environmental-justice populations. These energy values can similarly be compared with both programs. For example, we can compare with the following constrained minimization problem.

We next add the overall co-pollutant damage reduction goal:

$$\min_{E_{qi}} \sum_{i=1}^{I} c_i \cdot E_{qi}$$

Subject to:

$\sum_{i=1}^{I_{q,s}} E_{qi} \geq E_{q,s}^{2018} \quad \forall s,q$ (Meet 2018 demand for every region by time of day)

$M_{qi} \geq E_{qi} \geq 0$ (Facility non-negativity and capacity)

$\sum_{i=1}^{I} g_i \cdot E^*_i \leq G$ (Total GHG target)

$\sum_{i=1}^{I_s} p_i \cdot E^*_i \leq P_s \; \forall s$ (Co-Pollutant Damage Target for every region)

$\sum_{i=1}^{I_s} p_i^j \cdot E^*_i \leq P_s^j \; \forall j,s$ (EJ Co-Pollutant Damage Target for every region and group)

We can similarly compare this set of proposed electrical generation values E_{qi} for each facility at each time of day q by summing over q to get total annual electrical generation per facility, E_i, multiplying by unit-cost. and summing over facilities to get the total system cost $\sum_{i=1}^{I} c_i \cdot E_i$

This total cost can be used to evaluate the difference in cost between the baseline program, the CO_2 reduction program, and the overall RSEI score program. We can also evaluate the difference in terms of benefits of reduced human health damage from reduction of co-pollutants to both the baseline, the CO_2, and the overall RSEI score program. We can also similarly compare with this constrained minimization problem for different socially vulnerable environmental-justice populations, or by including all socially vulnerable environmental-justice populations in one model.

ANNEX B
ELECTRICAL FACILITIES: LOCAL POLLUTANT EXPOSURE DAMAGE

We employ the Air Pollution Emission Experiments and Policy (APEEP) model to assess the impacts of the co-pollutants (for review, Muller, N. Z., and Mendelsohn, R., 2006).

The APEEP model is a highly regarded peer-reviewed integrative assessment model that provides reliable damage estimates for the electrical generation sector. Integrative assessment includes information on the fate and transport of the pollutants released, the toxicity of the various pollutants, and exposed populations and other ecological receptors to provide a full assessment, often measured in money, of the environmental impact of polluting activity, such as electricity generation.

In addition to adverse effects on human health, APEEP assesses damage done by each emitted ton of five pollutants, volatile organic compounds, NH3, SO_2, NO_x, and PM2.5, in terms of reduced yields of agricultural crops and timber, reductions in visibility, enhanced depreciation of man-made materials, and damages due to lost recreation services. APEEP estimates damage done per ton of released pollutant based on the county in which the release occurs. The damage estimates from APEEP are estimated in dollars using a variety of standard EPA and other peer-reviewed valuation methodologies, including the EPA Valuation of a Statistical Life (VSL).

Among applications, APEEP was selected by the National Academy of Sciences for its 2010 report *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* (NAS 2010).

The US EPA eGRID program provides data on how much of each of three leading pollutants (SO_2, PM2.5, NO_x) are released by facility. We use 2018 data, the most recent available at the time of the analysis.

The total damages P_f from facility *f* in county *c* adds up, for three leading pollutants (SO_2, PM2.5, NO_x), the quantity (q_{tf}) in tons of each local pollutant t released by the facility multiplied by the APEEP-estimated damage in dollars per ton (d_{tc}) for that toxic released in county *c* where facility *f* is located:

$$P_f = \sum_{t \in SO_2, PM_{2.5}, NO_x} q_{tf} \times d_{tc}$$

By converting physical quantities into dollars of damage, the expression for damages per ton, d_{tc}, makes it possible to combine different pollutants on a common scale. This term depends on the characteristics of the toxic, the magnitude of the population and other receptors, and the transport of the toxic. The rate of damage per unit of CO_2 or per MWh of electricity is the total damage P_f divided by tons of CO_2 or MWh of electricity produced by the facility.

The key elements of the risk and damage created by an electrical generation facility depends on the number of people living near the facility, the level of activity, i.e., the amount of electricity generated, and how much and which fuels are used. The first two elements are readily determined from the latitude and longitude of the facility, which can be matched to population data from the U.S. Census, and the electrical generation report.

The original APEEP model does not have environmental justice capacity. We introduce environmental justice by computing the demographic shares within a 15-km radius of facilities. For the purposes of the present analysis, we assume that the demographic distribution of non-health damages mirrors that of health damages. We apportion these estimated impacts to environmental-justice populations on the basis of population shares within 5 km or 15 km of the generating facility.

ANNEX C
OTHER INDUSTRIAL FACILITIES: LOCAL POLLUTANT EXPOSURE DAMAGE

The US EPA's Risk Screening Environmental Indicators (RSEI) is a peer-reviewed model that brings toxicity-weighting, fate-and-transport modeling, and population exposure to underlying data on the quantity of industrial toxic pollutant releases from facilities, including many fossil-fuel electricity generating units. RSEI characterizes each chemical release from every facility on the basis of the potential chronic human health risk to the exposed population in a 50-kilometer (31-mile) ring around the facility. Some pollution travels farther than 50 kilometers, but the 50-kilometer ring includes a substantial share of the risk from high-impact toxic releases.

The RSEI score that emerges from the RSEI model is a linear measure of the total population chronic human health risk. Linear means that twice as many people exposed to the same risk is twice as bad, twice the amount of release is twice as bad, or the release of a chemical that is twice as toxic is twice as bad. It is a unitless measure (rather than, for example, being expressed in the number of expected cancer cases per 1,000,000 persons), but it permits meaningful comparisons of pollution impacts across facilities.

RSEI is used by state as well as federal environmental agencies to assess pollution risks and prioritize enforcement actions. For example, it has been embedded into CalEnviroscreen, a multi-criteria tool used by the California EPA's Office of Environmental Health Hazard Assessment to identify communities with high pollution and vulnerability (California Office of Environmental Health Hazard Assessment, 2014). RSEI has also provided the empirical backbone for research on public exposure to industrial toxics and research on differential exposure along lines of race, ethnicity, and income class (see, for example, Ash and Fetter, 2004; Ash et al. 2009; Ash and Boyce, 2010; and Zwickl et al. 2014).

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