Integrating air quality and health considerations into power sector decarbonization strategies

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1. Introduction

Climate change and public health are two interconnected societal challenges. Curbing fossil-based electricity generation reduces the emissions of both CO_2 and air pollutants, which brings tangible health benefits from improved air quality. The potential health benefits from decarbonizing the grid are enormous, immediate, and widespread. From renewable portfolio standards to carbon market, the health co-benefits from clean electricity policies often outweigh their policy costs (1–3). As climate action goes local, framing decarbonization around health benefits also makes it more personally relevant and economically attractive.

Yet, to date, the health impacts have largely been viewed as ancillary benefits from decarbonization, rather than as a core consideration when energy strategies are formed, assessed and implemented. When strategic choices are made about retiring old infrastructure and building new ones, bringing public health to the center of the discussion can generate greater health benefits with more equitable distribution.

Here we identify concrete ways to incorporate air quality and health considerations into power sector decarbonization strategies. We draw insights mainly from empirical and modeling evidence for the United States. These insights are generally applicable and could guide health-oriented decarbonization efforts in other countries as well.

2. Importance of power sector decarbonization for air pollution and health

Air quality has improved substantially in the United States in the past decades, thanks to the tightening of pollution controls and the transition from coal to gas. Yet, the exposure to ambient air pollution is still associated with 100,000 to 200,000 annual deaths (4–6), among which 10-15% are caused by emissions from the electricity sector (5,6).

To understand the plausible future patterns, here we review evidence from a series of assessments we conducted using a leading integrated assessment model, the Global Change Analysis Model with state-level representation for the US. We highlight three core insights from our modeling exercises.

First, current federal and state regulations that promote clean electricity generation provide huge potential for reducing air pollution and health impacts. For instance, in a Reference scenario that considers existing policies, we found that current mandates and regulations facilitate both fuel switching (e.g., from incentives for clean electricity such as the Renewable Portfolio Standards) and the lowering of emission intensities (e.g., from regulations such as the New Source Performance Standards). Consequently, the estimated $PM_{2.5}$-related mortality costs per unit of power generation would decrease by 36% from 2015 ($86/MWh) to 2050 ($55/MWh) nationally. Despite 31% higher electricity demand, the nationwide mortality costs from electricity-related emissions are reduced by 44% over this time period (see Figure 1a; more in Ou et al., 2020 (7)).

Second, the health impacts from power generation activities vary substantially across subnational regions, which demonstrates significant regional inequality (Figure 1c). Such variations are driven by cross-state differences in fuel sources, economic structure, population density, and atmospheric transport and dispersion of pollutants. Looking into the future, we found the states with the following features have a larger potential for reducing the pollution and health impacts (Figure 1d): (i) smaller increases in population and economy, (ii) greater decreases in emission factors per unit fuel consumption (from both fuel switching and end-of-pipe controls on fossil facilities), and (iii) abundant renewable resources to replace coal-based electricity (8). As found in other studies too, socio-demographic, technology, and economic drivers will collectively shape the future spatial patterns (5).

Third, coordinated efforts between electricity and end-use sectors are critical. Thanks to the increasingly affordable renewables and electric vehicles, electrifying road transport with decarbonized electricity is a widely acknowledged strategy for decarbonization. Plenty of end-of-pipe control technologies also exist to remove air pollutant emissions from thermal power plants (e.g., wet flue gas desulfurization and low-NO_x burners). As such, we found that current policies are quite effective in lowering the health damages from the power and transportation sectors (Figure 1a). However, to achieve deeper pollution reductions beyond current policies, two areas need more attention. First is the highly-polluting sources in industry and building sectors. We found that targeting highly emitting sources of primary $PM_{2.5}$ in the industry and building sectors (e.g., industrial coal boilers and residential biomass burning) can reduce nearly half of the $PM_{2.5}$-related mortality costs in the Reference case in 2050 (Figure 1b; more in Ou et al., 2020 (7)). This is because primary $PM_{2.5}$ emissions contribute directly to the ambient $PM_{2.5}$ (as compared to SO_2 and NO_x emissions from power plants that contribute to secondary $PM_{2.5}$ through chemical reactions) (9). The emissions from residential sources are also often at the ground level and close to the exposed population (10). Second is to shift away from fossil fuels to achieve deep decarbonization in all end-use sectors. Electrification of residential uses (e.g., heating and cooking) and selected industrial processes provides a promising opportunity to eliminate the carbon and air pollutant emissions from those activities.

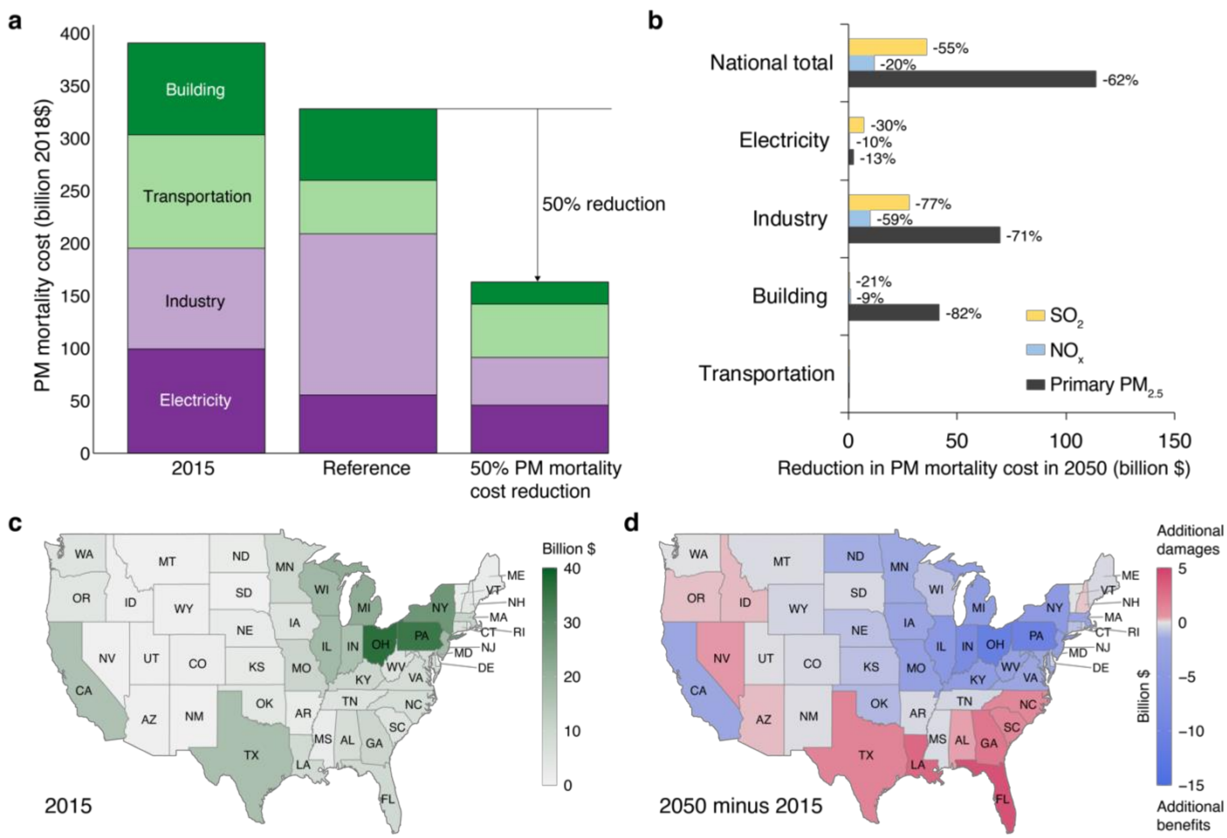

Figure 1. National and state-level monetized $PM_{2.5}$-related mortality cost (billion 2018$). (a) National PM mortality cost in 2015 and under two 2050 scenarios, a *Reference* case that assumes implementation of current policies and a *50% PM mortality cost reduction* case that applies a target to reduce the economy-wide PM mortality cost by 50% relative to Reference. (b) Reduction in pollutant-specific PM mortality cost by sector to achieve a 50% economy-wide PM mortality cost reduction target

in 2050 (i.e., comparing the *50% PM mortality cost reduction* case to the *Reference* case). (c) State-level PM mortality cost in 2015. (d) Changes in PM mortality cost in 2050 relative to 2015 in the Reference case. Note that the Reference case includes major clean electricity regulations currently in place, without additional future regulations being considered (see more details in Ou et al., 2019 (8)). The results here are based on Ou et al., 2020 (7).

3. Four priorities for integrating air quality and health considerations

Drawing insights from our own analyses and a growing literature in this space, we identify four priorities for integrating air quality and health considerations into power sector decarbonization strategies (Figure 2).

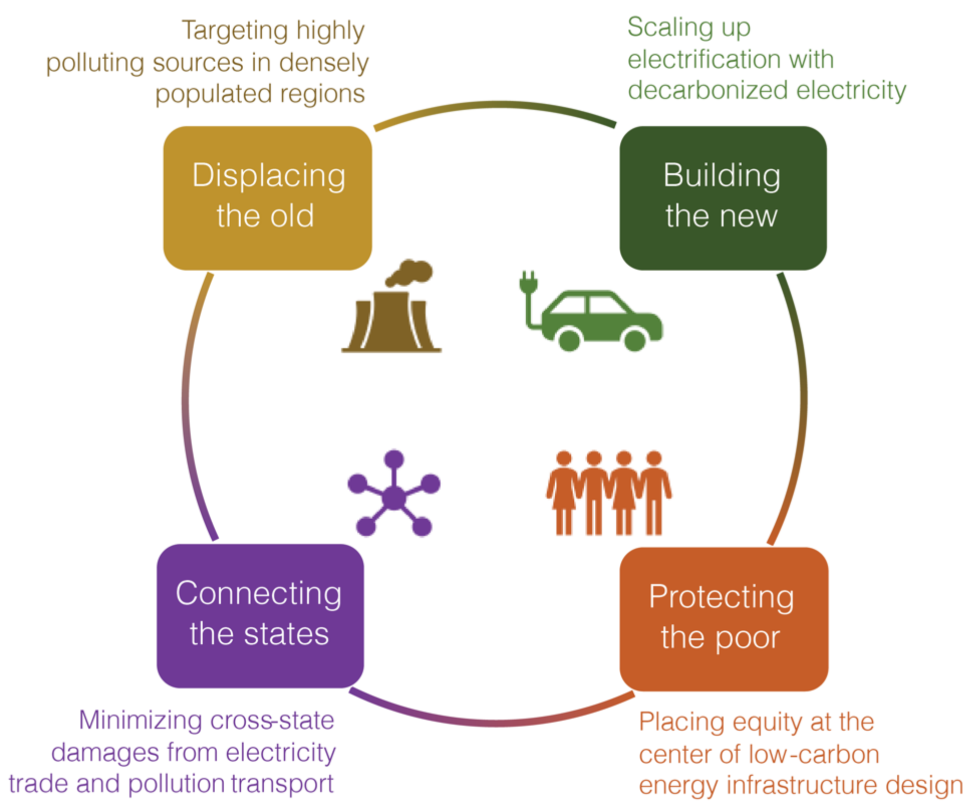

Figure 2. Four priorities for integrating health considerations into power sector decarbonization strategies.

i) Displacing the old: Targeting highly polluting sources in densely populated regions

Location matters. Air quality and health damages from fossil-based generation vary greatly across plant facilities. This variation is not only driven by plant characteristics such as fuel type and emission control devices. Location plays a central role too, due to the cleanness of the local grid and size of affected population. As low-carbon generation displaces conventional generation, the health effects can vary dramatically across the United States. For instance, despite greatest solar resources in the Southwest, a solar panel in New Jersey may displace significantly more air pollutant emissions than a panel in Arizona, given the higher share of coal power in the local grid. By further considering the regional variations in population density and meteorology, the associated health benefits were estimated to be 15 times higher for a panel installed in New Jersey than in Arizona around 2010 (11). Such regional differences may have changed and will continue to change over time as demographic patterns and fuel mixes evolve.

Targeting regions with high pollution and large population increases the health benefits from displacing existing fossil-based infrastructure. Indeed, a recent study found that based only on operational cost and climate damage considerations, reducing 30% of the power sector CO_2 emissions throughout the country can yield $21-68 billion annual health benefits. Yet, with the same carbon mitigation target, prioritizing reductions in counties with high population exposure can accrue additional benefits of $9-36 billion (12). Realizing these additional benefits demands a change in perspective when designing clean electricity policies – from viewing the health effects merely as “co-benefits” of climate action to a central part of the policy evaluation.

ii) Building the new: Scaling up electrification with decarbonized electricity

End-use matters. Tackling climate change requires decarbonization efforts beyond the electricity sector. For instance, the residential and transport sectors are not only major sources of carbon emissions; they also currently account for 13% and 19% of national total air-pollution-related deaths, respectively (6). Looking forward, deep decarbonization can be achieved by different technology pathways that are associated with different pollution and health impacts. For instance, wind and solar electricity is zero-emitting in both CO_2 and air pollutants. In contrast, biofuel for transportation use emits a non-trivial amount of air pollutant emissions during the combustion process, along with additional emissions from upstream agricultural activities (13). Emerging low-carbon technologies, such as hydrogen, could also result in new sources of air pollution (14).

Scaling up electrification with a decarbonized electricity system is a promising strategy to address climate and health objectives simultaneously. Indeed, technology pathways that rely on end-use electrification fueled by renewable electricity can yield much larger health benefits than alternative decarbonization pathways that rely more on bioenergy. A study on California found that to remove 80% of all-sector CO_2 emissions, a pathway that depends on electrification and clean renewable energy leads to 3 times higher health co-benefits than the pathway relying more on combustible renewable fuels (15). Similar results have been found at the national level, too (16,17).

iii) Connecting the states: Minimizing cross-state damages from electricity trade and pollution transport

Transport matters. The health impacts can cross state borders, both directly through wind transport of pollution and indirectly through grid transmission of electricity. As wind blows air pollution to downwind regions, half of the deaths related to air pollution are linked to out-of-state emissions (5). Compared to other economic sectors, emissions from electric power generation also have the greatest cross-state impacts as a fraction of their total impacts, because smoke stacks are tall and wind blows faster at higher elevations (5). Therefore, decarbonizing the electricity sector in upwind states could clean up the air in downwind states, reducing the impacts of interstate pollution transport that is currently regulated under the Cross-State Air Pollution Rule.

In addition, as power grids transport electricity across states, a cleaner generation fleet in one state could have complex implications on the electricity market operations locally and elsewhere. For instance, as Pennsylvania plans to join the Regional Greenhouse Gas Initiative (RGGI) in 2022, the Commonwealth is anticipated to accrue cumulative air quality-related health co-benefits of $17.7-40.8 billion from now to 2030 (18). However, Pennsylvania is part of the PJM electricity market, where many other states are not a member of RGGI. As a result, coal power plants in these non-RGGI states may be dispatched more in the PJM market, because they are not subject to a carbon price and hence more cost-competitive than those in Pennsylvania. The potential “leakage” issue could result in increased emissions and health co-harms outside Pennsylvania (18).

Accounting for these direct and indirect cross-state linkages is important in understanding the health impacts from clean electricity policies both locally and in interconnected regions. Interstate cooperation would be needed to encourage participation from other states that benefit from a cleaner grid and to ensure that efforts in one place would not lead to unintended consequences elsewhere.

iv) Protecting the poor: Placing equity at the center of low-carbon energy infrastructure design

Equity matters. The poor and minority communities have been suffering more from the dirty air and health burden caused by coal-fired power plants (4,19). The scale of health disparities differ by state and electricity market regions. For instance, black people are found to have the highest air pollution-related mortality risks in the MISO and PJM grid regions (19). These differences depend on where people live in relation to power plants, the share of coal in local generation mix, and whether the state is a net electricity importer or exporter.

The potential impacts of low-carbon transition on pollution and health inequities are complex. For instance, closing the polluting coal plants may lower the pollution among disadvantaged communities that live close to those facilities. In comparison, the adoption of electric vehicles (EVs) improves air quality mainly in urban centers; yet, depending on how/where the electricity and battery is produced, pollution may go up in other communities living near those power and industrial facilities that support the EV transition.

Incorporating equity considerations into the low-carbon infrastructure design is crucial to manage the potentially conflicting goals for decarbonization and equity. Better and smarter pollution monitoring system is needed to characterize exposure disparities at fine scale (10). Advancement in modeling capabilities is also important to represent and quantify the multi-sector dynamics that influence the health drivers, exposures, and outcomes. More broadly, cleaner air for all is only one aspect of a just energy transition. In addition to policies that target the technology and infrastructure system, we also need policies targeting the affected communities to provide social and economic support that can address other transition impacts (20).

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