The Clean Power Plan in Ohio

Analyzing power generation for health and equity

Prepared for NextGen Climate America
by PSE Healthy Energy

July 2016

About PSE Healthy Energy

PSE Healthy Energy is a non-profit energy science and policy research institute dedicated to supplying evidence-based, scientific and technical information and resources on the public health, environmental and climate dimensions of energy production and use. Our work predominantly focuses on unconventional oil and gas development, renewable energy, and energy storage. The mission of PSE Healthy Energy is to bring scientific transparency and clarity to energy policy discussions, helping to level the playing field for citizens, advocacy groups, the media, agency staff, and elected officials by generating, translating, and disseminating scientific information. No other interdisciplinary collaboration of physicians, scientists, and engineers exists to focus specifically on health and sustainability at the intersection of energy science and policy. PSE Healthy Energy has offices in Oakland, CA, Ithaca, NY, and New York, NY.

Lead author

Elena Krieger, PhD | PSE Healthy Energy

Contributing authors

Ana McPhail, PhD | PSE Healthy Energy

Dev Millstein, PhD | Berkeley Analytics and Research, LLC

Arman Shehabi, PhD | Berkeley Analytics and Research, LLC

Eliza Czolowski, MPS | PSE Healthy Energy

Jake Hays, MA | PSE Healthy Energy

Joan Casey, PhD | UC Berkeley/UC San Francisco

Seth B.C. Shonkoff, PhD, MPH | PSE Healthy Energy/UC Berkeley

Acknowledgements

We would like to thank Lisa Hallowell (Environmental Integrity Project), David Weiskopf (NextGen Climate America), Alex Abu-Hakima (PSE Healthy Energy) and Daisy Pistey-Lyhne (PSE Healthy Energy) for helpful discussions and feedback during the course of researching and writing this report.

Contact

PSE Healthy Energy
1440 Broadway, Suite 205
Oakland, CA 94612
info@psehealthyenergy.org

Executive Summary

The Clean Power Plan provides Ohio with an opportunity to achieve public health and environmental justice benefits across the state, while simultaneously reaching its carbon emission reduction goals in the power sector. In this report, we analyze the health, environmental, and equity dimensions of power plants affected by the Clean Power Plan. We first assess the socioeconomic and environmental public health burdens for populations living near these plants. We then model the public health impacts of particulate matter attributable to fossil fuel combustion at Ohio's power plants. Our findings point to where carbon emission reductions may have the greatest public health benefits, and help to identify where changes in power generation may add to or alleviate health burdens on vulnerable communities.

The Clean Power Plan is a regulation issued by the Environmental Protection Agency (EPA) in accordance with the legal requirements of section 111(d) of the Clean Air Act. It sets carbon emission reduction targets for the power sector in order to mitigate the impact of electricity generation on climate change. Compliance with these objectives can yield significant public health and environmental justice co-benefits in addition to the climate benefits of the rule. However, both the scale of these benefits, and their geographic and demographic distribution, may vary widely depending on the manner in which the standards are implemented in each state.

Fossil fuel power generation is associated with numerous environmental health burdens that, historically, disproportionately affect vulnerable and already overburdened communities. Power plants are often located near low income and minority populations. These communities are more likely to experience a cumulative burden of multiple socioeconomic and environmental stressors, such as poor air quality and proximity to hazardous waste facilities. Residents in these areas are also likely to be more susceptible to adverse health outcomes when exposed to pollutants from fossil fuel combustion. In order to ensure that State Plans do not disproportionately impact these communities or increase the health and environmental burdens borne by these communities, the EPA strongly suggests that states consider the emissions of multiple pollutants beyond carbon dioxide (CO_2) when developing their Clean Power Plan compliance approach.

The Clean Power Plan provides states with significant flexibility to determine their own pathway to meet the 2030 carbon reduction targets. **By considering the many dimensions of power generation impacts together, the pathway to carbon mitigation can help achieve public health and equity benefits as well as climate benefits.** In this report, we build on this initial set of information provided by the EPA to model the regional health burden associated with emissions from each power plant covered by the Clean Power Plan in Ohio and analyze toxic releases and environmental hazards associated with these plants. We also assess socioeconomic and environmental hazard burdens for populations living near the plants, and develop a cumulative vulnerability index to reflect these burdens.

Findings and recommendations

1. Our models suggest that particulate matter ($PM_{2.5}$) attributable to Ohio power plant emissions is responsible for a high estimate of 2,130 premature deaths per year and tens of thousands of incidents of respiratory symptoms, asthma exacerbations and other health effects.[a] The majority of these particulate matter health impacts are attributed to coal plants.
   Reducing CO_2 emissions in Ohio under the Clean Power Plan has the potential to additionally reduce these harmful emissions and associated health impacts, particularly under a multi-pollutant approach that targets plants with high emission rates for multiple pollutants.

2. Populations living near many of Ohio's currently active power plants are disproportionately burdened by multiple socioeconomic, health and environmental stressors. For example, 88% of plants are located in communities with larger proportions of low income people; 76% are located in communities with a higher prevalence of disability; and 76% are located in communities with more elevated proportions of elderly people, compared to the Ohio median. These patterns are particularly strong near existing and proposed natural gas combined cycle plants.
   As such, while reductions should be prioritized at Ohio's dirtiest plants, an approach to the Clean Power Plan that relies on shifting generation from these dirtiest plants to existing and proposed natural gas combined cycle plants, rather than clean energy resources such as wind, solar, and energy efficiency, may increase associated hazards near already overburdened and vulnerable communities.

3. Ohio power plants are associated with numerous environmental health hazards in nearby communities in addition to their particulate matter air pollution impacts, including five coal ash impoundments with a high risk of failure resulting in leakage, and numerous groundwater measurements near four plants showing incidences showing illegal or advisory exceeded levels of radioactive particles and of heavy metals such as arsenic and manganese.
   Engagement with local communities can provide insight into these and other environmental public health concerns near power plants and in power plant-affected airsheds. The State Plan should seek to ameliorate these burdens by reducing Ohio's reliance on fossil fuels under the Clean Power Plan.

[a] The EPA COBRA modeled used reports both a "high" and "low" value and gives them equal weight.

Our analysis presents a baseline portrait of the impacts, hazards, and risks associated with the power plants in Ohio that are regulated under the Clean Power Plan. This report builds on the EPA's initial national analyses of co-benefits and environmental justice concerns by examining three significant facets of power generation in Ohio:

1. **Disease prevalence and demographic vulnerability near power generation:** We expand on the EPA proximity analysis by adding health vulnerability indicators (e.g., prevalence of disease or poor birth outcomes) and analyzing population characteristics (e.g. race, income level, age) for communities living near power plants (including coal, natural gas combined cycle (NGCC), fossil steam, planned, and recently retired).

2. **Environmental health hazard identification:** We analyze specific indicators of environmental health hazards near power plants, including the location and structural integrity of coal ash impoundments, toxic releases on and off the power plant site, groundwater well-monitoring data, and power plant compliance with applicable laws, including violations of federal environmental statutes.

3. **Particulate matter health impact modeling:** We analyze 2015 power plant criteria pollutant emissions and model the health impacts of associated primary and secondary particulate matter pollution, on a per-plant basis and aggregated for each county in the state.

This Executive Summary highlights the main findings from our analysis and discusses the implications of these findings for how Clean Power Plan implementation in Ohio may take into consideration public health and equity.

Vulnerable and overburdened populations

Our research finds that populations living near both coal and natural gas power plants in Ohio are in many cases burdened with a disproportionate share of environmental health hazards. These hazards include, for example, proximity to traffic and hazardous facilities. Communities living near power plants also have a larger share of socioeconomic and health vulnerabilities, such as elevated concentrations of people with low incomes, with less than a high school education, with disabilities, and over age 64 among their residents.

These vulnerabilities combine with other environmental stressors to create a cumulative burden on residents in these areas. This accumulation of burdens makes these residents more susceptible to impacts from exposures to environmental hazards attributable to power plants than populations without these burdens. Furthermore, while exposure to primary and secondary air pollutants from power generation affects populations over hundreds of miles, a growing body of scientific literature suggests that populations that live near all types of fossil-fueled generation facilities are at an elevated risk of experiencing adverse health outcomes [1, 2, 3, 4, 5].

Building on the EPA's proximity analysis, we analyze **demographic** (e.g. minority, low income), **environmental** (e.g. air quality, traffic proximity) and **health** indicators (e.g. health insurance rate, disability prevalence) for populations living within three miles of plants subject to the Clean Power Plan. We analyze our results for individual plants and for each power plant class (coal, natural gas combined cycle, etc.). We also include analysis of planned natural gas combined cycle plans as reported by the Ohio Power Plant Siting Board [6]. In recent years, ten of Ohio's coal plants that were considered in the development of the state's Clean Power Plan pollution reduction targets have retired. Six natural gas combined cycle plants are currently proposed and/or under construction–more than doubling the number that currently operate in the state.[1] Demographic measures of populations living within three miles of each power plant class, including percent low income, over age 64, and disabled, are shown in **Figure 1**.

[1]While these retirements are likely to bring much needed relief from many pollution-related hazards for surrounding communities and across the region, legacy pollution at these sites and potential re-powering of these plants with fossil fuels continue to present risks for these communities. These communities should therefore be consulted alongside other vulnerable and overburdened areas in development of Ohio's State Plan.

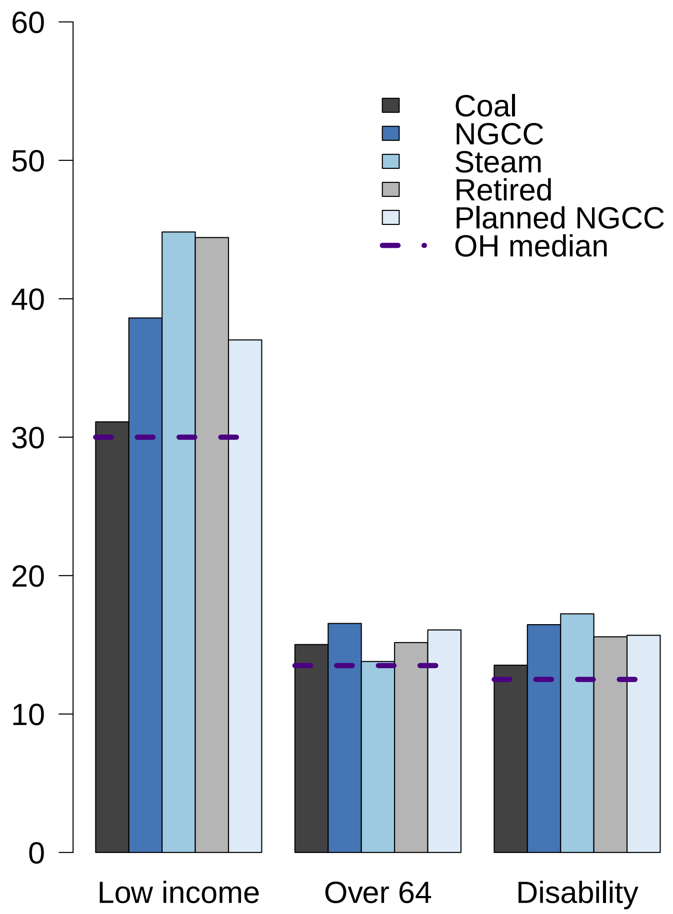


Figure 1: Demographics of populations that live within three miles of Clean Power Plan subject power plants, compared to populations living near planned NGCC plants and the state median.

Our results indicate that populations that live within three miles of either coal or natural gas power plants regulated under the Clean Power Plan have a larger percentage of low income residents than either the state median or the state average. This trend is most pronounced for natural gas combined cycle plants, all five of which rank above the state median for nearby low income populations. The share of minority residents near natural gas combined cycle plants is also above the state median and higher than it is near coal plants. Areas near all classes of power plant have a larger proportion of residents without a high school education and of populations over the age of 64 than the state median. The elderly are particularly vulnerable to experiencing adverse health outcomes from environmental health stressors. Switching from coal to existing or planned natural gas plants therefore has the potential to increase generation and associated health and environmental burdens closer to vulnerable communities.

We developed a Cumulative Vulnerability Index by aggregating our demographic, environmental and health results. This index averages percentile rankings for eighteen different vulnerability indicators (e.g. low income, access to health care, regional air quality) to reflect cumulative burden for populations living near affected power plants. The Cumulative Vulnerability Index, shown for the 15 highest ranking plants in **Figure 2** (including planned plants, and excluding retired plants), reveals that three of the five most vulnerable communities living near plants are living near existing or planned NGCC plants, suggesting that increased use of these plants may shift some burdens onto vulnerable populations. While not reflected in this figure, we also note that many of the recently retired plants were also located in vulnerable communities, presenting both concerns for legacy contamination in these areas as well as highlighting the importance of considering nearby communities in the case of future repowering to natural gas.

The Cumulative Vulnerability Index can be helpful to screen for vulnerable and overburdened populations for engagement under the Clean Power Plan to ensure that no increased burden is placed on these populations from this regulation and to develop approaches for

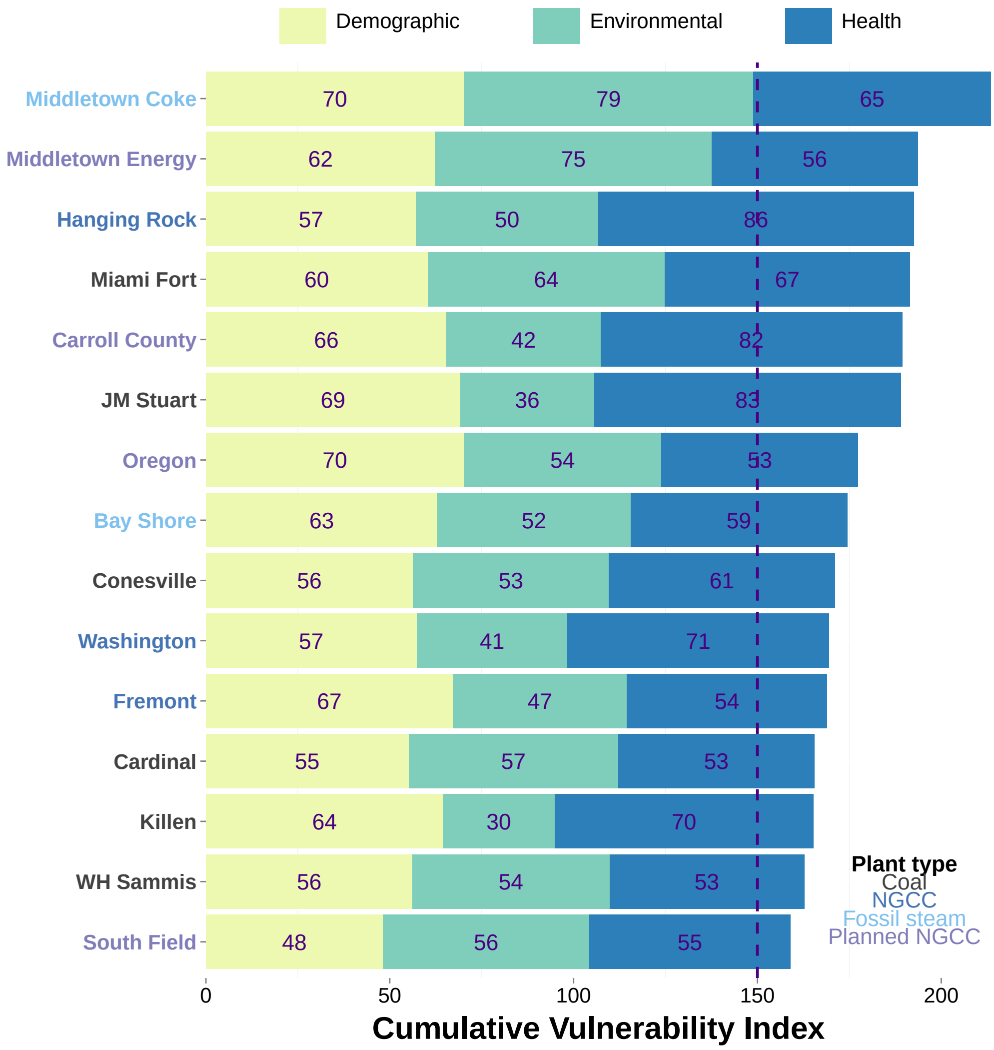


Figure 2: Cumulative Vulnerability Index reflecting aggregate demographic, environmental and health burdens for populations living within three miles of the 15 highest-ranked power plants, excluding retired and including proposed NGCC plants. A median score on all indicators gives an Index score of 150 (purple dashed line).

maximizing environmental benefits to these communities. The Index can also be used to inform approaches to decreasing environmental hazard and human health impacts on these populations.

Our results indicate that a State Plan that relies on increasing electricity generation at existing (or new) natural gas plants, rather than replacing coal generation with energy efficiency or renewable generation, may have the potential to increase the utilization of plants disproportionately located near low income and other vulnerable populations.

In addition to background vulnerability indicators reflected in the Cumulative Vulnerability Index, we also analyze environmental hazards associated with the plants themselves. Water well-monitoring data near coal ash impoundments show high levels of toxic releases of heavy metals; persistent bioaccumulative toxins and other health-harming contaminants that exceed allowable levels of radioactive alpha and beta particles; and arsenic and other contaminants at rates hundreds of times higher than the EPA's maximum contaminant level (MCL) standards, although all exceedances cannot necessarily be attributed to impoundments. While background levels prior to the coal ash impoundment's existence were not available for review, the fact that well water is a large source of drinking water for rural residents is cause for special concern with regards to exceedances above MCL and health advisory standards. Furthermore, nine different coal plants received up to eight million dollars in federal penalties for environmental violations in recent years, with 29 violations for coal plants in total, and NGCC plants received two violations. Coal plants in high minority and low income areas (ranking high on the EPA's "Demographic Index") areas received three times as many violations per plant as those in lower minority, higher income areas. Killen received the most violations, with 11, including seven for contaminant-related violations of the Clean Air Act or Clean Water Act.

These results, in aggregate, suggest that there is potential to reduce burdens on vulnerable communities through decreased reliance on fossil generation under the Clean Power Plan. However, if there is a switch from coal to existing natural gas-fired power plants or new power plants sited in vulnerable or historically overburdened areas, there is a risk of increasing near-source health burdens on socioeconomically and environmentally vulnerable communities or of shifting burdens among vulnerable communities. Given the wide distribution of levels of existing burden for communities living near all classes of power plants, extensive community input and careful modeling of projected changes in generation levels under any compliance plan should be encouraged to provide insight into whether demand, and associated health burdens, are likely to increase from these decisions.

Air pollutant emissions and public health

Our models suggest that particulate matter ($PM_{2.5}$) attributable to Ohio power plant emissions is responsible for thousands of premature deaths per year and tens of thousands of incidents of respiratory symptoms, asthma exacerbations and other health effects. Taking emissions and production of health-damaging criteria pollutants into consideration when developing carbon reduction strategies can help to reduce or eliminate some of these health burdens. Such multi-pollutant approaches to State Plans may target both the plants with the largest total health impacts, as well as those with the highest intensity of health impacts per megawatt-hour (MWh) of generation or per ton of CO_2.

We analyze emissions of CO_2, nitrogen oxides (NO_x) and sulfur dioxide (SO_2) from power plants in Ohio in 2015, and find a wide range among power plants of both total mass of emissions and in rate of emissions per MWh. NO_x and SO_2 contribute to elevated levels of secondary $PM_{2.5}$. NO_x also reacts in the atmosphere to form tropospheric ozone, a strong respiratory irritant which contributes to a wide range of cardiovascular and respiratory health impacts, particularly among members of already-vulnerable populations that suffer from vulnerability to and cumulative burdens of these exposures (e.g. low income, minority, the elderly, and those with pre-existing diseases). We use estimated primary $PM_{2.5}$ and these historic NO_x and SO_2 emissions to model health impacts from each plant using the EPA-developed Co-Benefits Risk Assessment (COBRA) model and an externally developed Air Pollution Emission Experiments and Policy (AP2) model. COBRA provides a low and a high estimate based on two different underlying epidemiological studies.

Case study: Avon Lake coal plant

- Particulate matter alone associated with 2015 emissions contributed to low and high estimates of **232 and 526 premature deaths** across the country.
- In 2015, emitted the **second highest total tonnage of SO_2** in the country.
- Located in Lorain County, which has the second-largest cumulative impact of Ohio power plant emissions, **highest per-capita impact**, and one of the highest asthma prevalence rates in the state.
- Highest cumulative impacts are on Lorain County and next-door Cuyahoga County, home to Cleveland; **air quality in both counties is designated non-attainment** for both ozone and particulate matter concentrations.
- Designated **in serious non-compliance** under the Clean Air Act for at least the last three years.

A number of power plants in Ohio have uniquely elevated rates or levels of total emissions of criteria air pollutants. The power plant Avon Lake, for example, has the second highest total emissions of SO_2 in the country, and emits SO_2 at a very high rate per MWh. A number of the highest-rate emitters in Ohio have been retired in recent years,[2] but plants like Avon Lake remain online and have widespread health impacts. Even though Avon Lake is located in a community that ranks low on many vulnerability indicators, the stack emissions from this plant affect air quality and health across the state and beyond.

Coal plants have higher rates of CO_2, NO_x and SO_2 than natural gas combined cycle plants, and are responsible for the largest total mass emissions for all of the criteria air pollutants examined in our analysis. **We find that particulate matter associated with pollution from power plant operations in Ohio in 2015 contributes to an estimated 940 (low estimate) or 2,130 (high estimate) premature deaths nationwide. The annual estimated costs of health burdens attributable to Clean Power Plan-affected power plants from our three models, including both mortality and non-fatal diseases, are $5.4 billion (AP2), $8.1 billion (COBRA low estimate), and $18.2 billion (COBRA high estimate).**

Approximately 90% of these $PM_{2.5}$ health impacts are attributable to the ten highest-impact plants. While a number of high-emitting power plants covered by the Clean Power Plan have come offline in recent years, the health impacts of the plants still online remain high. If we remove the power plants that were retired by the end of 2015 from our analysis, the estimated particulate matter health impacts from the COBRA model are $6.9 billion (low estimate), and $15.6 billion (high estimate), including 810 and 1,830 premature deaths in the low and high estimates, respectively.

The mortality estimates attributable to air pollutant emissions from power plant stacks for each county are mapped in **Figure 3**. Circle size represents the total nationwide mortality impacts from each plant. The blue lines outline federally designated non-attainment areas for National Ambient Air Quality Standards (NAAQS). Certain areas show both high aggregate health impacts as well as an existing burden of poor air quality on the county

[2] For example Ashtabula, retired in 2015, had the third highest rate of SO_2 emissions per MWh in the country.

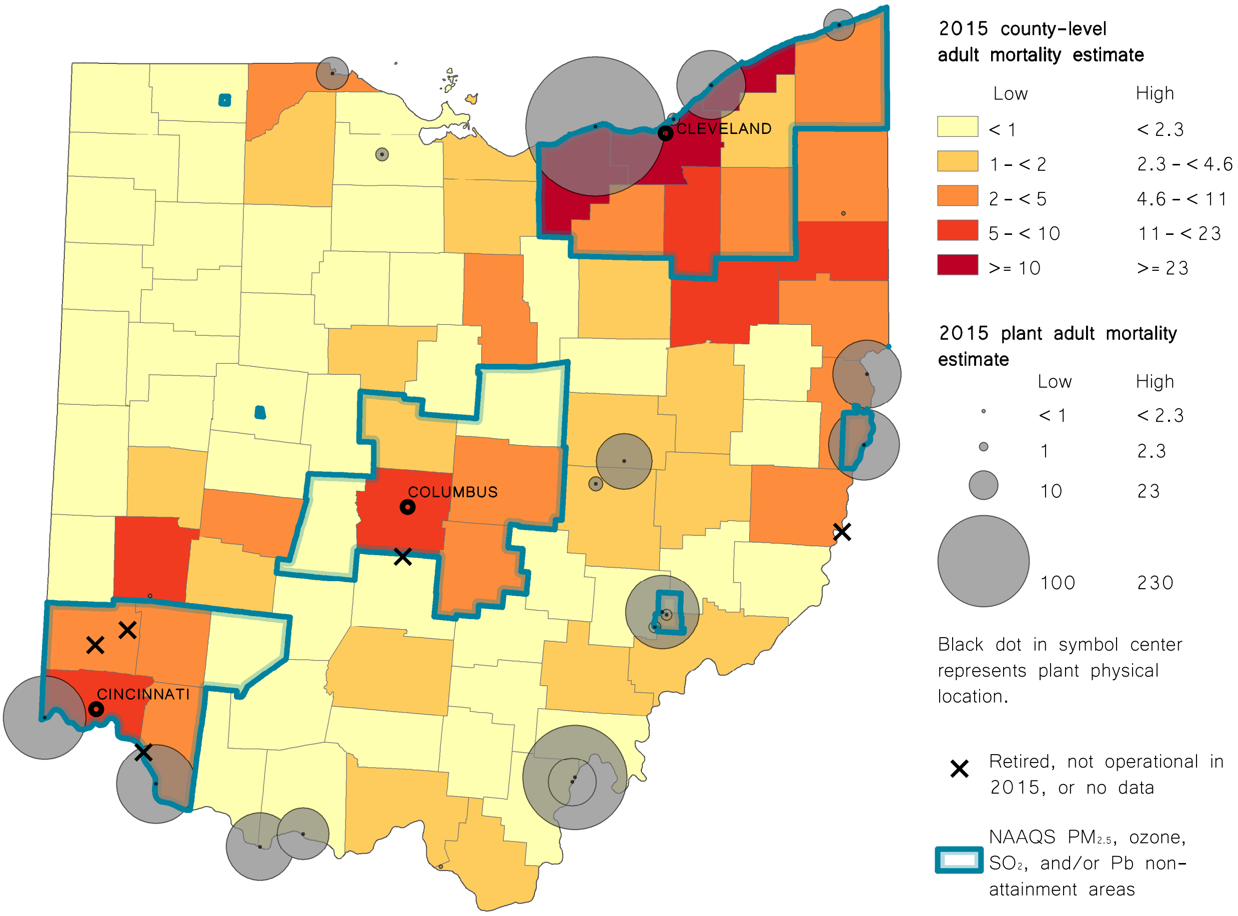


Figure 3: Modeled $PM_{2.5}$ mortality impacts by county from 2015 Ohio power plant emissions. Circle size represents each plant's nationwide mortality impact (80% of which are out of state). Blue outlines indicate non-attainment areas for ozone, $PM_{2.5}$, SO_2 or lead under National Ambient Air Quality Standards.

level. For example, Lorain County (home to Avon Lake) has the second highest cumulative health impacts, the highest per-capita health impacts, very high background rates of asthma, and is designated as non-attainment status for particulate matter and ozone under NAAQS standards.

It is important to note that 80% of the human health impacts from power generation occur outside of Ohio–and similarly, electricity generated outside the state releases air pollutant emissions that contribute to poor air quality and health impacts in Ohio. Finally, while the aggregate health impacts shown in **Figure 3** are heavily influenced by population density, we also analyze the per-capita health impacts and find that there are typically a disproportionate number of health impacts per capita in the counties that contain or are downwind from power plants that emit high levels of SO_2 and NO_x.

We compare emissions totals and rates to health impacts in **Figures 4a** and **4b**. In **Figure 4a** we compare total CO_2 emissions to the total estimated cost of $PM_{2.5}$ health impacts attributable to that plant. This plot highlights the plants that contribute to the highest total climate and public health burdens.

In **Figure 4b** we compare the rate of CO_2 emissions per MWh to the intensity of this health burden in cost per MWh. Emission rates of CO_2 from coal plants are relatively similar, but the health impacts vary greatly from plant to plant. **This plot therefore highlights where an individual measure to reduce electricity generation may**

have the greatest climate and public health co-benefits, as reducing a MWh of generation or ton of CO_2 may have greater health benefits at one plant than another. These health impacts only reflect particulate matter, but additional health benefits may result from lower levels of ozone, toxic releases, and other power plant impacts that were not modeled here.

Our health burden modeling only assesses the health impacts of primary and secondary $PM_{2.5}$ for each power plant compared to total CO_2 emissions, and does not include the health impacts of other harmful pollutants. An approach to regulation that evaluates the intensity of impacts per MWh can also be extended to reducing NO_x emissions, associated ozone formation, and toxic releases, thereby increasing potential health co-benefits.

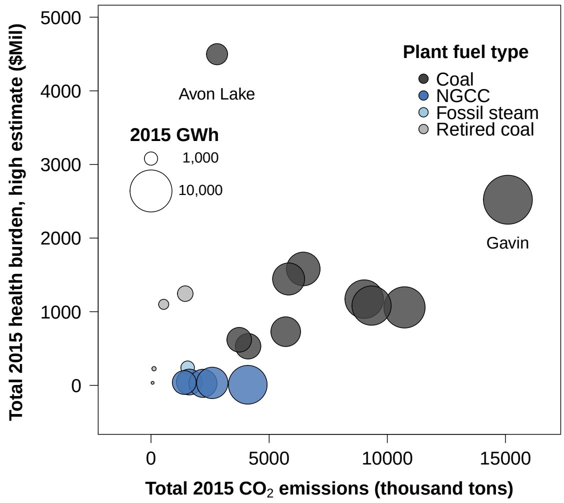


Figure 4a: 2015 cost of $PM_{2.5}$ health impacts from each power plant compared to total CO_2 emissions.

Legacy from retired plants

The list of power plants covered by the Clean Power Plan includes ten power plants that were running in 2012, but which have since been retired. More may retire in coming years. Many of these retired plants have legacy environmental hazards, such as coal ash impoundments at four of these sites. Many are located near vulnerable communities. There is therefore a need for ongoing monitoring and careful assessment at any site that may be under consideration for retirement or repowering with natural gas.

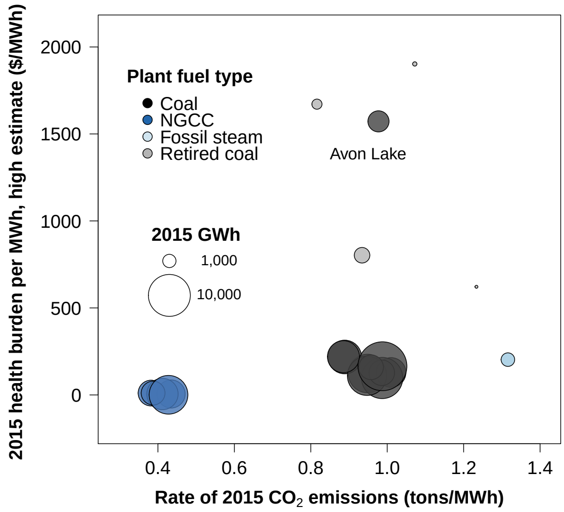


Figure 4b: Intensity of health impacts per MWh compared to intensity of CO2 emissions per MWh from each power plant in 2015.

For example, the Niles plant and Ashtabula plant, both retired, were in a continuous, most severe noncompliance status for the last 12 calendar quarters.[3] **Contamination exceedances were several thousand percent higher than the legal or advised limit for toxic releases for retired plants Muskingum and WC Beckjord, respectively.** Three retired plants, Muskingum, OH Hutchings, and WC Beckjord, all have one or more coal ash impoundments with the poorest structural integrity rating before failure (i.e. inability to contain coal ash), and have either high or significant hazard potential ratings. These hazard ratings mean that, should a failure of an impoundment occur, loss of life, property, and clean environment are highly probable.

[3]With the exception of Q4 2015 for Ashtabula which held a less egregious noncompliance status.

The communities living within three miles of these ten retired plants rank the highest for multiple socioeconomic, health and environmental hazard burdens, as shown in **Figure 1**. These results suggest that not only is ongoing monitoring important for these plants moving forward, but also that repowering of plants and monitoring of legacy environmental hazards may be important environmental health and equity considerations for these and potential future plant retirements. The socioeconomic status of existing nearby populations and the legacy environmental hazards identified in our analysis should also be taken into consideration when considering repowering these retired coal plants to natural gas combined cycle. Engagement with affected communities can help to identify environmental health concerns at these sites even after plant retirement.

Moving forward

Approaches to Clean Power Plan compliance that integrate health, environment and equity considerations hold potential to simultaneously mitigate climate change, improve public health, and alleviate disproportionate cumulative environmental burdens on vulnerable populations.

A multi-pollutant strategy that considers criteria and hazardous air pollutants and toxic releases along with CO_2 emission reductions holds the potential to reduce the numerous environmental health hazards and public health impacts associated with fossil fuel power generation in Ohio. Integration of climate, health, and equity factors will require careful consideration of the many dimensions of these issues. These issues include considerations of aggregate versus per-capita power plant impacts and hazards, and where, geographically, these impacts and hazards are disproportionately experienced.

Approaches to implementing the Clean Power Plan could result in shifting generation from coal to existing or planned natural gas combined cycle plants, or they could result in increasing energy efficiency and ramping up generation from renewables such as wind and solar. A combination of these outcomes may occur, depending on policy choices made by the state. In order to effectively limit the impacts of power plant pollution, Ohio's state plan should include these planned plants and any future fossil fuel-burning power plants under a single mass-based emissions standard by adopting the "New Source Complement" to the state's mass emissions target included in the Clean Power Plan.

Given the presence of vulnerable communities near existing and planned natural gas combined cycle generation, an emphasis on renewables and efficiency, rather than increased reliance on natural gas combined cycle generation, may be most likely to realize the many co-benefits of the Clean Power Plan without placing a disproportionate impact on vulnerable communities. Deployment of renewables and efficiency at faster rates than required to meet Clean Power Plan targets can help to achieve significant co-pollutant reductions at coal plants without increasing reliance on natural gas. Taken together, the data presented in this analysis provide a baseline of the environmental health and equity burdens associated with power generation in Ohio and can be used to prioritize and measure potential changes in these burdens when the state considers approaches to Clean Power Plan compliance and other energy regulations. Further engagement with disproportionately burdened communities identified in this analysis can highlight additional environmental and equity considerations and help to ensure that compliance plans ameliorate, rather than aggravate, the burdens of power generation on vulnerable communities.

Contents

List of Figures

List of Tables

Acronyms

ACS US Census American Community Survey
AP2 Air Pollution Emission Experiments and Policy
CAA Clean Air Act
CHA Childhood Health Advisory
CO_2 carbon dioxide
COBRA Co-benefits Risk Assessment
CPP Clean Power Plan
CWA Clean Water Act
DI Demographic Index
DWA Drinking Water Advisory
ECHO Enforcement and Compliance History Online
EIA US Energy Information Administration
EJ environmental justice
EPA US Environmental Protection Agency
g gram
GHG greenhouse gas
GWh gigawatt-hour (unit of energy)
kWh kilowatt-hour (unit of energy)
lbs pounds
LHA Lifetime Health Advisory
MATS Mercury and Air Toxics Standards
MCL Maximum Contaminant Level
MW megawatt (one million watts; unit of power)
MWh megawatt-hour (unit of energy)
NAAQS National Ambient Air Quality Standards
NGCC natural gas combined cycle
NO_x nitrous oxides
NOV Notice of Violation
NPDES National Pollutant Discharge Elimination System
NPL National Priorities List hazardous waste sites under the Superfund program
ORISPL Office of Regulatory Information Systems
PAH polycyclic aromatic hydrocarbons
PBT Persistant Bioaccumulative Toxins
PM particulate matter
$PM_{2.5}$ particulate matter with a diameter under 2.5 microns
POTW Publicly Owned Treatment Works
ppb parts per billion
ppm part per million
RCRA Resource Conservation and Recovery Act
RMP Risk Management Plan

RSL Regional Screening Levels
SDWA Safe Drinking Water Act
SO_2 sulfur dioxide
TRI Toxic Release Inventory
TSDF Hazardous Waste Treatment, Storage and Disposal Facilities
TWh terawatt-hour (unit of energy)
USD US dollars
VOC volatile organic compounds

1. Introduction

The United States Environmental Protection Agency's (EPA) Clean Power Plan (CPP) aims to reduce carbon dioxide emissions from electricity generation with the purpose of mitigating climate change. While this landmark rule primarily directs states to reduce emissions of climate warming pollutants, it holds great potential to simultaneously reduce emissions of health-damaging co-pollutants and other human health hazards and address environmental inequities from the burden of power generation facilities on vulnerable communities. In this report, we develop a baseline portrait of the environmental, health and equity dimensions of power sector burdens and impacts in Ohio. We look at which populations live near Clean Power Plan-affected power plants, analyze environmental health hazards at those plants, and model the regional public health impacts from associated fossil fuel combustion, in order to inform a State Plan that will realize the greatest environmental health and equity co-benefits.

1.0.1: Clean Power Plan recommendations on environmental justice and public health

- "Ensure that vulnerable communities are not disproportionately impacted by this rulemaking." (pp 64914)
- Pursue "multi-pollutant strategies that incorporate criteria pollutant reductions" in order to "accomplish greater environmental results with lower long-term costs [...] while limiting or eliminating localized emission increases that would otherwise affect overburdened communities." (pp 64918)
- Conduct "meaningful engagement with vulnerable communities." (pp 64916)
- Build on the EPA's initial proximity analysis of populations living within three miles of power plant using "available air quality modeling data and information from air quality models," and additional data on "health vulnerabilities such as asthma rates or access to health care." (pp 64916)

Electricity generation contributes to numerous health hazards and impacts that may disproportionately affect vulnerable communities across multiple geographic scales. Locally, power plants tend to be disproportionately located in low income and minority communities, which may often face a larger cumulative burden of socioeconomic, environmental and health hazards and stressors than wealthier, non-minority populations [7, 8, 9]. These plants are also often associated with the production and on-site disposal of toxic and hazardous contaminants [10], and studies have found that living near plants is associated with elevated incidence of poor health outcomes [2, 3, 5]. Fossil fuel combustion also emits criteria and hazardous air pollutants that contribute to poor air quality across large regions and even hundreds of miles from the emission source [11, 12]. Populations that are low income, young, elderly, or with elevated existing health conditions and illnesses, are particularly vulnerable to health impacts from exposure to air pollution [12, 13, 14, 15]. Globally, anthropogenic climate change driven by greenhouse gas emissions is projected to increase the burden of temperature and weather-related morbidity and mortality burdens. These burdens often fall disproportionately on young, old and economically-stressed populations [16], which frequently have the least resilience to adapt to a changing climate [17].

In order to maximize the public health benefits of the Clean Power Plan to ensure that atmospheric concentrations of air pollutants and other hazards do not increase the environmental and health burdens of power generation on vulnerable communities, the EPA suggests that states take a "multi-pollutant planning approach" and consider criteria and other air pollutants in addition to carbon in their compliance strategies (see Box 1.0.1). The EPA further requires that states demonstrate "meaningful engagement" with vulnerable and overburdened communities during the development of State Plans [18]. To catalyze this process, the EPA provided an initial proximity analysis of demographic and environmental health hazard indicators for populations living within three miles of Clean Power Plan-affected power plants using their environmental justice screening tool, EJSCREEN [7, 19], and encouraged states to build on this analysis.

In this report, we expand upon the EPA's environmental justice screening analysis of communities living near plants, incorporate additional data on environmental health hazards in proximity to power plants, and model regional public health impacts from power plant stack emissions in order to inform the development of an Ohio plan that incorporates multi-pollutant and equity approaches to Clean Power Plan compliance. The specific burdens, hazards and impacts of power plant generation depend on the technologies and fuels used at the plant, local geography and atmospheric conditions, the human populations exposed to the pollution from the plant, and the existing cumulative environmental, socioeconomic and health burden on those populations. As such, the magnitude of human health co-benefits of greenhouse gas emission reductions greatly depends upon where, when, and under what cumulative environmental hazard context emission reductions occur. We look at these many dimensions for individual plants and report trends for different classes of plants (i.e. coal, natural gas combined cycle (NGCC), and fossil steam).

This report is composed of four body sections. In Section 2, we provide background on the Clean Power Plan subject plants and electricity generation in Ohio. In Section 3, we create a portrait of the populations living within three miles of Clean Power Plan-affected power plants by building on the EPA's EJSCREEN analysis with additional metrics for air quality, health status, access to health insurance, and other measures of vulnerability and environmental burden. In Section 4, we analyze a set of environmental hazards and risks from affected existing coal, fossil steam, and NGCC power plants. This approach includes reviewing treatment and disposal of coal ash, water well-monitoring near coal ash impoundments, total chemical releases and fates from facilities, and historic environmental compliance. In Section 5, we analyze historic air pollutant emissions and use two different air quality models to estimate the cumulative and county-level health impacts of these emissions.

This analysis is developed to provide a more complete characterization of the public health and environmental landscape within which the Ohio power plants under the Clean Power Plan's jurisdiction exist. This report can therefore be used as a tool to support and facilitate state-level decision-making on the implementation of the Clean Power Plan to maximize environmental public health and equity co-benefits in the State of Ohio.

2. Background: Ohio electricity generation under the Clean Power Plan

Acting under the Clean Air Act (CAA), the EPA developed the Clean Power Plan to require a reduction in *direct*[1] combustion-related carbon dioxide (CO_2) emissions from existing coal, fossil steam[2] and NGCC plants, with a nationwide goal of reducing annual emissions by 32% from 2005 levels by 2030. The Clean Power Plan offers three "best available control technologies" to achieve this target [18]:

1. Improve efficiency at coal plants;
2. Switch from coal to existing NGCC plants;
3. Deploy non-emitting generation resources, such as renewables including wind and solar.

The agency further suggests that a fourth approach, demand-side efficiency, can also play a central role in reducing emissions. Targets for each state use a baseline year of 2012 and vary based in part on the existing generation mix in each state. These targets are given as both a *rate* of carbon emissions per megawatt-hour (MWh) of generation and a *mass* of total emissions, and states can choose to comply with either target. Policy levers to achieve these targets may range from carbon cap-and-trade policies to emission limits at specific plants to renewable portfolio and efficiency standards, among other approaches.

In Ohio, the power sector is the largest contributor to statewide greenhouse gas emissions [23, 24]. In 2015 Ohio had the fifth-highest total power sector CO_2 emissions compared to states nationwide, and the third-highest total emissions of the criteria pollutant sulfur dioxide (SO_2) [25].

Ohio has been directed under the Clean Power Plan to reduce the emission rate of CO_2 from affected electricity generation by 36% from the 2012 rate (1,855 lbs CO_2/MWh to 1,190 lbs CO_2/MWh) [18, 26]. The total mass (lbs) of CO_2 emissions is expected to fall by approximately 28%, which is lower than the rate target due in part to the inclusion of renewable energy generation in the denominator in the rate-based calculation (see [27, 28] for a full explanation). These Clean Power Plan targets do not include new fossil-fired power plants, which are regulated separately but addressed under the "New Source Complement" to the mass-based targets, and also do not cover some types of generation, such as certain cogeneration plants and simple cycle natural gas plants. However, states are encouraged to

[1] It is important to note that the Clean Power Plan does not include upstream or lifecycle greenhouse gas (GHG) emissions. Methane from coal mining increases the GHG footprint of coal by approximately 6% [20]. Lifecycle methane emissions from the natural gas sector are more uncertain but high rates of leakage above production fields (see: [21, 22]) may greatly erode climate benefits of switching from coal to natural gas.

[2] Typically oil- or gas-fired plants.

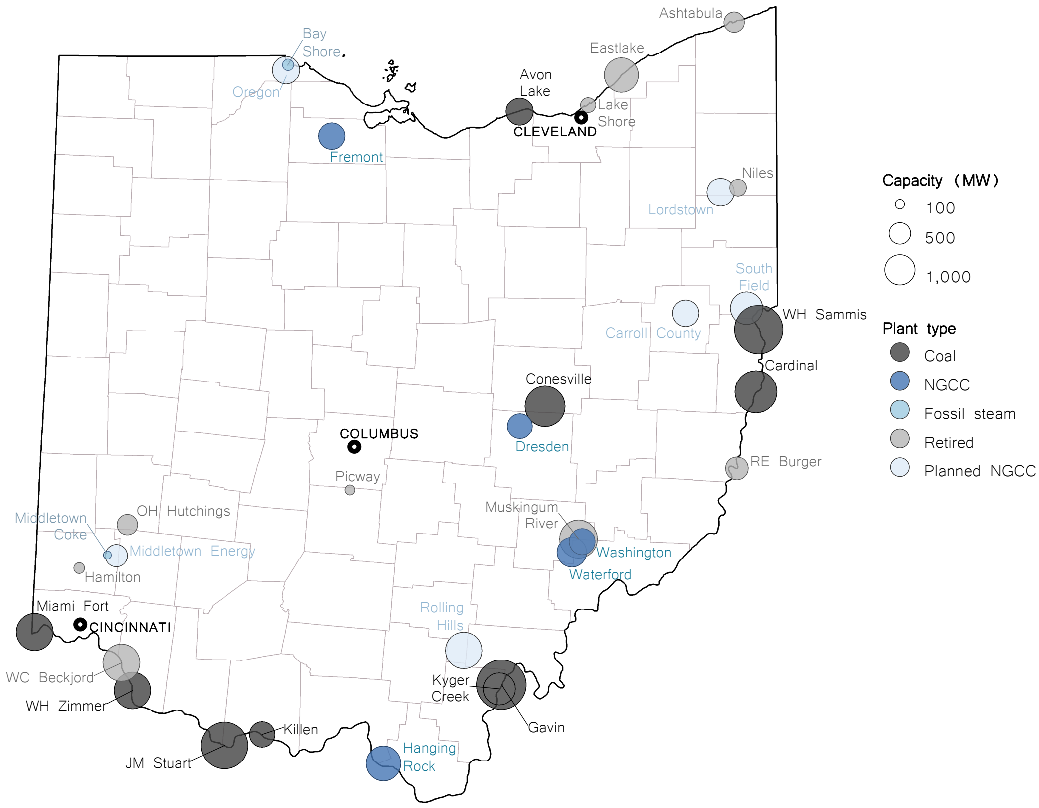


Figure 2.1: Map of power plants in Ohio regulated by the Clean Power Plan. Classification reflects plant status at the end of 2015. Circle size is proportional to plant capacity in MW.

protect against "leakage" that would occur from shifting emissions to electricity generation not covered by the Clean Power Plan because it would erode the potential for real air pollutant emission reductions to occur.

The Clean Power Plan covers all generation from in-state regulated plants. 27 plants are covered by the Clean Power Plan in Ohio, including five NGCC plants, 21 coal plants, and one fossil steam plant.[3] However, since the 2012 baseline year for the Clean Power Plan, ten of these coal plants have retired. One more (Bay Shore) shut down all units except one that burns petroleum coke, so we hereafter classify this unit as fossil steam. Six new NGCC plants are proposed or under construction [6].[4] **Figure 2.1** shows a map of all of the plants covered by the Clean Power Plan in Ohio, their capacity in megawatts (MW), and classification at the end of 2015 (coal, NGCC, fossil steam, retired, or planned NGCC).[5] Reference **Table 1** provides a cross reference for naming conventions for plants used in this text along with names used within the Clean Power Plan.

Net generation in Ohio by fuel type, from the years 2012 to 2015, is shown in **Figure 2.2**.[6] Coal provided 66% of electricity generation in Ohio in 2012, but dropped to 59% by 2015. Natural gas generation increased from 17% to 23% over this same time period, and nuclear generation held relatively constant at 13% (2012) and 14% (2015). The remaining 4% of the energy generation mix is made up primarily of wind, biomass, petroleum liquids and coke, and some hydropower (data source: [29]).

---

[3]Fossil steam plants include both oil- and gas-fired steam plants.

[4]Three additional coal or petroleum coke plants have also been approved, but appear to be stalled or cancelled and so are excluded from our analysis.

[5]The power plant capacity is reflective of MW designated active by the EPA in 2012 [28].

[6]These data include generation not covered by the Clean Power Plan.

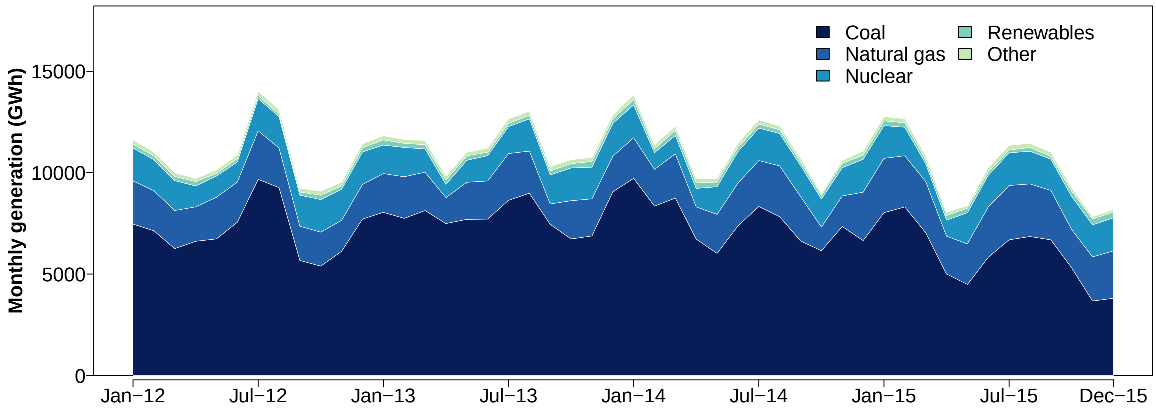


Figure 2.2: Historic electricity generation in Ohio, by fuel type, 2012-2015.

Current power generation in Ohio contributes to poor air quality across the state through both primary pollutant emissions and secondary atmospheric formation of ozone and particulate matter (PM). Adverse health outcomes associated with these pollutants include cardiovascular and respiratory disease [30], lung cancer [31, 32], and premature death [33], and these impacts are often highest on vulnerable populations like the elderly, those with pre-existing diseases, and populations with low socioeconomic status. Power generation also emits toxic and hazardous air pollutants like mercury, which is associated with brain damage and birth defects [34], heavy metals like cadmium and lead, which are carcinogens and can cause damage to the nervous system among other impacts, volatile organic compounds like benzene (also a carcinogen), and many others.

State-level air quality in Ohio has broadly improved since 2000 [35, 36], with variations across individual sites and years. However, many communities in Ohio still live in locations where air pollutant concentrations exceed federal National Ambient Air Quality Standards (NAAQS). In Ohio, multiple regions are designated as non-attainment for 8-hour ozone, 24-hour $PM_{2.5}$,[7] lead (rolling three month average), and sulfur dioxide (SO_2) [37]. Non-attainment statuses have not yet been determined for the 2015 ozone standard, which lowered the 8-hour exceedance level from 75 to 70 parts per billion (ppb), and will likely place new regions out of attainment.[8] Furthermore, the EPA considers air quality to be "unhealthy for sensitive groups" when concentrations rise above the NAAQS standards, even if a region does not record enough exceedance days to be designated a non-attainment area [38]. Some local populations near emitting facilities may experience elevated concentrations of air pollutants even when regional air quality monitors indicate that regional air quality meets standards.

Clean Power Plan compliance in Ohio could follow any number of different pathways, leading to a shift in both the state's overall electricity generation fuel mix and in the usage rate of individual plants. Some of these scenarios could lead to an increase in generation at some specific plants, particularly existing NGCC plants, if the shift from coal to natural gas generation continues. Other plants may shut down entirely, following the wave of coal retirements. While reducing CO_2 emissions from these plants can help reduce the overall greenhouse gas footprint of electricity generation, some emission reduction scenarios may yield a much greater reduction in air pollution, toxic releases, or in use of plants in overburdened communities than in other scenarios.

[7] $PM_{2.5}$ refers to particulate matter with a diameter under 2.5 microns.

[8] Non-attainment is based not on an individual measurement, but on a three-year average of the fourth-highest annual 8-hour ozone concentration.

Of all of the possible environmental health and equity co-benefits of power sector carbon emission reductions, the public health gains related to regional air quality improvement are likely the most commonly quantified. The EPA explicitly calculates the direct monetary value of Clean Power Plan-related health benefits (primarily reduced mortality) from lower emissions of $PM_{2.5}$, and SO_2 and nitrous oxides (NO_x) resulting in secondary $PM_{2.5}$ formation. In this analysis, the EPA concluded that there would be a human health benefit of $40-89,000 (2011 USD, 3% discount rate) for reducing $PM_{2.5}$ formation from every ton of SO_2 in the Eastern Interconnect [39]. The EPA also estimates the nationwide cumulative monetized health benefit of reducing both direct emissions of $PM_{2.5}$, SO_2, NO_x, and secondary formation of $PM_{2.5}$ and ozone as $14-34 billion under a rate-based plan (2011 USD, 3% discount rate). These benefits include the avoidance of 3,600 premature deaths, 1,700 heart attacks, 90,000 asthma attacks, and 300,000 missed work days and school days each year [39]. Additional non-monetized benefits are expected from reducing direct and indirect exposures to SO_2, NO_x, carbon monoxide, mercury, and other air pollutants.

A study by Driscoll *et al.* [40] corroborated the EPA findings [39], concluding that carbon standards for power plants (under assumptions used in the draft Clean Power Plan) would yield public health benefits due to a reduction in ambient ozone and $PM_{2.5}$ concentrations, including lower premature death rates, and cardiovascular and respiratory-related hospitals visits. Their model found even greater benefit when carbon emission reductions were achieved by pursuing strategies with high levels of demand-side efficiency in conjunction with fossil fuel emission rate limits rather than relying on improved efficiency at coal plants. This efficiency-based emission reduction strategy yielded particularly high benefits across the Eastern Interconnect due to reductions in peak ozone and $PM_{2.5}$ concentrations.

These assessments point to the regional public health benefits of the Clean Power Plan, but even greater benefits may be realized by taking a more nuanced approach to emission reductions. Levy *et al.* [41] highlight that the greatest health benefits can, intuitively, be achieved by prioritizing emission reductions at plants associated with the greatest health impacts first. These plants tend to be those that affect dense populations—which also tend to have higher background levels of PM in the first place. Levy *et al.* suggests that reductions in primary PM emissions and secondary atmospheric production of $PM_{2.5}$ in places with already high background $PM_{2.5}$ can typically yield some of the greatest benefits—again, both due to the fact that peak $PM_{2.5}$ values may be reduced, but also because these tend to be in more densely populated areas where more people may be affected.

In addition to the general benefits of air pollution abatement in areas with elevated PM concentrations, further studies suggest that emission reductions can yield greater health benefits for sensitive populations, and greater aggregate health benefits may be gained by taking underlying population vulnerability into account [42, 43, 44]. Certain communities have higher sensitivity to exposure to $PM_{2.5}$ and other pollutants, such as minority communities or communities with low socioeconomic status, including low educational attainment and high rates of poverty [45]. Consequently, these types of communities may see the most benefits from emission reductions. Additional public health benefits may also be gained by reducing the environmental health hazards described earlier, but these benefits are more difficult to quantify.

Available data suggest that the Clean Power Plan has the potential to yield environmental and public health benefits, especially for disproportionately vulnerable populations. In the following sections of this report we explore the equity, environmental and regional health dimensions of power generation covered by the Clean Power Plan in Ohio.

3. Environmental justice proximity screen

In this section, we assess the demographics and existing cumulative environmental and health burdens of populations living within three miles of power plants regulated under the Clean Power Plan in Ohio. These burdens provide the vulnerability context for other hazards attributable to the power plants themselves as explored in Section 4.

3.1 Background: environmental justice and power generation

Power plants and other potentially hazardous facilities are often located in low income or minority communities [7, 8, 9] due to a combination of social inequities, economic incentives, land use regulations, and other factors that can contribute to a disproportionate burden on surrounding populations. Furthermore, these communities may be more susceptible to adverse health outcomes due to both the cumulative burden of multiple environmental stressors and underlying vulnerabilities ranging from socioeconomic status to pre-existing diseases or access to health care [46]. *Environmental justice* (EJ) communities are often identified as having populations that experience a disproportionate burden of multiple environmental stressors, may have unique vulnerability to such stressors given characteristics such as elevated prevalence of disease or very young or old age, and also have a limited ability to withstand these stressors, due to lack of income, disenfranchisement, or lack of access of health-protecting resources [46]. The EPA refers to these populations as "vulnerable" and "overburdened."

The same environmental factors can therefore lead to worse health outcomes under a cumulative burden of environmental stressors in vulnerable populations, and consideration of these multiple burdens and vulnerabilities is important when assessing hazards and impacts from industrial facilities like power plants. As an example, asthma incidence and prevalence in Ohio tends to be more elevated in low income and minority communities compared to higher income and white communities. According to the Behavioral Risk Factor Surveillance System from the Center for Disease Control and Prevention, the average asthma prevalence among Ohio adults (2014) is 11%. However, it is 10% for white, non-Hispanic populations, 16% for black, non-Hispanic populations, and 14% for Hispanic populations. Asthma prevalence is 22% for those who live in households that make less than $15,000 annually, and only 7% for those that earn over $50,000 annually; and 7% for those with a college degree, and 20% for those with less than a high school education [47].

Elevated concentrations of particulate matter are associated with higher rates of asthma attacks and related hospital visits [48]. Susceptibility to negative health outcomes from particulate matter exposure is not only associated with pre-existing cardiovascular and respiratory diseases (e.g., asthma), but also with socioeconomic and demographic characteristics including age, race, socioeconomic status, access to healthcare, and educational attainment [49]. Consequently, some communities may be more susceptible to health impacts of particulate matter attributable to power plants due to higher prevalence of diseases such as asthma, as well as higher cumulative concentrations of pollutants from multiple sources. Moreover, community vulnerability to poor health outcomes from exposures to particulate matter can also be exacerbated by additional environmental and socioeconomic vulnerabilities, including structural contributors such as substandard housing quality, low socioeconomic status and educational attainment [45].

The health impacts of power plants are not limited to those populations living in close proximity to these plants. Furthermore, the characteristic distance of different impacts on local populations may vary by plant due to local geography, plant characteristics, and multiple exposure pathways. However, by looking at environmental hazards from a given power plant, additional environmental hazards in the area, and characteristics of the communities living nearby, we can determine some of the relative burdens and risks for these communities.

The Clean Power Plan requires both engagement with vulnerable communities living near power plants and the assurance that no State Plan places an undue burden on these communities. The EPA provides an initial proximity analysis of the populations living within three miles of the affected power plants using their environmental justice screening tool, EJSCREEN, and encourages states to build on this analysis using additional environmental, health and demographic data [7, 18]. As noted, health impacts and burdens from power plants are not contained within a three-mile radius, and we will look more carefully at regional health impacts in Part 5. Here, however, we build on the EPA's proximity analysis under the assumption that the characteristics of the population in a three-mile radius provide a relatively good proxy for those who might be adversely affected by living in proximity to these plants. We note that additional insight may be gained by further analysis of populations living within a closer radius, particularly in more dense urban areas.

Multiple indicators can be used to identify a potentially vulnerable or overburdened community. The EPA recently introduced a screening tool called EJSCREEN, which incorporates demographic indicators such as age, educational attainment, and linguistic isolation as well as additional environmental indicators such as air quality, traffic proximity, and lead paint. It also includes proximity to potentially hazardous facilities or waste disposal [19]. The State of California developed CalEnviroscreen 2.0, which in addition to the previous categories includes indicators such as groundwater risks and contamination, pesticide use, rates of asthma, low birthweight, and unemployment [50]. CalEnviroscreen 2.0 weighs different components of this index to yield a final environmental justice score. The EPA introduced a Demographic Index, which integrates low income and minority population metrics, and an EJ Index, which combines this score with population density and individual environmental hazards, but does not utilize a cumulative score like California does.

All of these indicators may be useful to determine which communities may suffer disproportionate adverse health outcomes in response to environmental pollutants and stressors. They may also help identify communities where a reduction in cumulative burdens may be particularly beneficial. While the EPA used the EJSCREEN tool to provide an initial analysis of the communities living in proximity to power plants, the agency also suggests incorporating additional indicators (e.g., access to health care) when considering vulnerable communities under the Clean Power Plan. Assessing the environmental public health and equity dimensions of power plants can provide insight into two sets of results, broadly: 1) the determination of whether power plants, in aggregate, are located in or impact certain types of communities and 2) even if such power plants are evenly distributed on average, whether certain populations are particularly susceptible to the hazards and burdens from power plants due to some cumulative burden indicators discussed above. It is therefore useful to look at both the aggregate and distribution of power plants across these different indicators.

3.2 Data and methods: environmental justice proximity screen

In this section, we analyze demographic data along with environmental and health burdens for the populations living in proximity to each power plant regulated by the Clean Power Plan. This analysis builds on the results of the EPA's EJSCREEN analysis, updated to address retirements and proposed plants and broken down by power plant classification (i.e. coal, NGCC, or fossil steam). We next evaluate several health indicators, including prevalence of cancer, disability, low birthweight, and adult health insurance coverage. We aggregate cumulative burdens across all plants and compare these aggregate results to the EPA's Demographic Index. We also integrate additional data on regional air quality.

We additionally apply this analysis to proposed power plants reported by the Ohio Power Siting Board [6]. These plants include two coal plants, one coke cogeneration plant, and six NGCC plants. However, the coal and coke cogeneration plants appear to be either paused or cancelled, so we focus most of our analysis on the six NGCC plants. Four of these plants are recorded as "under construction," one is an expansion of an existing simple cycle natural gas plant, and one recent proposal is pending.

We combine health, environmental, and demographic data from multiple datasets for this analysis. Although we incorporate a broad range of indicators, our list is by no means exhaustive and engagement with specific communities may help identify burdens and vulnerabilities we have omitted. Due to limitations in data availability, some of these data are aggregated from different years or over different population areas. Much of these data are derived from the United States Census American Community Survey (ACS). These surveys engage only a portion of households and therefore introduce a measure of uncertainty into the results. Indicators used to measure environmental burden also contain uncertainty sourced from the underlying dataset and the means of data collection (e.g., concentration and accuracy of air monitors for air quality data). A full list of indicators, data sources, and years is given in Reference **Table 2**.

We apply our demographic analysis to populations living within a three-mile radius of each affected power plant, following a buffer approach used by the EPA in their initial demographic proximity screen [7]. Data for each census block (or in some cases, minor civil division) for each data set is weighted by the population in that block and the fraction of the block encompassed within a three-mile buffer zone for the power plant. This calculation is given in **Equation 3.1** [19].

$$Value(A) = \sum_{\forall Blk, Blk \cap A} \frac{\frac{BlockPop10}{BGPop10} * BGACSPop * BG_{RawValue}}{\sum_{\forall Blk, Blk \cap A} * \frac{BlockPop10}{BGPop10} * BGACSPop} \tag{3.1}$$

BlockPop10 is the 2010 Census block-level population total, BG refers to each block group, and BGACSPop is the estimated block population from the ACS, which is often different from the Census 2010 total because the ACS data are based on five years of surveys while the Census reflects a single year [19]. A similar calculation was used for data available on a municipal civil division level, using this regional measure instead of block groups in the equation above. All populations living within this buffer region are treated equally.

3.2.1 Prevalence of poor health

Health data used in this assessment were acquired from the 2008-2012 American Community Survey [51]. Disability and insurance data were available at the minor civil division level in Ohio, and cancer and birthweight data were available on the county level. Minor civil divisions are administrative divisions of a county composed of townships, boroughs, and cities. These boundaries are thought to reflect social and cultural space that is significant to residents [52]. We did not have access to asthma data at this spatial scale, but note that we discuss asthma prevalence within the context of broader air quality health impacts in Section 5.3.2.

We included the following health metrics to provide a range of health-related data reflecting disease prevalence, vulnerability and resilience among populations living near power plants in Ohio:

- **Uninsurance rate:** percent of adult population over 18 without health insurance;
- **Cancer prevalence:** percent of population with a cancer diagnosis of any kind in 2012;
- **Disability prevalence:** percent of population with a disability, defined as having one or more of six difficulties: hearing, vision, cognitive, ambulatory, self-care, or independent living;
- **Low birthweight births:** percent of babies born with a low birthweight (2008-2012 data), defined as < 2500g.

3.2.2 Demographic data

Demographic data were drawn from the EPA's EJSCREEN analysis [7, 19], which also uses American Community Survey data from 2008-2012 [51]. The populations identified are known to suffer higher levels of negative health outcomes than the average population to environmental exposures such as poor air quality [12, 13, 14, 15]. These demographic indicators include [7, 19]:

- **Minority:** percent of population identified as minority, defined as "all people other than non-Hispanic, white-alone individuals;"
- **Low income:** percent of population living in households earning less than or equal to double the federal poverty rate;
- **Less than a high school education:** percent of those over age 25 without a high school diploma;
- **Linguistically isolated:** percent of population living in households where all inhabitants over 14 speak a non-English language and speak English less than "very well;"
- **Under age five:** percent of population under age five;
- **Over age 64:** percent of population over age 64.

There are numerous approaches to aggregating these indicators. The EPA developed a Demographic Index (DI) to identify minority and low income communities. This index is defined in **Equation 3.2** [7]:

$$DI = \frac{\%\ low\ income + \%\ minority}{2} \tag{3.2}$$

3.2.3 Environmental data

The environmental data used in this environmental justice screening analysis come primarily from the EPA's EJSCREEN analysis [7, 19]. These indicators include:

- **Average PM:** average 24-hour concentrations of $PM_{2.5}$ ($\mu g/m^3$);
- **Average ozone:** average summer 8-hour ozone concentration (ppm);
- **Lead paint:** percent of houses built before 1960;
- **Traffic proximity:** count of traffic at major intersections;
- **RMP:** count of facilities with Risk Management Plans for chemical spills;
- **TSDF:** count of hazardous waste Treatment, Storage and Disposal Facilities;
- **NPL:** count of National Priorities List facilities (NPL) covered by the Superfund program;
- **NPDES:** National Pollutant Discharge Elimination System sites that discharge waste into waterways.

The EPA calculated an EJ Index for each environmental indicator by incorporating the difference between the block demographic index (DI_{block}) and the national average (DI_{US}) and the population of the block group ($Population_{block}$)as follows:

$$EJ\ Index = Indicator * (DI_{block} - DI_{US}) * Population_{block} \tag{3.3}$$

This value is then given a national (or state) percentile, which we use as a weighting for the burden of a given environmental indicator given additional demographic data. The percentile is calculated by ranking the EJ Index of each block group, and assigning percentiles within the state (or county) according to this ranking.

We additionally include air quality data reflecting the EPA's NAAQS standards. We first identify areas designated as "non-attainment" for 24-hour $PM_{2.5}$ concentrations,[1] 8-hour ozone concentrations,[2] and 1-hour primary SO_2 concentrations[3] in the EPA's Green Book Nonattainment Areas [37]. However, the NAAQS non-attainment areas have not been updated to reflect the 2015 update to the ozone standard [53], and regions may see high short-term concentrations of ozone and $PM_{2.5}$ even if the region is not out of attainment. We therefore also incorporate data on daily maximum ozone and $PM_{2.5}$ concentrations in Ohio for 2013-2015, aggregated from EPA's AirData website [54]. For each monitor, located using the EPA site description report [55], we calculate the number of days during these three years that ozone or $PM_{2.5}$ exceeded the NAAQS standards (70 ppb 8-hour ozone or

[1] 24-hour $PM_{2.5}$: 35 $\mu g/m^3$ (2012); "98th percentile, averaged over 3 years."

[2] 8-hour Ozone: 75 ppb (2008); 70 ppb (2015); "annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years."

[3] Primary SO_2: 75 ppb (2010); "99th percentile of 1-hour daily maximum concentrations, averaged over 3 years."

35 μg/m^3 24-hour $PM_{2.5}$). Not all of the monitors collect data every day, however, and air quality trends are typically regional, so we also calculated the number of days these exceedances were recorded anywhere in each of the Air Quality Management Districts in Ohio. This approach does not reflect the fact that air quality may be poor in one part of a district but not another, but provides us with a general screen for regions with poor air quality given the constraint of a limited distribution of air monitors. This calculation gives us a count of the number of days with acute ozone or $PM_{2.5}$ concentrations in a given region over the years 2013-2015.

Power plants are classified as coal, NGCC, fossil steam, or retired. Plants were initially classified using the EPA's Performance Rate Goal Appendix to the Clean Power Plan [28], but updated to reflect their current status using generation and fuel data from EIA schedules 860 and 923 and, in some instances, newspaper articles on proposed retirements [56, 57]. We refer to two plants that primarily burn either oil or petroleum coke as fossil steam plants. We designated ten coal plants as retired since 2012. We include these plants in their own category in our analysis, both to analyze trends in retirements and given the potential for these sites to be considered for repowering as NGCC plants. Plant capacity is derived from the EPA Performance Rate Goal Appendix [28]. We include full plant capacity operational in 2012, even though some units at certain plants are excluded by the Clean Power Plan. The excluded units are typically small peaking units which come on only at times of peak demand and their inclusion would not significantly change the capacity. Finally, we also include data on proposed or under-construction NGCC plants reported by the Ohio Power Siting Board [6]. These proposed plants may be covered under the Clean Power Plan using the New Source Complement.

3.3 Results: environmental justice proximity screen

In this section we look at demographic, environmental, health, and cumulative burden indicators for populations living near power plants in Ohio.

3.3.1 Demographics of populations near power plants

Demographic data for populations living within three miles of each power plant, aggregated by plant class, are shown in a box plot in **Figure 3.1**. The middle dark line in each box plot in **Figure 3.1** shows the median indicator value (e.g., percent minority population) for the population living around plants of each class; the box shows the 25th and 75th percentile range and contains 50% of the power plants; the bottom and top lines indicate the minimum and maximum plant values. We note that there are *only two* fossil steam plants, so the edges of the box show only those two plants and this box is not meant to indicate any broad trends about this plant class (the median line is actually the average in this case). The dark purple line indicates the *state median* value, where this median represents the middle value for all census blocks in Ohio. For example, the median percentage of the adult population without a high school degree is 10%, meaning that in 50% of census blocks, less than 10% of the adult population does not have a high school degree. The dashed lavender line indicates the *state average* population fraction without a high school degree, which at 12% is higher than the median. The data points for each individual plant are plotted on top of the box plot to help illustrate the distribution of indicator values for these plants.

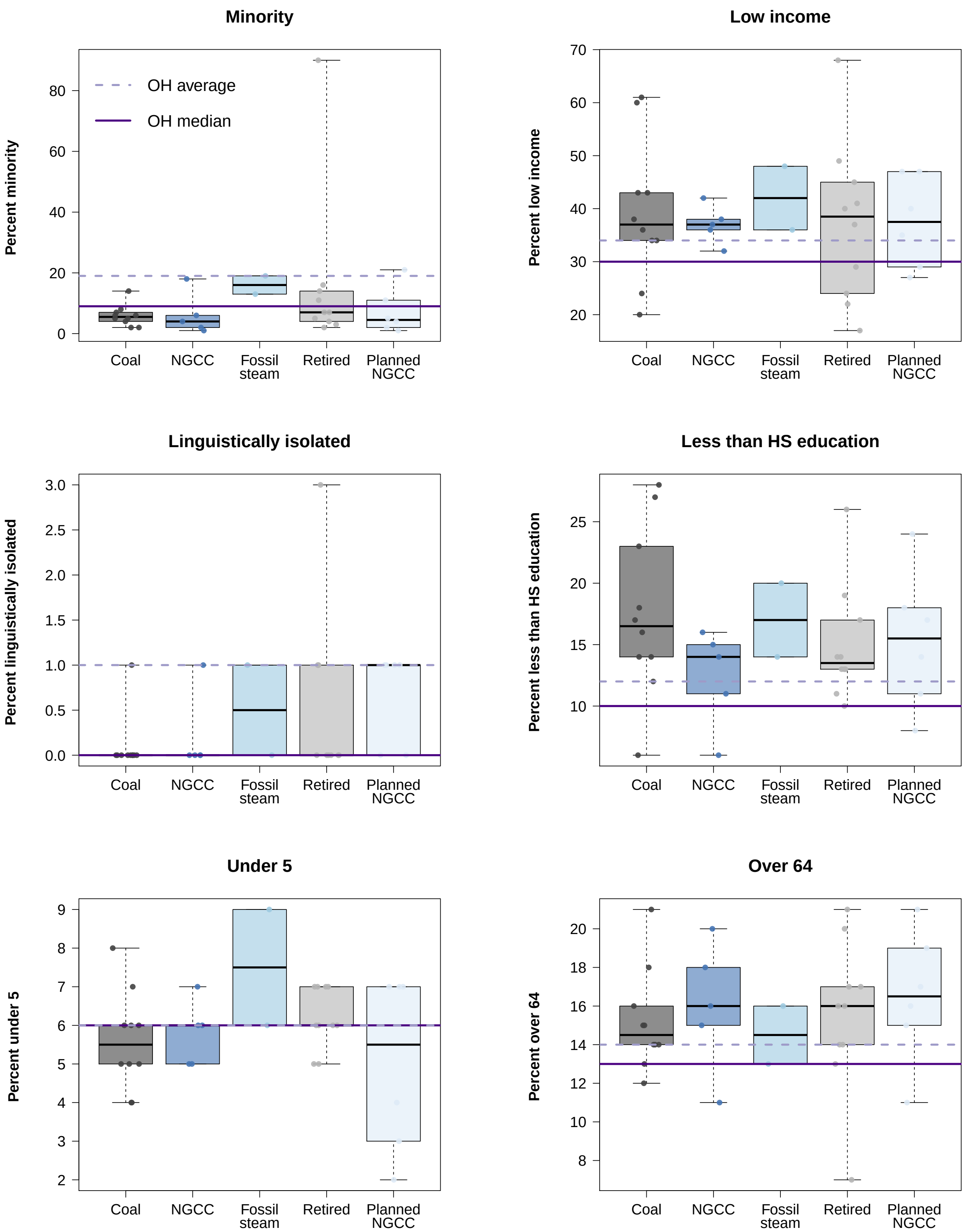


Figure 3.1: Box plot of demographic indicators for populations near Ohio power plants, by plant class. Solid dark purple line indicates the median value of census blocks in Ohio. Dashed lavender line represents the state average. Each dot represents the indicator value for the population living within three miles of each specific power plant.

Our results indicate a wide distribution of indicators for each plant class. Populations living within three miles of non-retired Clean Power Plan subject plants in Ohio range from 20-61% low income, for example. All five of the NGCC plants, both fossil steam plants, and

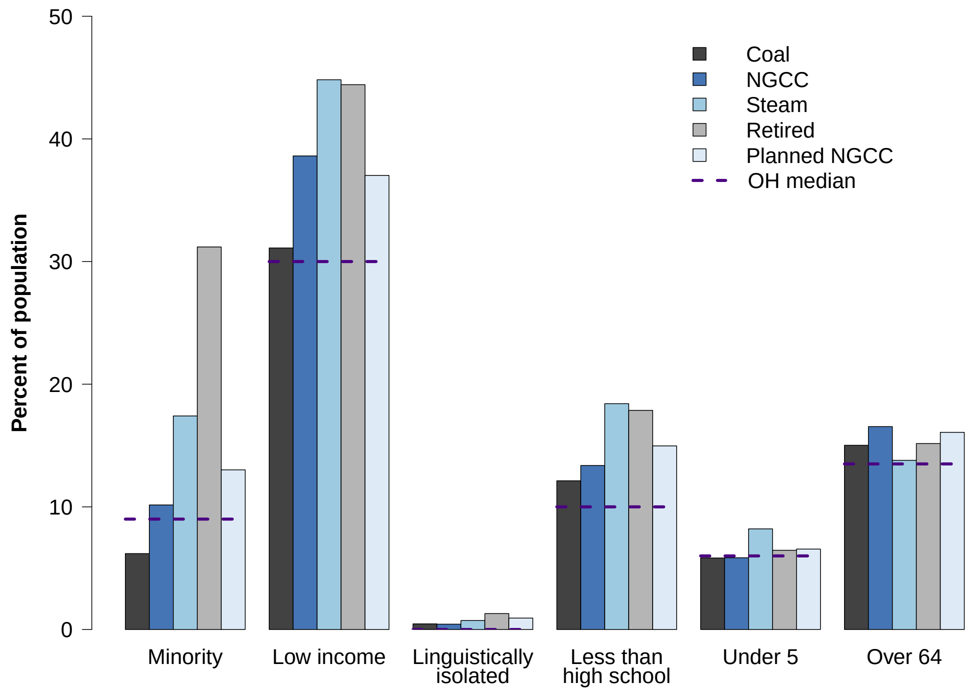
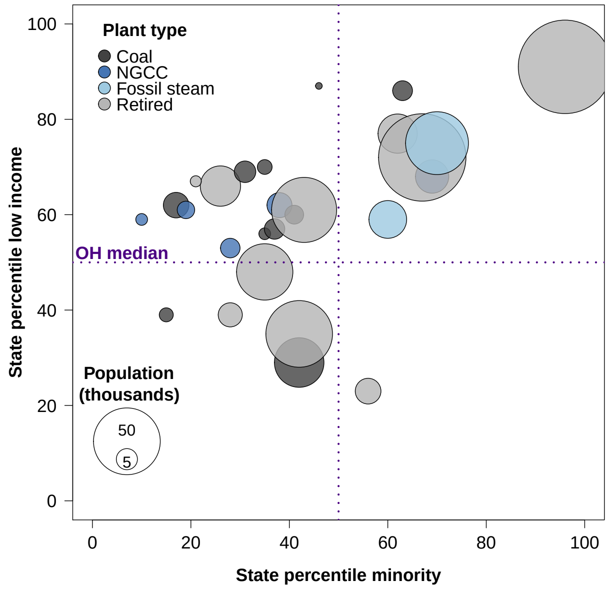


Figure 3.2: Bar chart of demographic indicators for total statewide population living within three miles of an Ohio power plant, by plant class, including existing plants and planned NGCC plants.

eight of the ten non-retired coal plants are located in communities above the state median for low income populations. Six of the ten recently retired coal plants are also above the state median for low income populations. However, only one gas, one coal, and both steam plants are above the median for minority populations, suggesting most plants tend to be located in poor but typically white communities. The coal plant Lake Shore was located in a 90% minority (96th percentile), 68% low income (91st percentile) area, but it retired in 2012. All but five of the communities around subject plants are above the median for percentage of population without a high school education, and similarly all but five are above the median for percentage of population over age 64. These findings suggest that a reduction in generation at fossil-fuel power plants under the Clean Power Plan is likely to reduce generation near vulnerable communities, but any increase in generation, such as at fossil steam or NGCC plants, may also result in an increase in generation near vulnerable communities, effectively causing a shift from populations with one set of vulnerabilities to another. However, the broad distribution of results for each indicator suggests that individual plants must be taken into account: a shift in generation from one plant to another could be a shift from a less vulnerable community to a more vulnerable one, or vice versa.

While the box plots in **Figure 3.1** illustrate how communities around each plant class are distributed along various demographic indicators, these plots do not take into account the population size living around each plant. Of Ohio's 11.6 million inhabitants, 47,100 live within three miles of a coal plant, 22,600 live within three miles of a NGCC plant, 47,400 within three miles of a fossil steam plant, and 289,200 within three miles of a plant retired between 2012 and 2015. To calculate the population-weighted value for each indicator we multiplied each metric (e.g., percent minority) by the total population living around each plant, and then sum results by plant class (**Figure 3.2**). The picture changes from the previous one. We also parse out that percentage for populations living near NGCC, coal, steam, retired, or planned NGCC plants, and compare the results to the state median.

The data in **Figure 3.2** indicate that the total population living near existing and planned NGCC, fossil steam and recently retired plants scores above the median on nearly every demographic indicator. Populations near coal plants ranked lower than other plant classes on every indicator except over age 64, which is of concern as the elderly are often more vulnerable to numerous health hazards than younger healthy adults. Populations near coal plants also ranked above the median for measures of low income and adults without a high school education. These results suggest that shifting generation from coal to existing or planned NGCC plants has potential to reduce generation near some vulnerable populations but increase it near others.



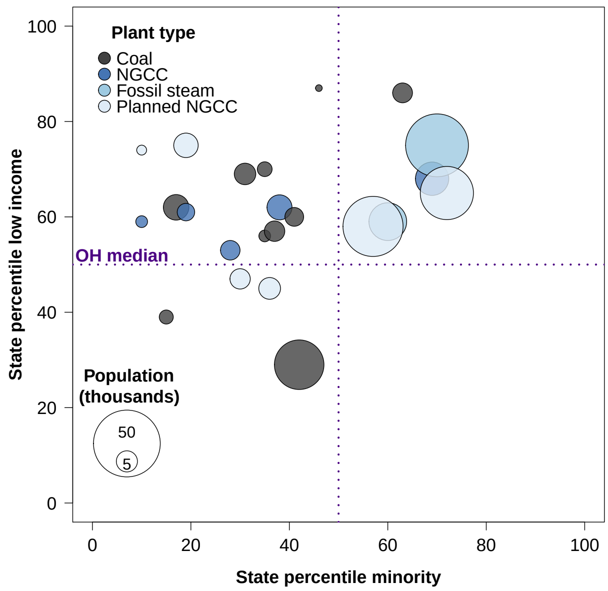


Figure 3.3: Bubble chart of state percentile rankings for low income and minority percentage for populations living within three miles of each power plant, by plant class, including retired plants (top) and proposed NGCC plants (bottom). Circle size represents the number of inhabitants living within three miles of each plant. Purple line represents the state median.

The aggregate population living near retired plants ranks above the median for percentage of individuals identified as low income, minority, linguistically isolated, with low level of educational attainment, and over 64. This plant retirement trend may help to reduce the burden of electricity generation near vulnerable populations, but there are still hazards and risks associated with living near retired plants, including potential legacy contamination. The vulnerability of these populations highlights the continued need to monitor these plants and their associated hazards, such as waste disposal sites, after retirement. Some of these hazards, such as coal ash impoundments, are discussed in Section 4. This vulnerability screening approach can also help inform decisions related to repowering at some of these sites.

Figure 3.3 provides a closer look at some of these data by plotting demographic measures for the populations living in proximity to each plant, including the state percentile minority and the state percentile low income for communities within three miles of the plant.[4] The

[4]The state percentile for the population living near a plant reflects the percent of census blocks in Ohio that have a larger or smaller percent of the population with the same indicator, e.g., percent low income population.

circle size indicates the population size within the three-mile buffer around each plant. This figure can be used to assess trends in demographics, population size, and geographic location of power plants. The majority of the plants, as noted, are located in communities with a larger low-income population than the median, including in a range of urban and rural locations. The average number of inhabitants living within three miles of a NGCC is 4,500 (median 3,400); the average number near a coal plant is 4,700 (median 3,300); and the average number near one of the two fossil steam plants is 23,700, suggesting these plants are in more urban areas than most of the coal or NGCC plants. The plants with both the highest and lowest fractions of nearby low-income populations are active and retired coal plants. In the bottom figure, we also look at the planned NGCC plants from the Ohio Power Plant Siting Board [6]. As noted previously, two coal plants and one coke cogeneration plant appear to be cancelled or on hold and are omitted here. Four of the six NGCC plants are reported as under construction, including the two in the upper right quadrant that rank above the median for both low-income and minority populations. Furthermore, each of these two plants (Middletown Energy Center and Oregon Clean Energy Center) has a larger population living nearby than all but one non-retired plant regulated under the Clean Power Plan. If coal generation is reduced under the Clean Power Plan and New Source Complement by shifting generation to these new gas plants in particular, there will therefore likely be an increase in generation near low-income and minority populations in higher-density areas.

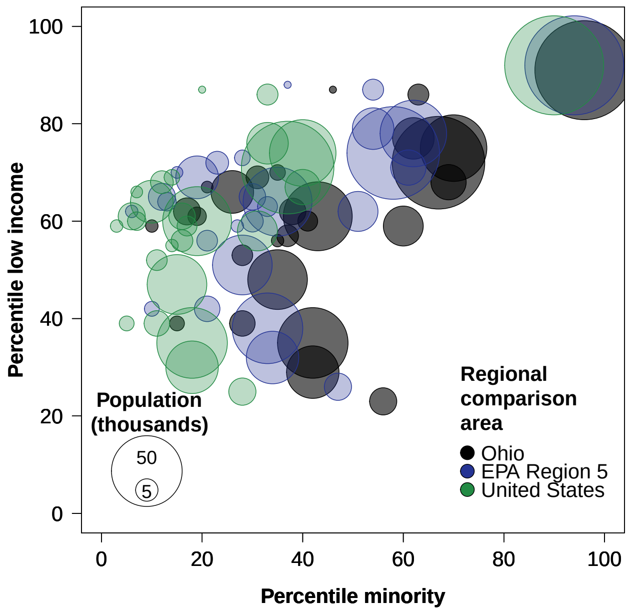


Figure 3.4: Bubble chart comparing of percentile rankings of each plant against low income and minority demographics for Ohio, EPA Region 5, and the US. Circle size corresponds with number of inhabitants living within three miles of each plant.

The state percentile is a useful metric for comparing power plant locations within the context of a single-state plan under the Clean Power Plan. However, the EPA also proposes that states consider multi-state plans to reduce overall compliance costs, which raises a question of how these indicators rank compared to regional distributions in the case that electricity is exported from one state to another. **Figure 3.4** shows the same power plants as the top plot in **Figure 3.3**, but also includes the percentile rankings for each area compared to EPA Region 5 (Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin) and the US as a whole. The results suggest that Region 5 has a higher percentage minority population but slightly lower percentage low income population than Ohio alone, and the US as a whole has higher percentage of minority but similar percentage of low income inhabitants. Although the regions that might be considered for multi-state plans are unknown, these results highlight the need to assess equity dimensions of compliance plans across an entire region in the case that one state has a higher burden from power plant generation than another.

3.3.2 Environmental burden analysis

In addition to demographic indicators, we next assess environmental burdens on communities living near power plants. Box plots of the environmental values for each indicator are shown in **Figure 3.5**. An additional figure showing the Environmental Justice Index value for each indicator weighting population size and minority and low income populations is given in **Figure 1** in Appendix .1, and the calculation for this Index is shown in **Equation 3.3**. Each indicator shows a relatively broad distribution around each class of plants, suggesting the need to look at aggregate burdens on the populations living near each individual plant. However, a few indicators stand out. Communities near every single active power plant, for example, rank above the state median for concentration of water discharge sites under the National Pollutant Discharge Elimination System (NPDES), and the majority of plants are located in communities above the median for indicators such as lead paint. Seven of ten coal plants are also in locations above the median for ozone concentrations.

The environmental burden indicators for air quality used in the EPA's EJSCREEN provide averages of 24-hour $PM_{2.5}$ and 8-hour summer ozone concentrations, but this averaging may obscure the number of days when ozone or $PM_{2.5}$ concentrations reach "unhealthy" levels under EPA standards. The EPA has designated multiple regions of Ohio as non-attainment areas for ozone and $PM_{2.5}$, reflecting regions where ambient air concentrations have exceeded "healthy" levels on a requisite number of days over a three-year period. Two counties in Ohio are designated non-attainment for $PM_{2.5}$ and 19 counties designated non-attainment for ozone. One active coal plant, Avon Lake, is located in a $PM_{2.5}$ non-attainment area. Three coal plants and one fossil steam plant are located in ozone non-attainment areas.

These non-attainment areas have not yet been updated to reflect the 2015 update to the ozone standard, and also do not reflect areas that have unhealthy air quality days but not enough to be classified as non-attainment. We therefore also calculated the number of days these standards were exceeded at any monitor within each Air Quality Management District over the years 2013-2015.

The average number of air district ozone exceedance days for NGCC plants in those districts was four over a three-year period, compared to 12 days for coal plants and 19 for fossil steam. The average number of $PM_{2.5}$ exceedance days was one for NGCC and four for coal and fossil steam. These data suggest that reduced carbon emissions under the Clean Power Plan have the potential to simultaneously reduce criteria pollutant emissions in areas with exceedances of ozone and $PM_{2.5}$, and a multi-pollutant state plan could specifically target such emission reductions. We note that the full regional impacts of any emissions are across a much broader area and these broader air quality impacts must be considered as well, as we will address in Section 5. These data simply highlight the utility of modeling the impact of any projected change in emissions on local air quality under the Clean Power Plan, particularly in these poor air quality areas.

3.3.3 Existing health vulnerability analysis

Population health indicators for each class of plants are shown in **Figure 3.6**. Most plants are located in communities with prevalences of adult uninsurance rates and disability prevalence above the state median, with more mixed results for low birthweight births and cancer prevalence. The population-weighted results are given in a bar plot in **Figure 3.7**. When

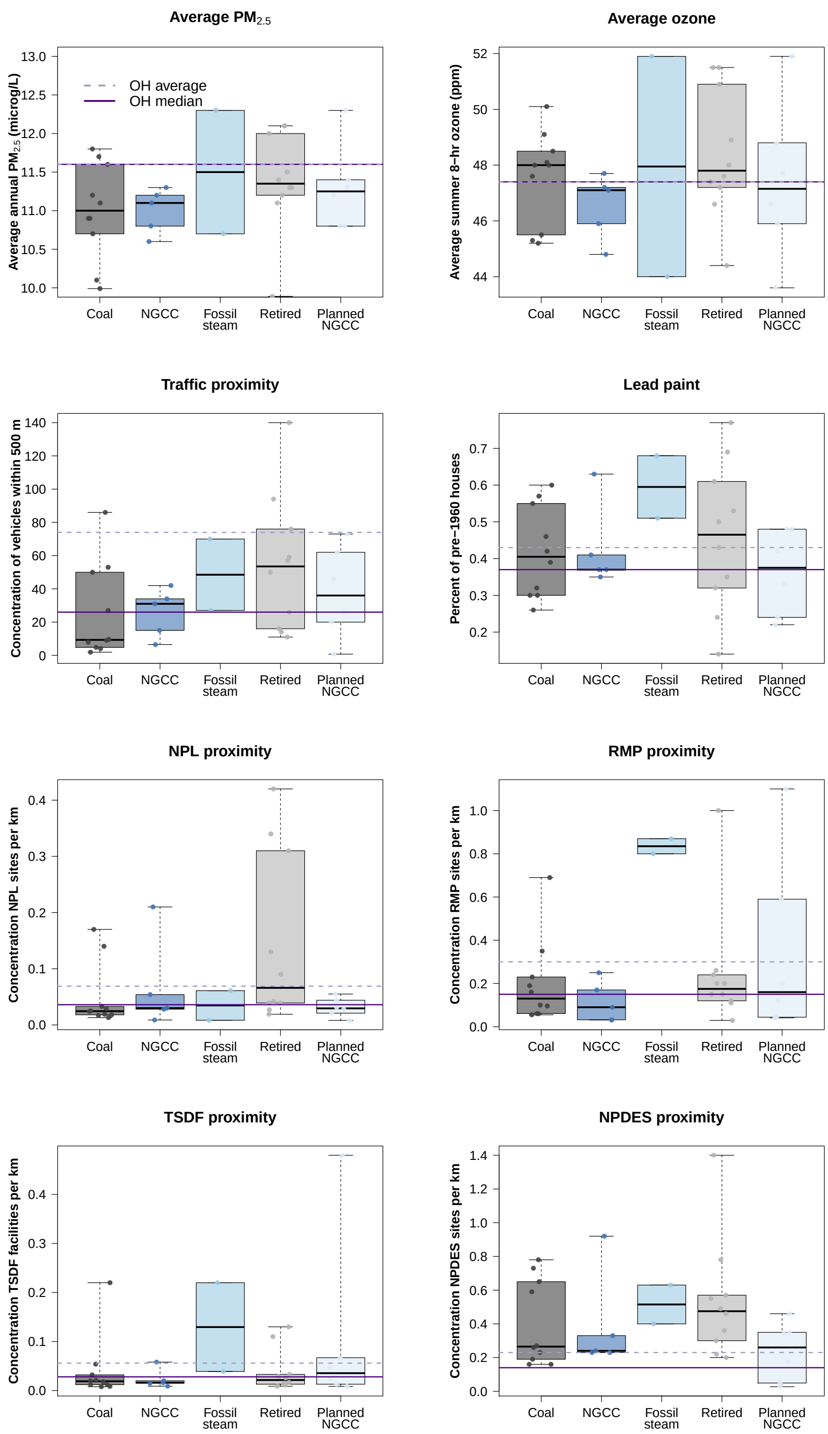


Figure 3.5: Box plot comparing environmental indicators for communities near power plants, by plant class. Each dot reflects the population living near a power plant. The purple lines indicate the median at 50%. Indicators include average 24-hour $PM_{2.5}$ concentration, average 8-hour ozone concentration, traffic proximity, lead paint in houses, national priorities list (Superfund) sites (NPL), facilities with chemical risk management plans (RMP), hazardous waste, treatment, storage and disposal facilities (TSDF), and National Pollutant Discharge Elimination System sites reflecting water discharges (NPDES).

population-weighted, the populations living near NGCC and fossil steam plants tend to have a higher prevalence of health burdens than both coal plants and the state median. A number of plants have been retired near populations that rank high for health vulnerability across these indicators, highlighting the need for careful monitoring even in retirement. We note that the prevalence and rates of poor health and birth outcomes is not necessarily attributable to living near the power plant, but they do indicate increased health vulnerability to potential exposures from power plants should they occur.

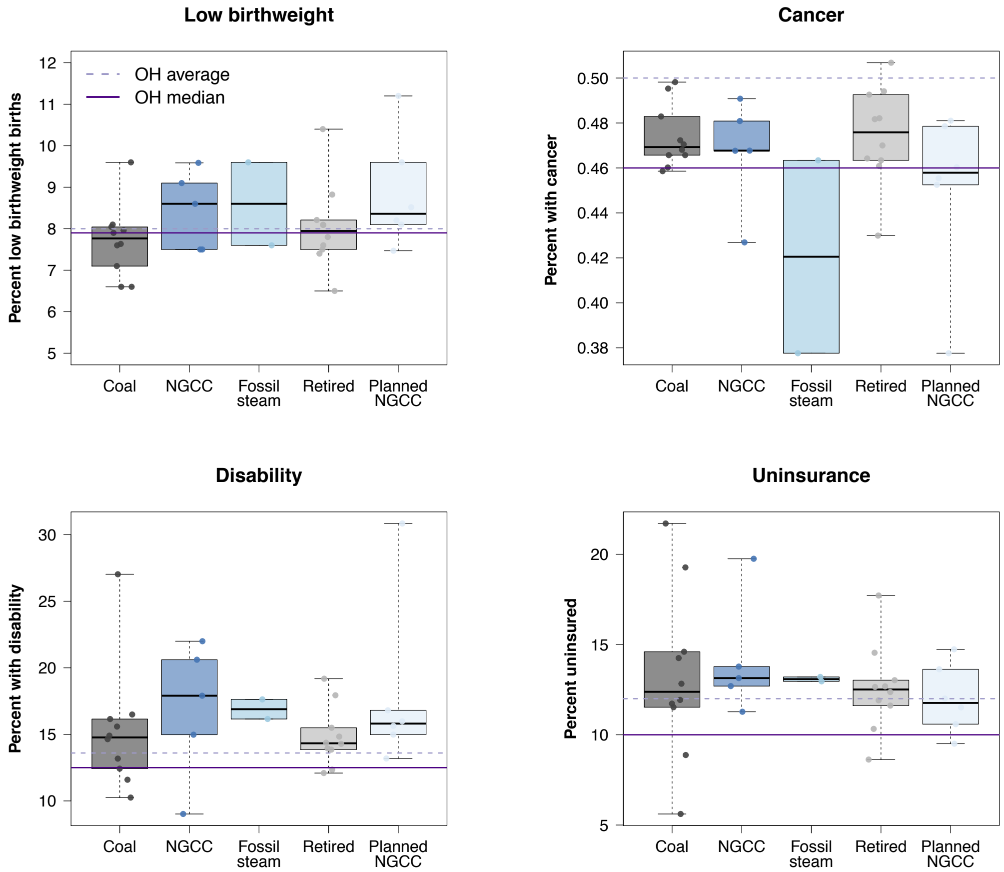


Figure 3.6: Box plot comparing health indicators for populations near Ohio power plants, by plant class. Solid dark purple line indicates the median value of census blocks within Ohio. Each dot reflects the the population living around each power plant.

3.3.4 Cumulative burden analysis

Given the variety of metrics and units involved, complex interactions between metrics, and differences in relative influence of socioeconomic and environmental factors for different communities, there is no one agreed upon approach to assess relative cumulative burdens among and between populations. Nevertheless, it is useful to aggregate available indicators of vulnerability and socio-economic and environmental stressors to gain a better understanding of relative cumulative burdens on communities.

In order to compare cumulative burden among populations living near power plants in Ohio, we aggregated the EPA's Demographic Index and our own vulnerability indicators. We developed a simple index based on the state percentiles of the indicators discussed previously in this section. We first aggregated our indicators into three groups: demographic, environmental, and health. There are different numbers of indicators in each cluster, so we

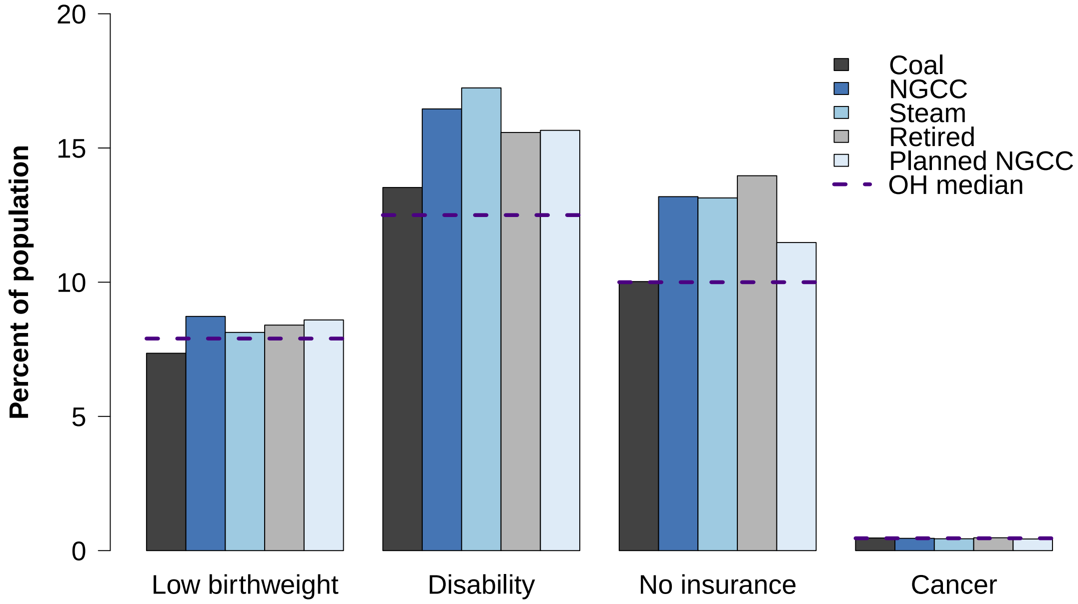


Figure 3.7: Box chart comparing indicators for total statewide population living within three miles of Ohio power plants, by plant class. Indicators include cancer prevalence, prevalence of low birthweight births, disability rates, and percent of adult population without health insurance.

average the percentile ranking for each indicator in each group for each plant (e.g. average percentile for environmental indicators). If the population living around a plant was at the median for every indicator, it would score a 50 in each group, and a total of 150. The results are given in a stacked bar chart in **Figure 3.8**. The plants with the highest cumulative burden across these indices are at the top.

In **Figure 3.8**, 23 of 27 of the original Clean Power Plan plants and 5 of 6 planned NGCC plants receive a cumulative burden score above 150. The results are mixed by plant type, with one coal, one fossil steam, and one existing and two planned NGCC plants receiving the five highest scores (indicating highest cumulative burden) among non-retired plants. Many of the plants on this list have been retired since 2012, but remain of interest due to both potential repowering projects and remaining coal ash impoundments and other hazards that are left behind when a plant retires. Indeed, many of the highest ranking plants have been retired in recent years. Nine of the 27 communities living near power plants, and two of six near planned plants, rank above the median for the EPA's Demographic Index, including the four of highest-ranked ten on our list. However, the exceptions point to the value of assessing multiple types of vulnerabilities beyond race and income, because incorporation of these additional health, demographic and environmental burden indicators can highlight additional populations that may be considered vulnerable or overburdened.

These results suggest that while there is some similarity in these two approaches to evaluating overburdened communities, taking additional indicators into account (18 instead of 2) can provide additional insight into the existing cumulative burden on a given community. Our results point to areas where power generation may contribute to an already elevated level of environmental and health burdens and where increased reliance on these plants may exacerbate this burden—or where reducing generation may have the opposite effect. These areas may also be appropriate for outreach under the EPA's directive to engage with vulnerable and overburdened populations.

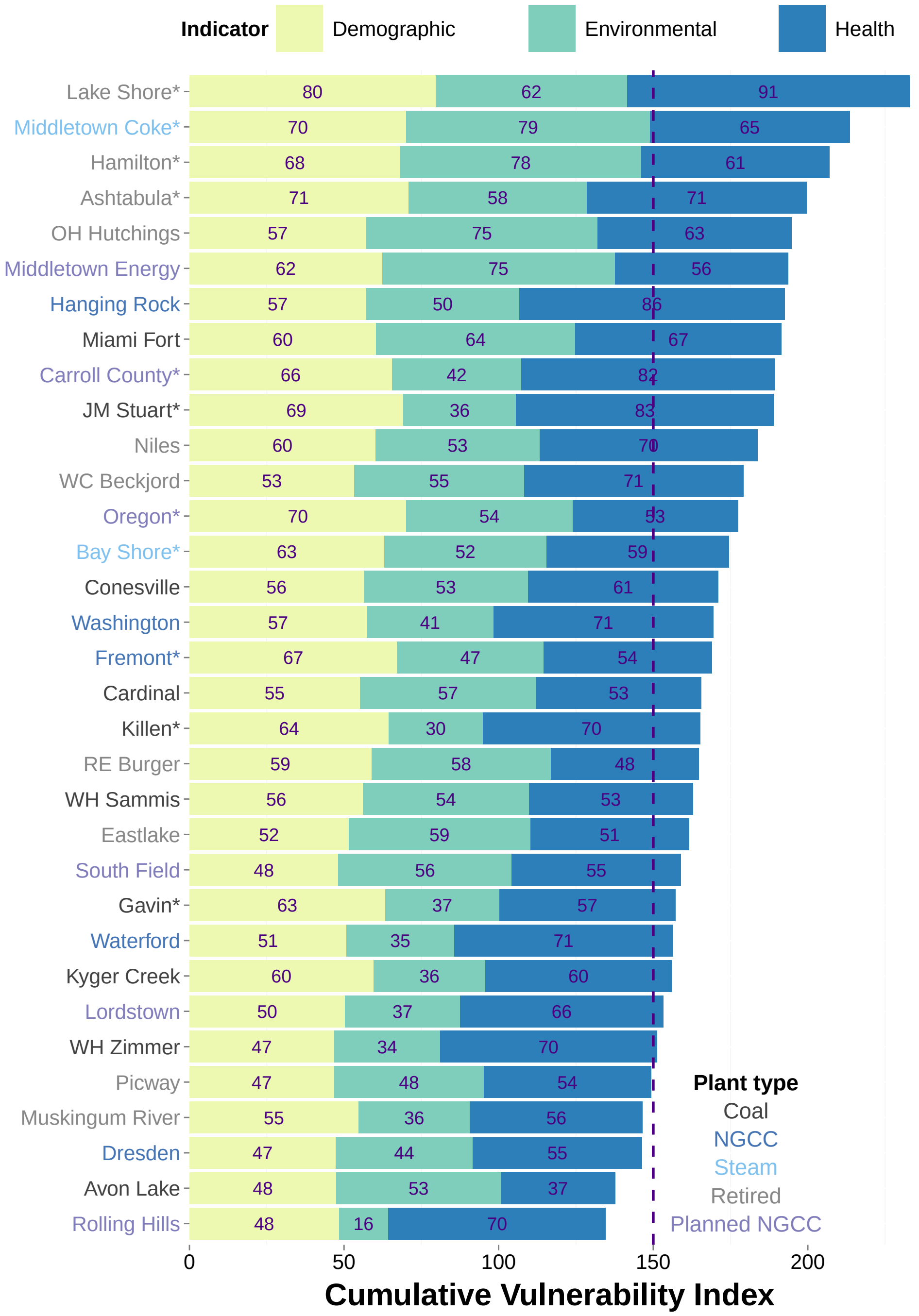


Figure 3.8: Cumulative Vulnerability Index of demographic, environmental and health indicators reflecting cumulative socioeconomic and environmental hazard burden for populations living within three miles of each power plant in Ohio. Each color represents a class of indicators (demographic, environmental, health). Bar length is the average of state percentiles for that group of indicators for the nearby population. If a plant were ranked at the median for all indicators, its Index would be 150 (purple dashed line). Plants above the 60th percentile on the EPA's Demographic Index are marked with *.

4. Local power plant environmental health hazards and compliance analysis

In the previous section, we analyzed the demographics and non-power plant-specific human and environmental health hazards within a three-mile radius of power plants in Ohio. In this section we focus on power plant-specific human health hazards, environmental health hazards, violations, and compliance information within these same areas. This analysis can help determine where reductions in fossil fuel use under the Clean Power Plan may simultaneously mitigate some of these burdens.

Assessing how fossil fuel-fired power plants may influence public health begins with hazard and risk identification. A hazard is defined as a source of potential harm or adverse health outcome, whereas a risk is the probability that a given population will be harmed if exposed to a hazard. A risk is influenced by the type, level, and duration of exposure. By way of example, arsenic emissions would constitute a human health hazard associated with coal-fired power plants; neuromuscular disease represents an adverse health outcome associated with this hazard. The risk of neuromuscular disease for those living near power plants would depend on various factors, including how often and in what concentrations an individual or population is exposed to arsenic. While the hazards associated with coal-fired power plants are well defined in the peer-reviewed literature, less is known about risks and distribution of adverse health outcomes across geographic and social space. Even less is known about the hazards and risks attributable to natural gas-fired power plants.

In this section, we first evaluate coal ash impoundments within a three-mile radius of each facility, reviewing the hazard potential, historical releases, and structural integrity of impoundments where coal ash is or was disposed. This analysis also includes a review of contaminant data available for ground water monitoring directly under and in close proximity to coal ash impoundments (within three miles). Second, we analyze the hazardous pollutants produced from each plant as recorded in the EPA Toxic Release Inventory (TRI) database, and where applicable, the disposal route for each of these pollutants. Third, we assess power plant violations and compliance history over the past five complete years from the primary federal environmental statutes: the Clean Air Act (CAA), the Clean Water Act (CWA), the Safe Drinking Water Act (SDWA), and the Resource Conservation and Recovery Act (RCRA). Our analysis of violations and compliance history under these federal statutes provides insights into some of the historical and cumulative environmental hazards attributable to these plants. We note, however, that we do not capture all hazards and potential environmental exposure pathways in this approach. There are additional burdens from these power plants that were beyond the scope of our analysis including, but not limited to, physical hazards such as noise and light pollution as well as traffic and other kinetic accidents.

4.1 Coal ash

This section evaluates hazards of coal ash impoundments attributable to and located within a three-mile radius of power plants subject to the Clean Power Plan in Ohio. These structures contain ash with a variety of pollutants from various stages of coal combustion that, if spilled, leaked, or otherwise not zonally isolated, can contaminate groundwater and land, which may create potential exposure pathways and associated risks to surrounding communities, particularly those that depend on local aquifers for access to water for drinking, bathing, food production, and other uses.

4.1.1 Background: coal ash

Coal ash, also known as coal combustion residuals and coal combustion waste, is the non-combustible and mineral fractions of coal and unburned residuals that are captured before flue gas is released through the smokestack [58, 59]. Coal ash is typically subcategorized into fly ash (fine, powdery silica), bottom ash (coarse ash that forms in the bottom of a coal furnace), boiler slag (molten bottom ash), and flue gas desulfurization sludge (wet mixture of sulfite and sulfate sludge from reducing SO_2) [60]. Coal ash is generally held in wet ponds known as surface impoundments to prevent ash from entering the air and otherwise aerosolizing. Residue from these impoundments is often recycled as a secondary product in other industrial practices (e.g., road filler).

Flue gas, which contains fly ash, is primarily composed of metals, polycyclic aromatics, and silica [61], and often contains substantial quantities of mercury and selenium. The sludge (from the flue gas desulfurization emission control process) and boiler bottoms contain various trace elements such as arsenic, lead, manganese, and other heavy metals, in addition to mercury and selenium [58]. The proportion of these elements depends on the coal source and coal plant combustion processes. Chemical distribution and solubility of trace metals vary, with boron and sulfur being more soluble, and thus more prone to leaching than some of the other heavy metals, such as arsenic and lead [62].

Coal ash impoundments gained national attention after the largest coal ash spill in the US occurred when the Tennessee Valley Authority (TVA) Kingston Fossil Plant coal ash impoundment released over 5.4 million cubic meters of coal ash into the Clinch and Emory Rivers in 2008 [59, 63]. Fines from this incident reached over $11.5 million from the Tennessee Department of Environment and Conservation [64]. A partial monetization for the Kingston spill for fish and wildlife is valued at $29.5 million [65]. In a single coal ash spill, the TVA Kingston spill released more chromium, lead, manganese, and nickel into the Emory River than the entire US power industry released in all of 2007 [66].

Coal ash is known to have a significant impact on water quality. For instance, Ruhl *et al.* [67] used isotopic ratios of strontium and boron to attribute large quantities of contaminants to the 2008 TVA Kingston coal ash spill downstream from the site in samples taken between 2009 and 2011. Mercury may also be a useful isotopic indicator of coal ash contamination [59]. Remediation dredging efforts to remove toxins after the TVA Kingston coal ash spill had a minimal impact on improving surface water arsenic concentrations in the Emory and Clinch Rivers even over a year after the incident [68]. The accumulation of coal ash concentrations for arsenic and mercury could impact the ecological system downstream of the spill via fish poisoning and the generation of anaerobic river sediments [69].

To date, coal ash is not regulated as a toxic waste stream, and while federal regulations for coal ash residuals as industrial waste were finalized in 2015 [70], there are many legacy coal ash impoundments, contaminated sites, and potential human health hazards resulting from years of limited regulation. One of the most vulnerable and common exposure pathways for coal ash contamination is through leaching of contaminants into groundwater. Nearly half of all Ohio residents and businesses rely on groundwater as a primary source of fresh water [71, 72]. Ohio's EPA has found contamination directly related to RCRA impoundments, which may include coal ash impoundments, amongst other industrial contamination [72].

Coal ash contamination can have direct and indirect economic costs associated with remediation, health costs, and social impacts. Indirect costs include social impacts and damage to natural resources, including wildlife, whereas direct costs can include damage to fisheries, tourism, and other industries. A 2010 EPA Regulatory Impact Analysis for RCRA coal ash regulations found that avoided costs from human health impacts totaled $207 million from cancer alone, and between $2.5 to $3 billion annually in total regulatory benefit if there is an induced increase in future annual coal combustion residuals.

However, when EPA performed its Regulatory Impact Analysis [73], it omitted the cost-benefit associated with fish and wildlife [65]. Lemly estimated that potential coal ash damage cases assessed by the EPA would total nearly $3 billion "in documented wildlife damage costs" [74]. It is important to note that this assessment focused on less than 5% of active coal ash impoundment wastewater disposal sites.

More recent spills and impoundment cases have occurred since the TVA Kingston spill. In 2012, a lawsuit from the Pennsylvania Department of Environmental Protection, along with the support of several environmental groups, resulted in the closure of the largest coal ash site in the US, the Little Blue Run Dam from the Bruce Mansfield coal-fired power plant run by First Energy [75]. In 2014 the Dan River spill by Duke Energy released over 27 million gallons of untreated liquid ash slurry and over 80,000 tons of impoundment ash into the Dan River at Eden, North Carolina [74]. Ohio's WC Beckjord and Cardinal plants had documented releases of coal ash in 1999 and 2004, respectively [76, 77]. Coal ash from both of these facilities has been found to contain heavy metals such as arsenic, selenium, manganese and boron, according to EPA TRI data [10].

4.1.2 Data and methods: coal ash

The data analyzed in this section are derived from two EPA datasets: 1) 2012 Electric Utility Self-Reported Survey [78]; and 2) 2014 Impoundment Assessment [79]. Using the 2012 Self-Reported Survey dataset, we mapped both the hazard potential rating and the historical deficiencies (historical violations, losses, or other infractions) identified. The hazard potential rating corresponds to the potential for harm should the impoundment fail, and not the current structural integrity of the impoundment. The hazard potential rating is derived from the National Inventory of Dams criteria, and categorizes hazard potential for a coal ash impoundment as one of the following [80]:

1. **High:** failure or misoperation "will probably cause loss of human life;"
2. **Significant:** failure or misoperation "results in no probable loss of human life but can cause economic loss, environmental damage, or can impact other concerns;"

3. **Low:** failure or misoperation "results in no probable loss of human life and low economic and/or environmental losses;"
4. **Less-than-low:** failure or misoperation results in no probable loss of human life or economic or environmental losses.

The 2012 Electric Utility Self-Reported Survey dataset contains only information provided to the EPA from power plant operators. In 2014, the EPA contracted with civil engineering firms with dam expertise to evaluate the structural integrity of the impoundments, evaluating each facility at least once during 12 rounds of evaluations between 2009-2014 [79].

Using the 2014 Impoundment Assessment dataset, we mapped both the engineering contractor-determined hazard potential rating and the EPA condition assessment for structural integrity of the impoundment. The 2012 Electric Utility Self-Reported Survey dataset was used to map locations with known historical releases from coal ash impoundments.

4.1.3 Results: coal ash

We map the results from our analysis of the 2012 Electric Utility Self-Reported Survey dataset and the 2014 Impoundment Assessment dataset in **Figure 4.1**. The plants with historical releases and/or significant deficiencies at their coal ash impoundments included the Cardinal and WC Beckjord coal-fired power plants [76, 77].

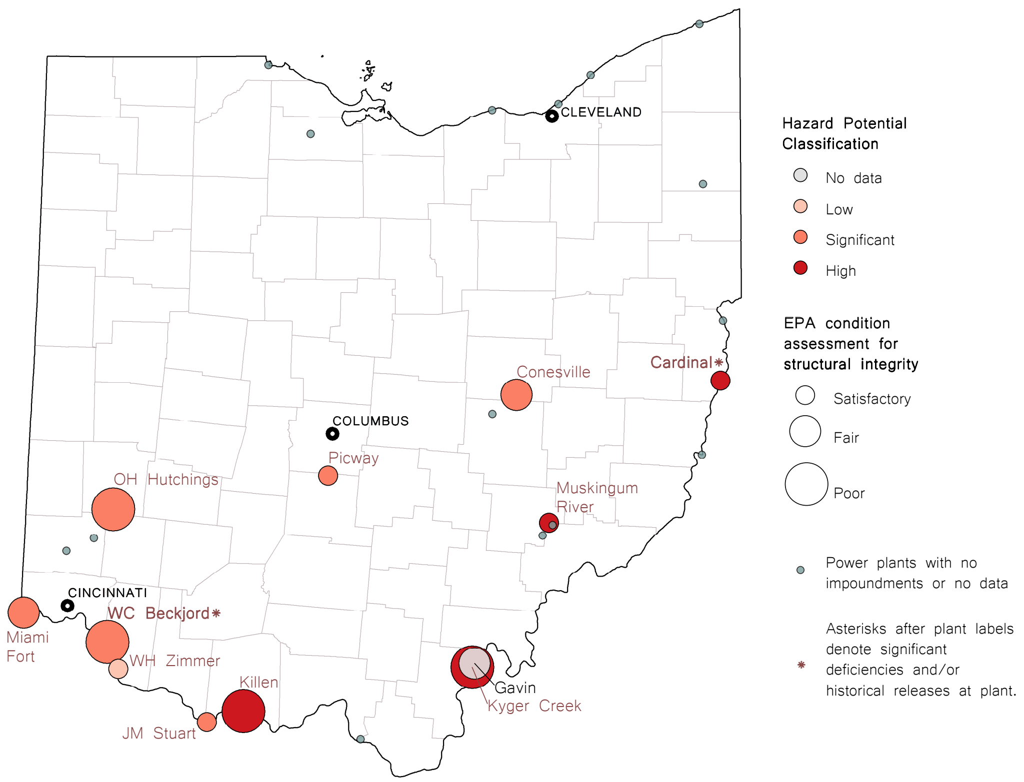


Figure 4.1: Map of coal ash impoundments at power plants, indicating hazard potential, structural integrity condition, and historical spills or unpermitted releases, from 2009-2014 (using available data). Circle size indicates EPA assessment of the structural integrity of impoundments; larger circles indicate poorer condition. Circle color denotes EPA hazard potential. If a plant has more than one coal ash impoundment unit with a hazard potential or condition assessment, the value of the greatest hazard is depicted. Names with * are plants with significant deficiencies and/or historical releases of pollution.

Of the 12 plants that have coal ash impoundments in Ohio, three plants are located within a high-Demographic Index area, three plants have at least one impoundment with a high hazard potential, six plants have at least one impoundment with a significant hazard potential, and six plants have a poor condition assessment rating (**Figure 4.1**). The bottom ash complex impoundment at Cardinal coal plant has a significant hazard potential rating, but a poor structural integrity condition assessment rating. The fly ash reservoir #1 impoundment at Cardinal, which had a seepage in a spring along an outcrop between February and April of 2004, was decommissioned as an impoundment and repurposed as a landfill foundation in 2009. There still remains an active landfill and new impoundment, fly ash reservoir #2 [77]. The boiler slag pond for units 1-4 at Muskingum River, a now retired coal plant, had both a high hazard potential and poor structural integrity condition.

In **Table 4.1**, we show six plants with the most severe hazard potential classification or EPA condition assessment ratings, three of which were retired by the end of 2015 (Muskingum River, OH Hutchings, and WC Beckjord). Killen is located in a community with a high Demographic Index. Operating near these communities and having poor structural integrity or high hazard potential is cause for concern. Under a scenario that reduces the need for coal-fired electricity generation, a potential co-benefit of reducing carbon emissions would be to reduce the amount of coal ash produced and stored in impoundments.

Most of the facilities in **Table 4.1** produced one or more of the following: fly ash, bottom ash, boiler slag, flue gas desulfurization emission control residuals, and other residuals [74, 79, 78]. In addition, the Cardinal plant impounded sluiced fly ash, and the WH Zimmer plant stored wastewater processing waste. When these by-products are permanently disposed of without monitoring, they may pose environmental health hazards due to the contaminants inherently found in coal ash.

Plants with a poor rating in the EPA condition assessment for structural integrity that do not take appropriate remedial action are more likely to receive additional surveillance and monitoring by the EPA due to the more immediate safety threats for this category (as compared to satisfactory or fair) [79]. Plants that received a poor structural integrity condition assessment rating include WC Beckjord (three impoundments, retired), OH Hutchings (three impoundments, retired), Kyger Creek (two impoundments), Killen (two impoundments), and Muskingum River (one impoundment, retired), as shown in **Table 4.1**. Additionally, Miami Fort (Hamilton County), WC Beckjord (Clermont County, retired), WH Zimmer (Clermont County), and Picway (Pickaway County, retired) are located in counties which have RCRA surface impoundment documented contamination of local groundwater resources [72]. RCRA surface impoundments include, but are not limited to, those that store coal ash. However, there are other impoundments that we do not have conclusive data on, and therefore cannot assess the potential associated environmental health hazards.

Understanding plant location and management can provide insight for continued safe operations. For example, if Cardinal's fly ash reservoir #2 were to at any point fail, its contents would "inundate Salt Run, State Route 7, the power plant and eventually spill into the Ohio River with probable loss of life and environmental impacts" as the total volume is substantial, and its contents harmful to human and environmental health [77]. The Muskingum River would likely be inundated should there be a failure of its impoundment (one of four) with a poor structural integrity designation [81].

Facilities with poor structural integrity are most likely to fail, and those with a high hazard potential pose more risks to human health should they fail or be misoperated. We identified

Table 4.1: Coal ash impoundments based on most severe EPA structural integrity condition assessment, hazard potential rating, and/or historical releases for available 2009-2014 data. EPA condition assessment rating of poor is most severe rating before impoundment failure has occurred.

Site	Impoundment	Start year	Hazard potential rating	EPA structural integrity condition assessment	Historical releases	Near high DI area	Size
Cardinal	Bottom Ash Complex	1973	Significant	Fair		No	350 acre-ft
	Fly Ash Reservoir #2	1987	High	Satisfactory	2004 spill in right abutment		11,350 acre-ft
Killen	Fly Ash Pond	1982	Low	Poor	None	Yes	191 acres
	Bottom Ash Pond	1982	Low	Poor	None		39 acres
Kyger Creek	South Fly Ash Pond	1955	Significant	Poor	None	No	2,500 acre-ft
	Boiler Slag Pond	1955	Significant	Poor	None		1,435 acre-ft
Muskingum River	Unit 1-4 Bottom Ash Pond	1950s	High	Poor	None	No	100 acre-ft
	Upper Fly Ash Pond	1975	High	Satisfactory	None		5,250 acre-ft
	Middle Fly Ash Pond	1968	High	Fair	None		1,370 acre-ft
	Bottom Ash Pond	1968	Low	Fair	None		660 acre-ft
OH Hutchings	East Primary Settling Pond	1964	—	Poor	None	No	4.5 acres
	West Primary Settling Pond	1964	—	Poor	None		7.3 acres
	Secondary Settling Pond	1964	—	Poor	None		0.3 acres
WC Beckjord	Ash Pond B	1963	Significant	Poor	None	No	280 acre-ft
	Ash Pond C	1966	Significant	Poor	1999 ash leak into Indian Creek		1,400 acre-ft
	Ash Pond C Extension	1985	Significant	Poor	None		1,300 acre-ft

several plants that have both poor structural integrity and are in high hazard potential areas (**Figure 4.1** and **Table 4.1**). Regardless of whether the plant or impoundment is inactive or closed, it is important that monitoring of these sites continues in order to prevent and mitigate legacy issues that may arise or may have already occurred. The data presented in this section highlight the environmental hazards of some of these coal ash impoundments; a potential co-benefit of the Clean Power Plan may be a reduction in coal ash waste contributions to impoundments with high associated hazards and risks, and in particular near vulnerable communities. Our results also suggest the need for ongoing monitoring at and around impoundments at coal-fired power plants that are currently or soon will be retired as well as at plants that may be repowered with natural gas.

4.2 Water well-monitoring

Surface and groundwater monitoring can provide information on potential contamination from power plants. This section considers groundwater monitoring data for select power plants, based on data availability.

4.2.1 Background: water well-monitoring

Coal-fired power plants produce numerous toxic and hazardous compounds that, should they enter water sources used for human consumption, may increase risks of adverse health effects. Elevated concentrations of contaminant concentrations in aquifers in close proximity to a facility may suggest where contamination from power plant combustion and waste may have occurred, although direct attribution can be difficult. Key contaminants of concern include arsenic, lead, manganese, selenium, and boron.

Arsenic is a known human carcinogen and can impair and permanently damage dermal, cardiovascular, respiratory and neurological systems even with relatively low levels of exposure [66, 82]. Both total and dissolved arsenic levels are considered in this report. Gross alpha and beta particles, known as radioactive particles, are sourced from coal and may be in excess quantities compared to background levels in coal ash impoundments or other storage of coal residuals [83]. Radioactive particles can permeate various environmental media and pose numerous health hazards, including increased long-term incidence of cancer [84]. Selenium (total and dissolved concentrations) can cause dermal pigmentation disruption, tooth decay, and both gastrointestinal and neurological disturbances. Arsenic, lead and selenium are all legally limited by EPA Safe Drinking Water Act (SDWA) standards.

Manganese is considered an essential nutrient in small doses, but increased exposure at high levels can lead to 'manganism' which includes symptoms of impaired body movements and behavioral implications, and at higher levels can impact brain development in children [66, 85]. Boron has acute and chronic effects at large doses, including impacting the stomach, liver, kidney, and brain, and excessive amounts can be deadly [86].

The SDWA sets standard Maximum Contamination Levels (MCLs) to minimize health risks for concentrations of chemical constituents in drinking water supplies. The SDWA does not directly regulate all contaminants, especially those less common in municipal public drinking supplies. For a subset of these other contaminants, the EPA can issue Health Advisories. Health Advisories are not enforceable, but provide health-based guidance on drinking water concentrations from assessments conducted by the EPA [87], the Agency for Toxic Substances and Disease Registry, or the World Health Organization. Health advisories can be based on a variety of demographic (e.g. age, pregnancy, or compromised immune system), exposure dose or duration recommendations, and are used by State agencies, public health officials, and non-government groups interested in learning more about health-based limits for contaminants.

4.2.2 Data and methods: well-monitoring

Water well-monitoring data at sites within three miles of power plants subject to the Clean Power Plan were compiled from Ashtracker.org, a site sponsored by the Environmental Integrity Project (EIP), an environmental legal and technical expertise non-profit [88]. Ashtracker was developed to help the general public access detailed, non-electronic monitoring well data for coal plants. We used three Health Advisories, one regional screen,[1] and one regulatory limitation (MCL) to measure whether or not the sample exceeded a health-based value. The advisories used include (1) the Drinking Water advisory (DWA), which designates levels that are "not expected to cause adverse non-cancer health effects generally" [88], (2) the Lifetime Health Advisory for cumulative adult lifetime exposure (LHA), and (3) the Child Health Advisory for children exposed 1-10 days (CHA).

Water well-monitoring data records were collected from manual archives by the EIP from plant records for select sites. Therefore, site data are not available for all facilities; only 4 plants out of the 27 that are subject to the Clean Power Plan had available data. EIP selected plant sites based on community involvement, known contamination, or regulatory noncompliance. The facilities subject to the Clean Power Plan with available data included: Cardinal, Muskingum River, Gavin, and WC Beckjord, available at the Ashtracker website [88]. The data included in this report ranged from 2010-2014.

We calculated the cumulative number of times contaminant concentrations in groundwater samples at each plant exceeded advisory or regulatory levels from 2010-2014. We also calculated total levels of exceedance for arsenic, boron, manganese, selenium and alpha and beta particles. The heavy metals that were available for analysis included: antimony, barium, boron, cadmium, chromium, cobalt, molybdenum, nickel, nitrate, selenium, and sulfate. Contaminants not listed were not reported by Ashtracker. The data used are for the sample time period only; no background levels prior to the installation of the power plant were available for comparison. We cannot attribute any exceedance to a power plant specifically, although such attribution might be possible using isotopic tracer identification, as noted in Section 4.1.1. No more than one sample per well, per contaminant, was used in a day in our analysis. However, there were some contaminants whose concentration may include different forms of a given heavy metal, such as dissolved and total concentrations for arsenic. Since MCLs are set per pollutant, it is theoretically possible to meet the MCL for a contaminant in one form but exceed the MCL for the same contaminant in a different form. Therefore, where multiple forms existed to determine if the MCL or advisory level was exceeded, the results across all forms were used. We calculated the percentage of each exceedance above the regulatory or advisory limit and averaged them for each facility.

[1]Regional screening levels (RSL), are health-based guidelines published jointly by three EPA regions to assist in Superfund site investigations and exist in places where MCLs or advisories do not.

4.2.3 Results: water well-monitoring

Figure 4.2 (left) shows the cumulative number of exceedances by advisory or MCL for each Ohio Clean Power Plan subject plant that we had access to in the Ashtracker database. **Figure 4.2** (right) shows the average pollutant exceedance at each facility, measured in average percent above the recommended maximum concentration. Every plant exceeded advisory levels to various degrees, and most plants exceeded the mandated MCLs. Gavin had the greatest number of exceedances of any facility studied, with 388 exceedances between 2010 and 2014, out of a total 5,863 contaminant samples recorded. 6.6% of all samples for Gavin were in exceedance. Of those, 135 (2.3% of samples) were above MCLs, 206 (3.5% of samples) were above LHAs and less than 1% were above DWA levels. Muskingum River and WC Beckjord retired in 2015 and 2014, respectively.

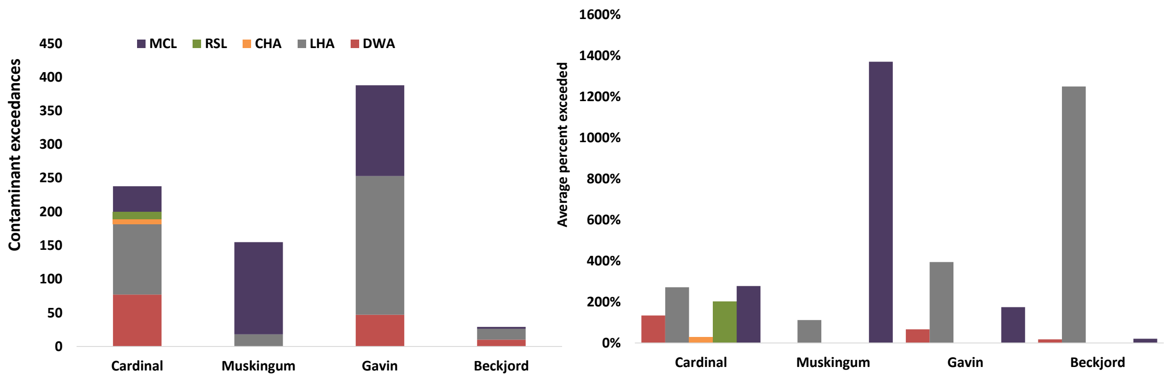


Figure 4.2: Contaminant exceedances by plant, for sample recordings within a three-mile radius of the power plant, 2010-2014. (Left) Total exceedences. (Right) Average percentage above designated level. Colors indicate advisory or regulatory level attributed to exceedances, including: Drinking Water Advisory (DWA), Lifetime Health Advisory (LHA), Child Health Advisory (CHA), Regional Screening Level (RSL), and EPA's Maximum Contaminant Level (MCL). Retired facilities as of 2016 include Muskingum River and WC Beckjord.

When an exceedance did occur, the average percentage of the exceedance varied from plant to plant, but was generally on the magnitude of several hundred percent or higher. Muskingum River had the highest average MCL exceedances, at 1,370%. WC Beckjord exceeded the LHA the most at 1,250%. The CHA was exceeded the least. Where there is geographic and hydrological overlap between high and frequent observations of LHA exceedences and aquifers where human populations source drinking water, there exists increased risks of health effects in residents that drink this water. The only legally mandated level, the MCL, was exceeded by all plants.

Exceedances of the EPA MCLs for arsenic, selenium, gross alpha, and gross beta particles (0.01 mg/L, 0.05 mg/L, 15 pCi/L, and 50 pCi/L, respectively) are shown in **Figure 4.3**, along with manganese exceedances of the LHA and boron exceedances of the CHA. These exceedences suggest that there could be increased risks to populations that may have contact with this water or other groundwater sources with hydrological connectivity to the aquifers where these exceedances were measured.

Exceedances for radioactive alpha and beta particle MCL standards occurred for two plants: Muskingum River and Gavin. The highest percent exceedance for a single sample is shown for Muskingum River at 20,260% for gross alpha particles, and 922% for gross beta particles above the MCL for a sample date in 2012. The Gavin plant had average exceedances below 100%. Only WC Beckjord exceeded the MCL for selenium, with one datum.

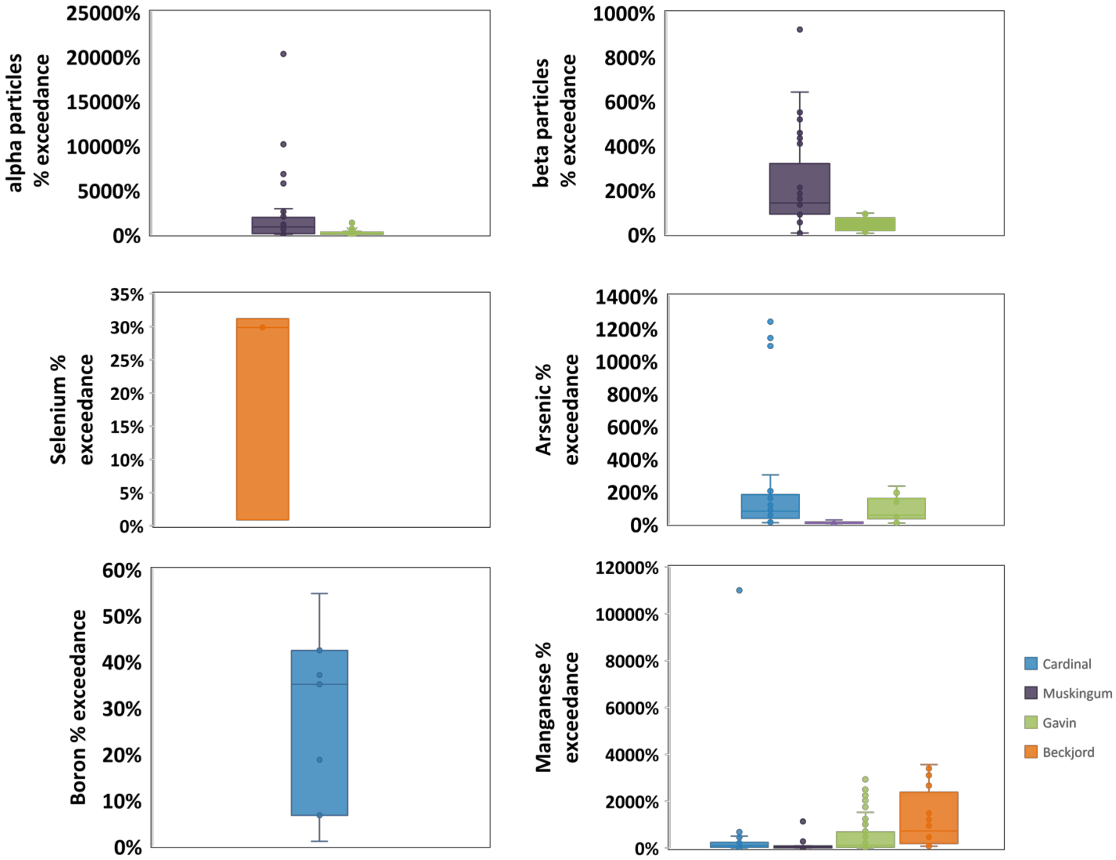


Figure 4.3: Box plot of percent exceedances for contaminants above health standard levels for plants with available data, 2010-2014. Gross alpha particles, gross beta particles, arsenic and selenium use the MCL. Boron uses the CHA standard. Manganese uses the LHA standard. Dots represent individual exceedance measurements. Solid line indicates mean for all data. Retired plants include: Muskingum River and WC Beckjord.

The LHA for manganese was exceeded by all four plants with available data. The highest single exceedances for manganese were at Cardinal (11,000% above the LHA) and WC Beckjord (3,400% above the LHA), although there was a broad range of exceedance levels at measured sites. Boron CHA levels were exceeded near the Cardinal plant. Any exceedance can contribute to or cause adverse health impacts, especially for children.

As noted previously, retired plants such as Muskingum River and WC Bekcjord can contribute to exceedances above health-based advisory and regulatory safe levels. The measurements shown here reflect an environmental health hazard, although further analysis is required to definitively attribute these hazards specifically to each power plant. Moreover, retired plants must still be monitored as contaminants can still make their way into the groundwater beyond the borders of the retired plant. Therefore, continuous monitoring of these wells is needed to ensure vulnerable communities are not left with legacy contamination in their groundwater.[2]

Again, the samples taken are only at one point in time. Without determining baseline concentrations of these contaminants, or tracing contamination via chemical tracer identification it is difficult to have definitive conclusions that power plants solely caused this contamination. It should be noted, however, that our analysis found consistent exceedences of groundwater contaminants near these industrial power facilities. Sampling was not com-

[2]Further epidemiological impacts of heavy metals and other contaminants can be found in Section 5.

prehensive at these four plants and we did not have access to the paper monitoring data for the remaining power plant sites. Given the lack of data for the majority of the power plants under the Clean Power Plan, the results in our analysis are likely to under- not over-estimate the hazard of nearby groundwater contamination at and near these facilities.

4.3 Power plant toxic releases

In this section we take a broad look at the total number and quantity of chemicals released by power plants in Ohio, and the disposal of these chemicals, using Toxic Release Inventory (TRI) air, land and water data for each facility. This section does not include analyses of power plant criteria pollutant stack emissions which we analyze in Section 5.

4.3.1 Background: toxic releases

Known exposure routes for contaminants from power plants include air, water, and land. Air pollutant emissions from power plants, notably from coal-fired power plants, include mercury, heavy metals, polycyclic aromatic hydrocarbons (PAH), radioisotopes (e.g., radium, uranium), acid gases (e.g., hydrogen chloride, hydrogen fluoride), dioxins, and a variety of volatile organic compounds (VOCs) (e.g., benzene, toluene), among others. The EPA estimates that power plants are responsible for large proportions of the total regional outdoor air pollution burden in the United States, including 50% of mercury air pollution, 62% of arsenic, and 77% of acid gases [89]. Mercury, for instance, is known to impact the nervous system and in high doses can cause permanent damage to the brain, kidneys, and developing fetuses [34]. Exposure to arsenic and other heavy metals can affect cardiovascular, dermal, respiratory, and immune systems at low levels and can cause cancer of the skin, liver, bladder, and lungs [34]. Dioxins are byproducts of combustion processes and are carcinogenic. They can cause developmental problems in children and severe skin conditions, such as the acne-like disease chloracne [90]. Bioaccumulative chemicals, such as these, accumulate in the lipid (fat) cells of humans and other biota. These pose health hazards over time and are commonly sourced from fossil fuel power plants.

Many of the same contaminants emitted to the atmosphere can also be discharged into the air and soil, causing contamination. Contaminant transport from coal ash impoundments into surface and groundwater, as covered in Section 4.1.1, is a known source of surface water, aquifer, and soil contamination when not properly controlled or remediated.

Accidental and improper releases into water bodies, or intentional releases during permitted activities through NPDES permits or other regulatory statutes, can be associated with environmental contamination and environmental public health risks. Land disposal of chemical by-products from power plants is common, and thus these byproducts are a notable potential source of contamination. Historic incidents in other regions (see: [51, 91, 92]) have demonstrated that in some cases these toxic chemicals are disposed of in disproportionately low income and minority communities, including both on- and off-site disposal.

4.3.2 Data and methods: toxic releases

We aggregated data on toxic chemical releases from power plants from the EPA Toxic Release Inventory (TRI) [10]. A *release* is a chemical that is emitted from a facility into the air, water or land, whether permitted or not. TRI includes more than 650 chemicals that are carcinogenic, have known chronic and/or significant acute human health effects, or have significant adverse environmental effects. Facilities subject to TRI reporting include, but are not limited to, electric generation utilities. While TRI reporting and monitoring overlaps with other EPA statutes such as the CAA's National Emissions Inventory and Risk Management Plan or the CWA's Permit Compliance System, only TRI requires such a broad chemical reporting structure for all media, providing an inclusive understanding of the toxic releases and potential health hazards at a facility.

Categorical information from the TRI database that we included in our assessment are the following:

- **Classification:** chemicals fall into three standard categories: 1) persistent bioaccumulative toxic chemicals (PBT); 2) dioxins (and dioxin-like compounds); and 3) standard chemicals (no additional known impacts to be categorized as a PBT or dioxin);
- **Metals:** if the chemical is considered a metal;
- **Carcinogen:** if the chemical causes cancer.

We included TRI data for all power plants regulated under the Clean Power Plan for the following release categories:

1. Fugitive air pollutants (unpermitted and uncapturable releases from leaky valves, joints and other process equipment),
2. Stack air pollutants,
3. Water for on-site releases,
4. Total off-site releases,
5. One-time releases,
6. Publicly owned treatment works (POTW) releases.

We summed all on-site, off-site, and POTW releases to come up with a database of all releases from a facility within the defined timeframe. TRI data are collected annually. Data may not be reported for every category for every facility. We only included facilities and data that were reported and had numerical values greater than zero. Bay Shore switched primary fuels during the 2010-2014 timeframe from coal to petroleum coke, and while all available data from that time frame were considered, the plant class is categorized as coal for all TRI data and calculations.

4.3.3 Results: toxic releases

Figure 4.4 depicts the amount of dioxins, PBTs and other TRI-reported chemicals that are not classified as a dioxin or PBT. To see the relative nature of each of the three categories, given the broad scale of releases, from extremely small fractions of dioxins to multiple thousands of other TRI chemicals, a logarithmic scale was used. Coal, the only TRI reported plant class, released the most cumulative TRI chemicals.

Data for NGCC plants were not available from the EPA's TRI website, as the reporting of these plants is not required if the exclusive and sole fuel is natural gas. Natural gas is primarily comprised of methane with small quantities of other hydrocarbons, however, contaminants such as hydrogen sulfide, nitrogen oxides, and other hazardous air pollutants can be found in the processing, distribution, and/or the combustion byproduct emissions from NGCC facilities [93, 94, 95]. While the relative aggregate emissions from NGCC plants are estimated to be significantly lower than other plant classes, such as coal, the environmental health burdens from NGCC plants should be considered prior to refueling or increasing utilization of NGCC plants. Therefore, due to lack of data, we assume there is an underestimation of chemical releases from NGCC plants.

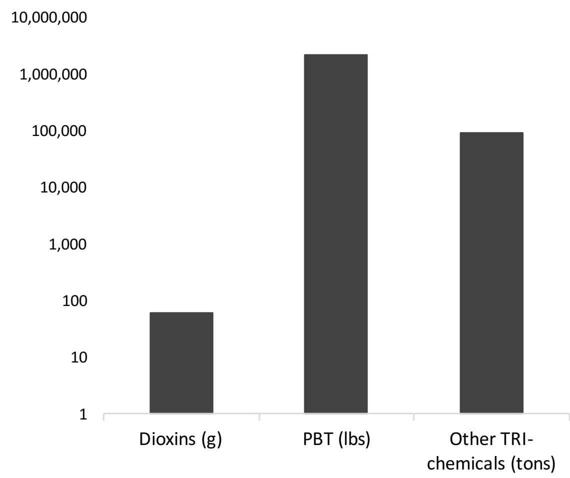


Figure 4.4: Logarithmic bar chart for total on-site toxic releases from Ohio's CPP subject coal plants. Dioxins, PBTs, and other TRI chemicals not covered by the previous two categories are shown.

Figure 4.5 compares the mass of TRI releases per MWh to the mass of CO_2 emissions per MWh, which highlights where a reduction in carbon emissions may have the greatest co-benefit in simultaneous reductions in toxic releases. Coal plants emit the most, and since natural gas exclusive plants are not required to report TRI data, a comparison to coal plants is not feasible. Coal plants have a narrow range of CO_2 emission rates, suggesting that the location and conditions surrounding the plant may not play a significant role in climate burden, as the climate burden for each coal plant is relatively similar with the exceptions of Bay Shore and RE Burger. However, there is an opportunity to reduce the TRI release burdens from specific plants more than others. Bay Shore transitioned from primarily burning to coal to burning petroleum coke and other fossil steam fuels between 2012-2014, which could account for the drastic increase in CO_2 emission rates. These results align with the previous data shown in **Figure 4.4**, and imply that limiting production from specific plants with high TRI releases per MWh can provide the biggest pollutant reduction impact, while simultaneously reducing climate burdens.

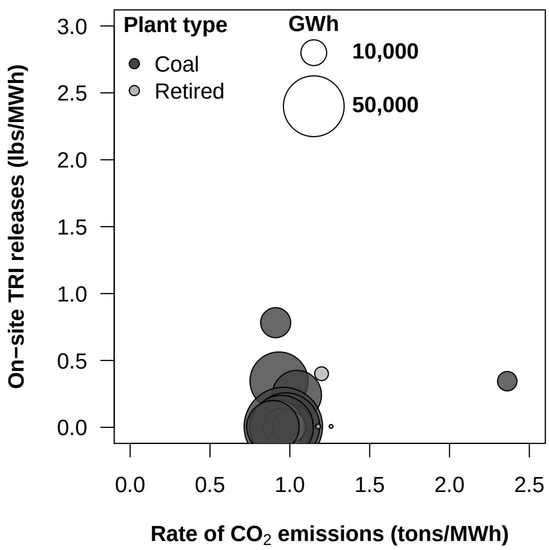


Figure 4.5: Mass of on-site toxic releases per MWh compared to mass of CO_2 emissions per MWh, 2010-2014.

Table 4.2: Total on-site toxic releases from power plants, and percentage of releases in high Demographic Index communities, 2010-2014. Releases of persistent bioaccumulative toxins (PBTs), dioxins and dioxin-like compounds, and all other TRI qualified chemicals. Not all plants reported data from 2010-2014. Bay Shore was considered a coal facility for this calculation.

	Dioxins (grams)	*% Near high DI area*	**PBTs** (lbs)	*% Near high DI area*	**Other chemicals** (tons)	*% Near high DI area*
Coal	63	*34%*	2,299,539	*50%*	94,643	*27%*

Table 4.2 presents the total mass of on-site releases of dioxins, PBTs, and other chemical releases, noting the percentage of these releases near communities (within three miles of the facility) ranked at the 60th percentile or higher using the EPA Demographic Index. Only reportable TRI data are depicted in this table. Dioxins are a relatively small fraction of total on-site releases on a mass basis but exposure to extremely small doses over time can be very harmful. From **Table 4.2**, coal emits low levels of dioxins. PBTs and other TRI chemicals are also released from coal, but in much higher quantities than dioxins. Coal power plant on-site releases included 2,299,539 lbs of PBTs and 94,643 tons of other TRI chemicals, with 50% and 27% being released within a three-mile radius of a high Demographic Index area, respectively.

Total releases are comprised of on-site, off-site and POTW releases combined. Coal plants sent some of their TRI releases off-site for disposal including approximately 17% of PBTs and 99.5% of other TRI chemicals. Fossil steam sent 93% of PBTs off-site for disposal. Whether TRI chemicals remain on-site, or if they are transferred off-site, it is important to recognize that disposal sites are often disproportionately located in vulnerable low income and minority communities [92].

4.4 Power plant compliance and violations

In this section we review the environmental regulatory compliance and violation history for each facility.

4.4.1 Background: compliance and violations

Compliance status provides information regarding whether or not power plants meet the minimum legal obligations to stay in compliance with regulations, permits, and other legally required mandates. Each federal and state statute dictates how compliance can be achieved. Self-reporting deadlines, agency and internal inspections, penalty assessments, and judicial disciplinary action are common enforcement techniques used to ensure compliance. Power plants that are in noncompliance pose increased potential hazards to nearby communities.

Varying degrees of infraction can lead to a noncompliance status. An infraction may be as minor as an administrative error or as egregious as the release of millions of gallons of coal ash being unintentionally released to a river (as in the case of the TVA Kingston spill). While each statute, and subsequent regulations thereafter, define the hierarchy of noncompliance, how noncompliance is to be handled, and how notifications and penalties are to be assigned and assessed, it is clear that a non-compliant facility is undesirable to communities. Depending on the level of noncompliance, and severity of an infraction, being in noncompliance can pose severe environmental health hazards, which in the most egregious examples can result in adverse health impacts such as in the 2008 TVA Kingston spill, the 2014 Dan River spill, and the contamination from Pennsylvania's Bruce Mansfield Little Blue Run impoundment.

4.4.2 Data and methods: compliance and violations

We accessed compliance and violation data using the EPA's Enforcement and Compliance History Online (ECHO) platform, which aggregates data over multiple statutes, including the CAA, CWA, SDWA, and RCRA [96]. ECHO contains facility inspection and enforcement data for the last five years (the last 20 consecutive completed quarters) and compliance data for the last three years, based on the federal calendar fiscal year. For this report, the range of data is available from 2011-2015.

Violation and compliance history for each plant was obtained from ECHO using the Office of Regulatory Information Systems (ORISPL) plant ID to verify the Clean Power Plan subject facilities. Violation data were obtained and categorized into two sections: formal and informal. Formal violations are the total enforcement actions and notices from RCRA, SDWA, CAA and CWA. Informal violations are considered the total enforcement actions and Notices of Violation (NOV) that are not formal. Compliance history is reported for current status (quarterly) and for the previous three years, the latter of which reflects additional updates to account for inaccuracies and delays in data collection. Therefore, the three-year compliance status is used to more accurately reflect the historical and current status for a facility [96]. Facilities are not required to report all noncompliance events. Examples of exclusions include, but are not limited to, facilities with minor permits (as opposed to major permits, which have different reporting requirements), and statute-defined nonreportable (not required to report) events. The CWA did not report all quarterly aggregated data with the specified designations above, and therefore, data for the CWA may not be fully reflected in all data presented.

The three-year facility compliance status designations are as follows [96]:

- **Significant noncompliance (S):** most severe noncompliance designation, including issuance of an enforcement action;
- **Noncompliance (V):** noncompliance status that is not deemed significant and has a violation in a current quarter. V statuses are not considered egregious enough for the S status;
- **None (N):** no reportable violations or compliance status required;
- **Unknown (U):** unknown facility-level compliance status (not tracked by EPA); all five NGCC plants in this report had a facility-level U status in the three-year timeframe studied.

We exclude retired facilities from our inspection and violation calculations (**Table 4.3**) to avoid overestimating the number of violations and inspections compared to the other current parameters (total plants by class, GWh produced, etc.). Caveats to note for ECHO data include the following: 1) dates used in ECHO are when the EPA became aware of the violations, not necessarily when violations occurred; and 2) violations may have been corrected, but will still show noncompliance status until EPA or the State authority has verified the corrections. Bay Shore, which began transitioning away from coal to primarily petroleum coke in 2012, was assigned the fossil steam plant class designation in this analysis due to that class having the greatest number of operational years between 2011-2015.

4.4.3 Results: compliance and violations

Figure 4.6 shows the total number of inspections and violations at Ohio power plants, subdivided by statute and whether the violation was formal or informal. According to data in **Figure 4.6**, Killen received 11 informal violations (ten from CWA, one from CAA) yet only four inspections. Several NGCC and coal plants received few or no violations as their inspection count increased. Over the years 2011-2015, there was inconsistency in the number of inspections and violations. We therefore may be underestimating the potential violations and associated hazards associated with these plants due to inconsistent numbers of inspections.

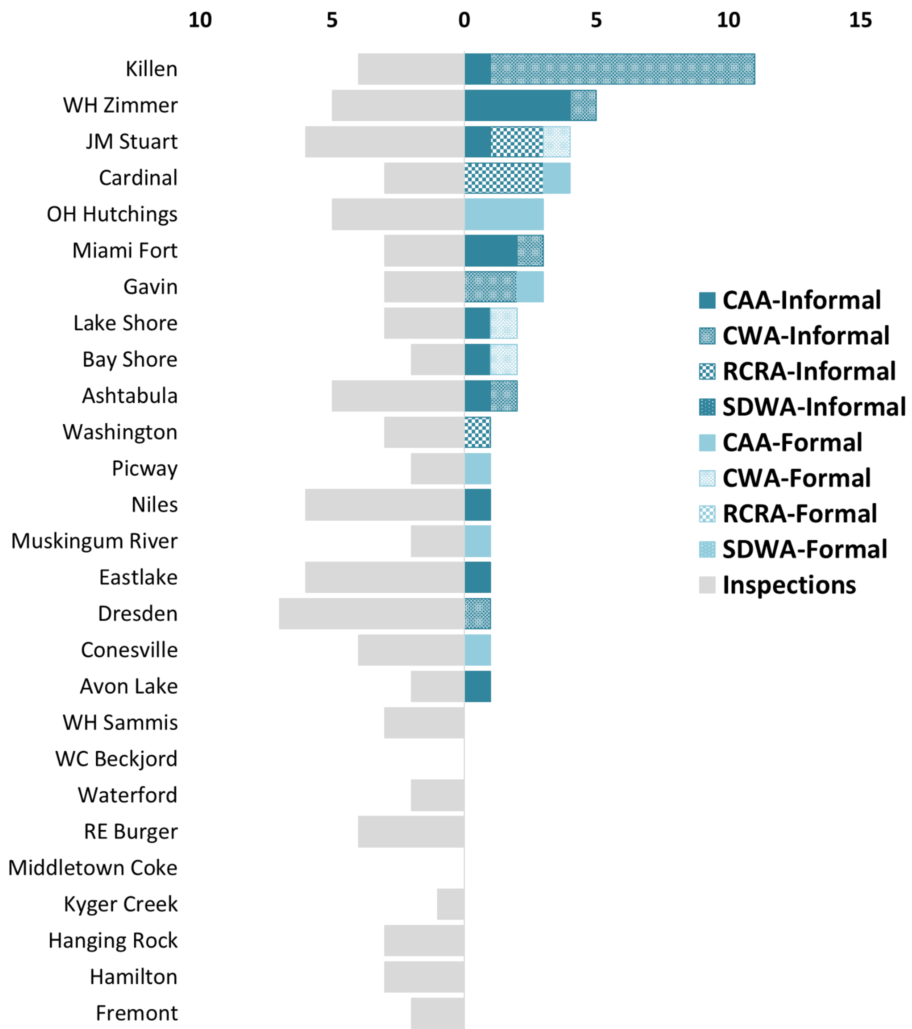


Figure 4.6: Chart of total plant inspections and violations between 2011-2015 and first quarter of 2016. Middletown Coke had no available data and WC Beckjord had no inspections or violations recorded.

Table 4.3: Total and average number of inspections and violations by power plant class, 2011-2015. Additional data on size of penalty and inspections and violations near high Demographic Index areas. Facilities that were retired in 2015 or prior are excluded.

	Total 2011-2015	Average per plant	Average per TWh	Average penalty per violation	Average number near high-DI area plant	Average number near low-DI area plant
VIOLATIONS						
Coal	29	3.22	.074	$834,310[a]	6	1.83
NGCC	2	0.33	.019	$0	0	0.50
Fossil steam [b]	2	1.00	.398	20,834	1	—
INSPECTIONS						
Coal	31	3.44	.079	—	4.33	3.00
NGCC	20	3.33	.185	—	2.50	3.75
Fossil steam	2	2.00	.398	—	2.00	—

[a] Cardinal, Conesville, Gavin, Muskingum River, OH Hutchings, and Picway were involved with an EPA lawsuit that settled on May 14, 2013, with a federal penalty for each facility of $8,025,000. Bay Shore and Lake Shore settled an EPA lawsuit on August 16, 2013 and August 26, 2013, respectively, with a federal penalty for each facility of $41,667. JM Stuart settled its federal lawsuit with EPA on September 25, 2013 for a $120,000 federal penalty.

[b] Fossil steam includes Bay Shore.

Figure 4.7 shows violation and compliance data in relation to potentially vulnerable communities. We include retired facilities in **Figure 4.7** to provide a historic and current picture of what types of plants do and do not have violations. We used the EPA's Environmental Justice Demographic Index, which combines and averages the population fraction of minority and low-income individuals (see **Equation 3.2**), to measure vulnerability by comparing communities living near power plants that rank above or below the 60th percentile.

The 18 power plants located in communities that fell below the 60th percentile on the EPA Demographic Index had 23 violations and 63 inspections over the past five years, whereas the remaining 9 power plants at or above the 60th percentile had 24 violations and 28 inspections—a similar number of violations for half the number of plants. Inspections rates are similar in both high and low Demographic Index areas. The outcome from this approach suggest that plants in vulnerable communities receive more violations, which may pose additional environmental health hazards in these areas.

Several NGCC and coal plants received few or no violations as their inspection count increased. Over the years 2011-2015, there was inconsistency in the number of inspections and violations. We therefore may be underestimating the potential violations and hazards associated with these plants due to inconsistent numbers of inspections.

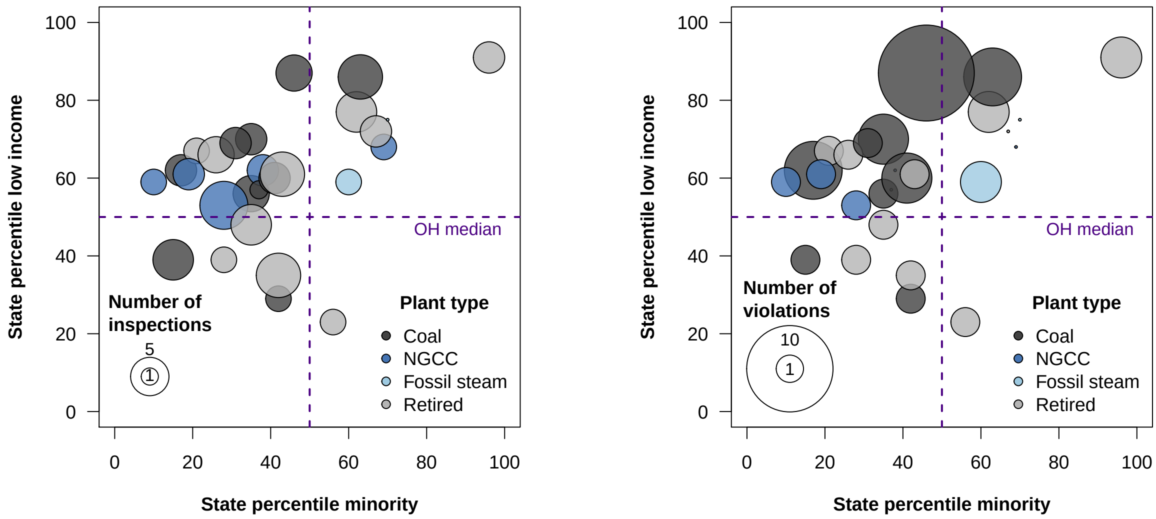


Figure 4.7: Clean Power Plan state-level minority and low-income percentile for nearby communities for total plant inspections (left), and violations (right), with circle size denoting number of inspections/violations between 2011-2015 for all plants, including currently retired.

We next compare these metrics to the Cumulative Vulnerability Index introduced in Section 3. Killen (11 violations), WH Zimmer (5 violations), JM Stuart (4 violations), and Cardinal (4 violations), all coal plants, are among the top four plants with violations between 2011-2015. JM Stuart is ranked among the highest ten plants for cumulative health burdens, as shown in **Figure 3.8** in Section 3.

The right plot of **Figure 4.7** represents the state percentile for low income and minority populations of communities living near plants in relation to total violations at those plants. The number of violations at power plants in relation to the demographics of the surrounding populations can provide insight into considerations of the potential hazards of these plants for vulnerable communities under different Clean Power Plan compliance scenarios.

Of the three plant classes, NGCC and coal had a similar average number of inspections held over the five-year period, however this was not the case within high Demographic Index areas, in which coal had a higher average. The largest total number of violations, along with the total number of inspections received between 2011-2015, were for coal plants. While the average number of inspections per plant were similar for both coal and NGCC plants, we note that NGCC plants within high Demographic Index areas (e.g. near more vulnerable communities) received a lower average number of inspections than other plants over the past five years. Coal had a higher rate of violations per TWh, while NGCC had a higher rate of inspections per TWh. It is important to note the most of the NGCC plants either did not have available data in ECHO or that their violation and/or compliance status is deemed unknown, leaving the data for NGCC incomplete and likely underestimated in the number of violations reported and their causes.

Figure 4.8 shows the compliance status for each plant class over the last three years (2013-2015). Compliance status provides information for the overall facility, which includes, but is not limited to, violations, and may contain information that otherwise would not be captured by a violation status alone. Washington, a NGCC plant, had one quarter in noncompliance within the last three consecutive years, but all five NGCC plants had at least six quarters out of the last 12 with an unknown compliance status.

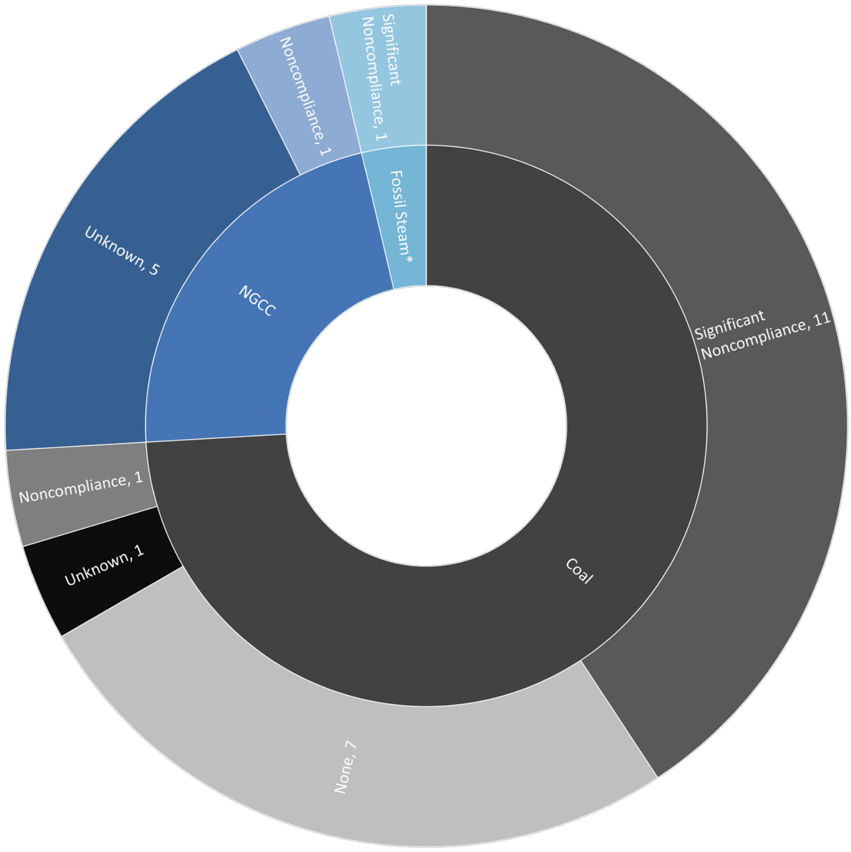


Figure 4.8: Most severe plant compliance status within the last 12 calendar quarters by plant class. Data are for all plants operational during timeframe. Circles segments are proportional to the total number of plants within that category. The inner circle shows the plant class. The outer circle is divided into four sections for each plant class: S (significant noncompliance), V (noncompliance),U (unknown facility-level compliance), and None (no reportable violations). Bay shore was considered a fossil steam facility for ECHO-based calculations.

One NGCC plant (out of five total) had one or more non-compliance status. Nearly 62% of all coal plants had one or more quarters in a noncompliance status within the last 12 calendar quarters, with 12 of those plants having a Significant noncompliance. For coal facilities, at least 60% of violations received during a noncompliance status period were contaminant-related. Violations may be issued outside of a noncompliance status period, however, the data did not verify the contamination relevancy of those violations. As shown in **Figure 4.8**, while coal did have a higher percentage of plants with a noncompliance status, all five NGCC plants held an unknown compliance status for numerous quarters from 2013-2015, which leads to an underestimation of the number of plants that potentially could have violations that are unreported. Being in a noncompliance status, even if for one quarter, could potentially pose hazards to the communities surrounding the plants, as noted in Section 4.1.1.

Figure 4.9 shows the total number of calendar quarters that a plant was in a particular compliance status within the last 12 completed calendar quarters. Plants that are not listed are designated as none, meaning they either had no data recorded by the EPA and/or State, or there was a non-reportable (not required to be reported) noncompliance. Hierarchy of compliance status is designated by S (significant noncompliance, most severe), V (noncompliance), none (not shown in **Figure 4.9**), and unknown (not shown in **Figure 4.8**).

Avon Lake, Niles, and WH Zimmer had the highest number (twelve) of calendar quarters in the most severe noncompliance status—S. Facilities that were in a noncompliance status, either S or V, were in that noncompliance status for at least two or more quarters within the last three years, with the exception of Washington which was in a V status for only one quarter but had numerous unknown status quarters. While coal plants typically have higher aggregate burdens of pollutant production than NGCC plants, these violation data suggest that living around all classes of plants can present environmental health hazards.

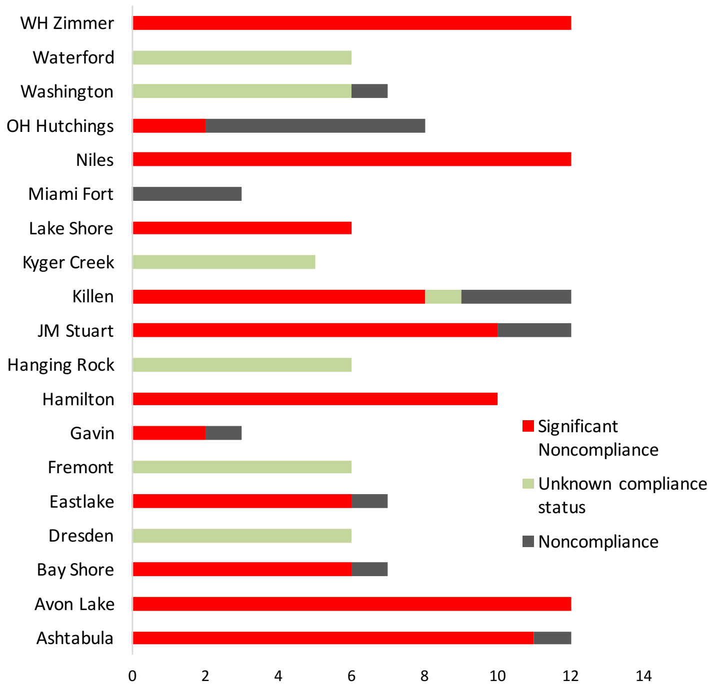


Figure 4.9: Facility compliance status for the last twelve calendar quarters. Facilities with no compliance status to report were not included; unknown status for a facility is included.

5. Air pollution from power plants: regional health impacts

In this section, we analyze the historic criteria air pollutant emissions from power plants in Ohio and model the projected health impacts of these emissions by county. Power plants emit *primary* air pollutants that can contribute directly to poor air quality and which may undergo reactions in the atmosphere to form *secondary* air pollutants, including ozone and particulate matter. These air pollutant emissions contribute to elevated concentrations of these pollutants in both the short and long term and across hundreds of miles from the generation source. Both acute and chronic exposure to these pollutants are associated with a wide range of cardiovascular, respiratory and other health impacts [97, 98]. Certain populations, such as the young, elderly, low income populations, and those with underlying diseases such as asthma are more likely to experience adverse health outcomes when exposed to these pollutants than those without underlying disease [99, 100]. The burden of disease from electricity generation is primarily attributable to $PM_{2.5}$, and secondarily to tropospheric ozone exposure. Negative health outcomes such as increased emergency room visits are also associated with elevated levels of NO_x, SO_2, and other pollutants; NO_x and SO_2 are common precursors for secondary particulate matter formation.

A co-benefit of power plant carbon dioxide emission reductions under the Clean Power Plan is the potential to simultaneously reduce emissions of health-damaging co-pollutants. Broadly, coal plants tend to have the highest rate of emissions of both CO_2 and of criteria pollutants, such as NO_x and SO_2, compared with natural gas [101] and renewable energy resources such as wind, water, and solar. As such, CO_2 emission reductions from coal plants hold great potential to reduce co-pollutant emissions. However, as we will see, the rate and total mass emissions vary from plant to plant, and the impacts depend both on individual plant emissions as well as local topography, weather, background pollutant concentrations, and the population density in the region of the plant.

In this section, we first provide a background literature review on the health impacts attributable to emissions from power plants. We then analyze the historic total mass and rate of emissions of power plants for various pollutants. In the second part of this section, we run the emissions data through two air models to calculate the morbidity and mortality impacts attributable to primary and secondary particulate matter from power plants both individually and by county. Our models also calculate the monetary impacts of this morbidity and mortality by individual power plant and across regional space. Our estimates of these health impacts are likely conservative, given that they exclude negative health outcomes from other hazardous and criteria air pollutants and other health toxics known to be emitted by the power generation sector, including mercury and other heavy metals that are more complex to model.

5.1 Background on health impacts from power plant air emissions

In addition to the toxic and hazardous air pollutants discussed in Section 4, fossil fuel-fired power plants emit criteria air pollutants that impact local and regional air quality and have a wide range of toxicological properties that contribute to adverse health outcomes. Although it can be difficult to link a particular health problem with a single air pollutant due to the complexity of air pollution mixtures, power plants produce primary and secondary air pollutants that pose acute and chronic adverse health risks that have been well established in the epidemiological literature. While the data are limited, there is some evidence provided below to suggest an association between human proximity to power plants and adverse health outcomes. Power plants also contribute to increased concentrations of primary and secondary criteria air pollutants, including PM, SO_2, NO_x and ground level ozone pollution. These criteria air pollutants are associated with acute and chronic adverse health outcomes in human populations. Primary PM and particles formed through atmospheric transformation of SO_2 and NO_x are responsible for many of the health impacts from coal-fired power plant pollution and are associated with lung cancer [31, 32], adverse birth outcomes [102], cardiovascular and respiratory disease [30], and mortality [33].

Power plants represent the greatest source of SO_2 emissions in the United States [103] which, along with emissions of NO_x and other volatile organic compounds (VOCs), react in the atmosphere to form secondary PM. SO_2 exposure itself is associated with morbidity and mortality and at high enough levels (100 ppm) is associated with impaired lung function [104]. Low level chronic exposures to SO_2 may also contribute to morbidity and mortality such as chronic obstructive pulmonary disease [105]. In other contexts, epidemiological studies have found an association between SO_2 exposure with circulatory system deaths [106], exacerbation of asthma [107], and symptomatic bronchoconstriction [108]. The EPA estimates that the Clean Power Plan will lower emissions of SO_2 from power plants by 90% by 2030 (compared to 2005 levels).

Power plants are also a significant source of NO_x emissions. Exposure to NO_x has been associated with various respiratory health outcomes, such as increased hospitalizations [109], increased frequency of respiratory symptoms [110], and increased mortality [111] in some populations. Tropospheric (ground level) ozone is a secondary air pollutant formed when NO_x, VOCs, and other reactive organic gases react in the atmosphere in the presence of sunlight. Elevated ozone concentrations are consistently associated with asthma [112], emergency department visits [113], cardiorespiratory morbidity [114], and mortality [115].

Preliminary epidemiology can help develop and test hypotheses about what health outcomes, if any, might be expected for populations living near power plants. An adverse health outcome can be described as a change in the function of the body that can lead to disease or health problems. Definitions of health are typically not confined to disease and infirmity and may also encompass well-being [117]. Initial epidemiological efforts often compare the prevalence of a particular health outcome (e.g., hospitalization rates, birth defects, etc.) among individuals living in closer proximity to the source of the hazard (e.g., coal-fired power plant) with individuals living further or away from this source, after adjusting for factors that may influence outcome, such as age, sex, race, and income, to determine whether any association exists.

Epidemiological research on adverse health outcomes associated with coal-fired power plants is relatively limited. A significant portion of this research focuses on children, adolescents,

Table 5.1: Notable pollutants and health hazards associated with fossil fuel-fired power plant air emissions*

Class	Pollutant	Health hazards and associated outcomes**
CRITERIA POLLUTANTS		
Primary	Particulate matter (PM)	Lung disease and decreased lung function, cancer, aggravated asthma, respiratory diseases/symptoms, birth outcomes, cardiovascular disease, mortality
	Sulfur dioxide (SO_2)	Decreased lung function, respiratory effects (e.g., bronchoconstriction, increased asthma), mortality
	Nitrogen oxides (NO_x)	Respiratory disease (e.g., emphysema, bronchitis), respiratory effects (e.g., airway inflammation)
Secondary	Tropospheric ozone (O_3)	Lung disease (asthma), decreased lung function, respiratory symptoms (e.g., throat irritation, pain, burning, discomfort in chest), cardiorespiratory morbidity, mortality
	Particulate matter (PM)	Lung disease and decreased lung function, cancer, aggravated asthma, respiratory diseases/symptoms, birth outcomes, and cardiovascular disease
HAZARDOUS AIR POLLUTANTS (HAPS)		
Acid gases	Hydrogen chloride, hydrogen fluoride	Irritation to skin, eyes, nose, throat, and breathing passages
Dioxins, furans	2,3,7,8-tetrachloro-dioxin (TCDD)	Probable carcinogen: stomach and immune system
Mercury	Methylmercury	Damage to brain, nervous system, kidneys, and liver; neurological and developmental birth defects
Metals	Antimony, arsenic, cadmium, lead	Carcinogen (lung, bladder, kidney, skin); impairment to nervous, cardiovascular, dermal, respiratory, and immune systems
Polycyclic aromatic hydrocarbons (PAH)	Benzo-a-anthracene, flouranthene, chrysene	Probable carcinogens; adverse effects to liver, kidney, and testes; reproductive impairment
Radioisotopes	Radium, uranium	Carcinogens (lung, bone, kidney)
Volatile organic compounds (VOC)	Aromatic hydrocarbons (benzene, xylene, ethylbenzene, toluene), aldehydes (formaldehyde)	Impaired lung function; skin, eye, nose, throat irritation; impaired memory; effect to liver, kidneys, nervous system; benzene is a carcinogen and formaldehyde is a probable carcinogen

* This table is adapted from [116] and incorporates US EPA and ATSDR information on health effects linked to pollutant exposure [34, 82, 104].

** Associated health outcomes refer to effects observed from acute and chronic exposure to the pollutants listed above. Vulnerable populations, such as children, the elderly, and those with pre-existing conditions, are more susceptible to these pollutants and therefore may be at an increased risk of harm.

and newborns because these populations are more vulnerable to environmental pollution due to a variety of biological and behavioral factors. Children are less able to metabolize and excrete toxins and receive proportionately larger doses because of their surface body area. They also have a longer shelf life for diseases with longer latency periods, such as cancer, since they have more years in life to be exposed. Children and other sensitive populations, therefore, tend to exhibit symptoms of exposure before adults and can be used as sentinels for monitoring and predicting adverse health outcomes.

Some epidemiological studies have found an association between proximity to coal and other fossil fuel-fired power plants with asthma and respiratory symptoms in young adults [1], hospitalization for asthma and acute respiratory infections [2], and birth defects [3]. Ha *et al.* examined other types of fuel-fired power plants in addition to coal (gas, nuclear, oil, solid waste), but found that women who were closest to coal plants were exposed to the highest levels of $PM_{2.5}$ and that coal was strongly associated with all adverse birth outcomes examined, including term low birthweight, preterm delivery, and very preterm delivery [3]. Another study found that children living in proximity to coal-fired power plants had significantly increased urinary 1-hydroxypyrene levels, which serves as a biomarker of exposure to PAHs [4]. Other evidence suggests an association between some respiratory symptoms and estimates of coal-fired power plant NO_x emissions [118]. A study of gas-fired power plants in Italy found a higher concentration of NO_x and PM_{10} within 3km of the plants shortly after the start of operation, and that this increase in pollutant concentrations was associated with increased emergency room visits and hospitalizations among the elderly [5].

While correlation should not be confused with causation, the epidemiological results have generally been consistent with what would be expected from exposure to the toxins associated with coal-fired power plants. Further, the epidemiological evidence supports the understanding that vulnerable populations may be at a greater risk from exposure to hazards associated with coal-fired power plants. Particularly at-risk populations include children, the elderly, and asthmatics. A list of notable pollution and hazards from power plants is provided in **Table 5.1**.

5.2 Total mass and rate of power plant air pollutant emissions

In Ohio, power plant emissions contribute to elevated concentrations of criteria air pollutants, both directly and through secondary formation of $PM_{2.5}$ and ozone. In this section, we look at the total mass and the rate (tons/MWh) of air pollutant emissions from power plants subject to the Clean Power Plan in Ohio. The next section will address some of the estimated regional health impacts of these emissions.

5.2.1 Data and methods

Total 2015 power plant generation (MWh) and NO_x, SO_2, and CO_2 emission data were downloaded for every Ohio power plant included in the EPA's Air Market Program Database [25]. Generation data were missing from a few power plants and filled in, when available, with generation data from EIA Schedule 923 [56]; we note that these data sometimes vary by a couple percent from the EPA data, but do not affect our results in a meaningful way. A few plants have individual units not covered by the Clean Power Plan, but we included all associated units here to provide a more complete picture of power plant operation. CPP-excluded units are typically small peaking units and should not greatly impact the findings. We do not have complete data for a few plants, and some of the data we have are preliminary. While more complete data are available for 2014, we report the 2015 data here because the Mercury and Air Toxics Standards (MATS) came into effect in 2015 [119] and may have led to the implementation of new emission control technologies and lower SO_2 emissions at certain plants. Overall, recent years have shown a decrease in generation from coal and an increase from natural gas, although coal still dominates the electricity mix [29]. We focus our results on power plants under the Clean Power Plan's jurisdiction that generated power in 2015. We include some plants that generated electricity in 2015 but retired before the end of the year, noting where they occur, to look at trends regarding characteristics of plants coming off line.

5.2.2 Emissions analysis

A number of power plants in Ohio rank among the highest emitters of total mass (tons) or rate (tons/MWh) of criteria pollutants in the United States. For example, Avon Lake, a coal plant outside of Cleveland, has the second highest total mass of emissions of SO_2 in the country, and the coal plant Gavin, located near the West Virginia border, ranks 11th. Gavin ranks eighth for total CO_2 emissions, but Avon Lake is much lower at 223rd, highlighting the value of considering multiple pollutants at once when targeting emission reductions. CO_2 emission reductions at one location may therefore have greater co-benefits from simultaneous reductions in co-pollutant emissions at some locations than others. Avon Lake ranks eighth nationwide for rate of SO_2 emissions per MWh (Ohio's now-retired Ashtabula plant ranked 3rd in 2015), but 293rd for rate of CO_2 emissions, meaning a reduction in a single ton of CO_2 at this plant would have a large co-benefit in SO_2 emission reductions. Emissions from all of Ohio's subject power plants are analyzed below.

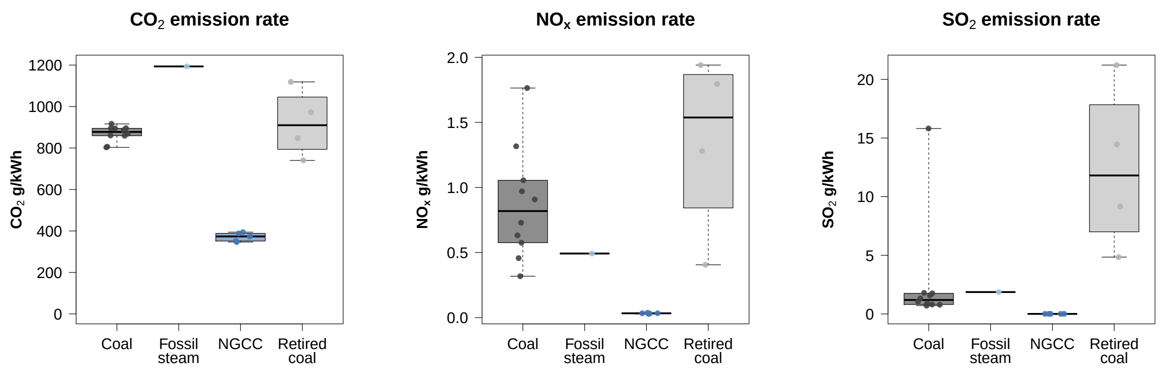


Figure 5.1: Box plot of 2015 power plant emission rates by plant class for CO_2, NO_x and SO_2. Data is available for only one fossil steam plant: Bay Shore.

Box plots of CO_2, NO_x and SO_2 emission rates from each power plant class are given in **Figure 5.1**. Data is available for only one fossil steam plant—Bay Shore, which primarily uses petroleum coke—so the box in this category is just a line. The *rate* of emissions—mass per MWh of electricity generated—is a useful measure for comparison because it gives insight into where an alternative resource might have the most impact in emission reductions per MWh. An efficiency program that reduces 10 MWh of demand, for example, will have the greatest reduction in criteria pollutant emissions if it displaces generation from a plant with a high rate of emissions per MWh, even if the source does not have the highest total emissions. The coal plants show a much broader range of pollutant emissions per MWh than the NGCC plants. Notably, some of the coal plants with the highest rate of emissions per MWh for each pollutant were retired over the course of 2015.

Figures 5.2 and **5.3** show bar plots of total and rate of CO_2, SO_2, and NO_x emissions from each plant in decreasing order of intensity. CO_2, SO_2, and NO_x values correspond with reported emissions from the EPA; we note that particulate matter is not measured directly but we model these emissions in the following section. A comparison of these values allows for quick identification of the plants with the highest total burden of emissions for each pollutant, as well as rate of emissions, indicating where the most benefit may be seen per MWh of alternative generation or efficiency.

Gavin power plant has the highest total CO_2 emissions, but the highest rate of CO_2 emissions per MWh falls on Bay Shore, which in recent years has relied on petroleum coke as its main fuel source. The next two highest rate emitters—Lake Shore and Ashtabula—both shut down in 2015. Three plants retired in 2015 rank among the four highest-rate SO_2 polluters as well—Ashtabula, Eastlake, and Muskingum River—suggesting a trend in taking polluters offline, but as noted before a number of high-rate and and high-total SO_2 emitters are still running (e.g. Avon Lake). Gavin has the highest total NO_x emissions, but the two highest-rate NO_x emitters have retired—again, Ashtabula and Lake Shore. These varying results suggest that a Clean Power Plan compliance approach that focuses solely on CO_2 may not yield the greatest health benefits unless all of these measures are considered.

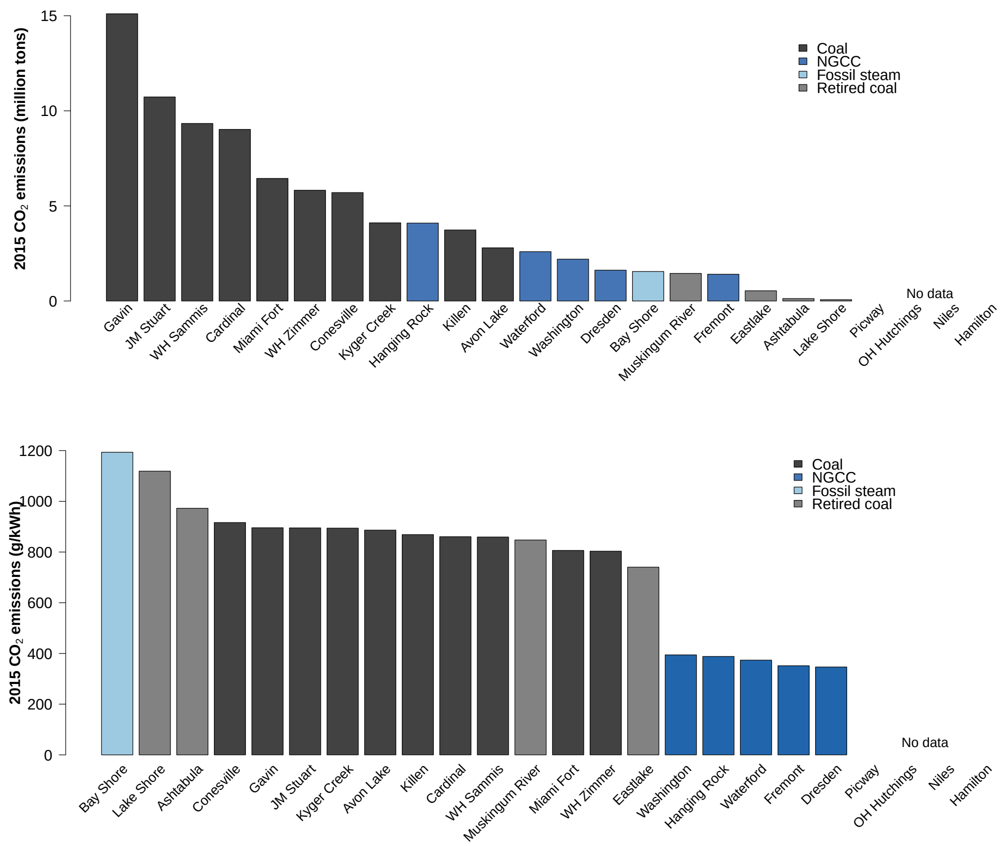


Figure 5.2: Bar chart of total mass and rate (g/kWh) of 2015 power plant CO_2 emissions.

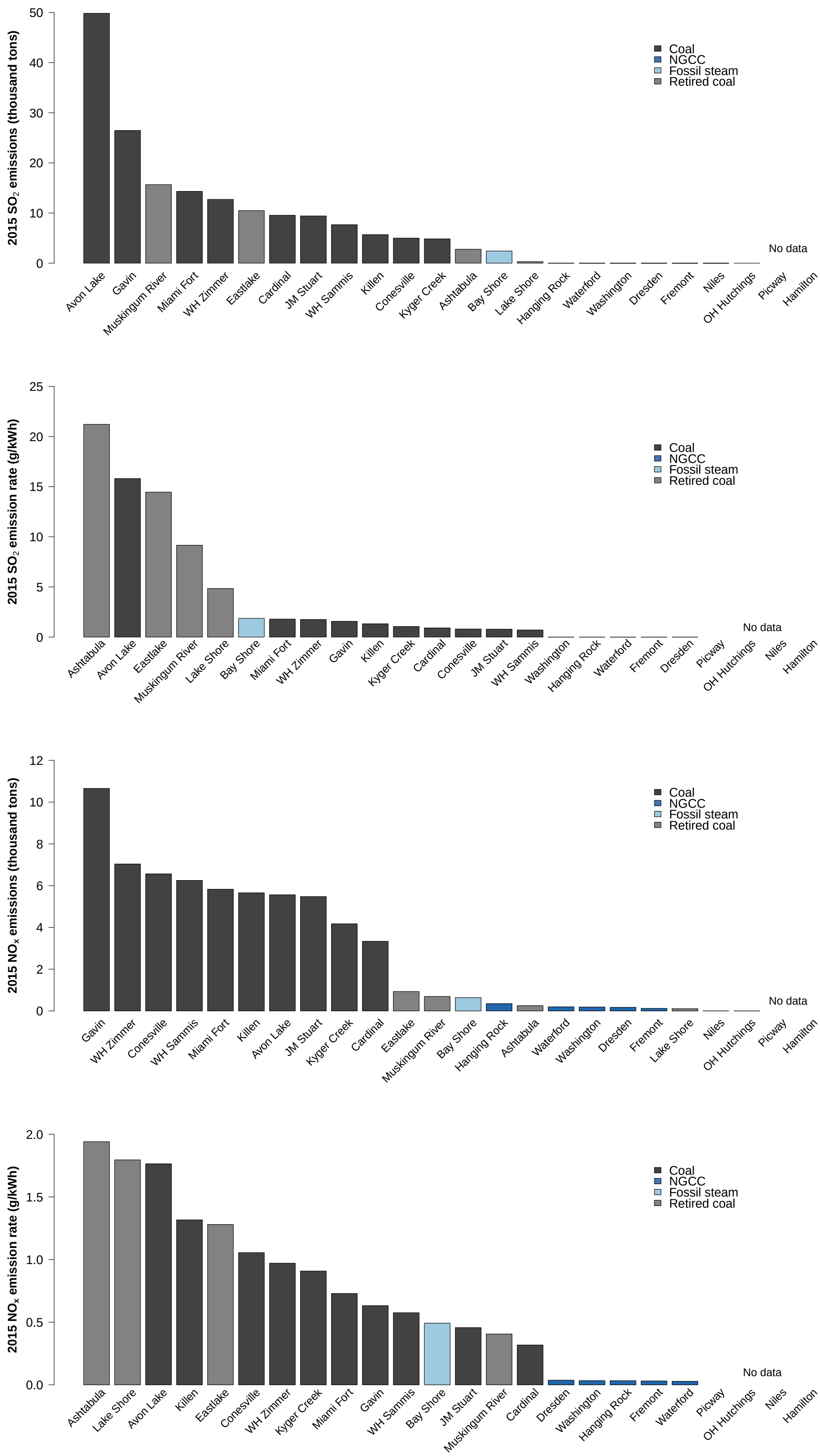


Figure 5.3: Bar chart of total mass and rate (g/kWh) of 2015 power plant SO_2 and NO_x emissions.

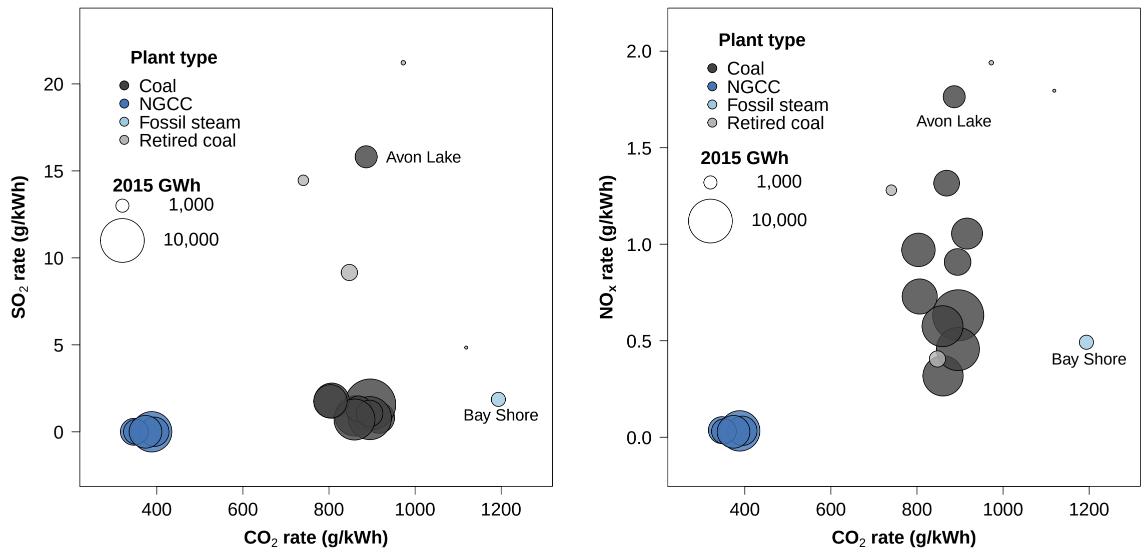


Figure 5.4: Bubble charts comparing 2015 plant CO_2 emission rates to SO_2 and NO_x emission rates. Circle size reflects GWh of generation in 2015.

Figure 5.4 compares NO_x and SO_2 emission rates to CO_2 emission rates. Circle size represents total 2015 generation (MWh). Both NO_x and SO_2 are precursors for $PM_{2.5}$ formation and NO_x contributes to ozone formation as well. Co-pollutant reductions per ton of CO_2 will vary greatly from plant to plant, suggesting the greatest emissions reductions will likely be found in a strategy that integrates multiple pollutants.

5.3 Estimated health impacts from power plant emissions

In this section we use two different models to estimate the $PM_{2.5}$-related health burdens and impacts from power generation in Ohio, based on 2015 emissions. Results are reported in aggregate as well as for individual power plants and individual counties to provide insight into where emission reductions may yield the greatest public health benefit as well as reduce disparities in health impacts from power generation.

5.3.1 Data and methods

Health impacts were estimated for the pollutant emissions from 45 different power plants operating in Ohio, including plants not covered by the Clean Power Plan. Health impacts are quantified in terms of mortality and morbidity associated with human exposure to ambient $PM_{2.5}$. In this case, changes in ambient $PM_{2.5}$ levels are a function of power plant annual emissions of primary $PM_{2.5}$ and $PM_{2.5}$ precursors SO_2 and NO_x, power plant location, as well as physical transport and chemical transformation of the pollutants in the atmosphere. The health impacts are calculated based on changes to population exposure and associated epidemiological responses.

Two different and independent peer-reviewed approaches are used to calculate an estimated range of health impacts: 1) EPA's Co-Benefits Risk Assessment (COBRA) Screening

Model [120], and 2) the Air Pollution Emission Experiments and Policy analysis model (AP2, formerly APEEP), which is described in Muller *et al.* [121] and was used in the National Research Council's *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* [122].

COBRA and AP2 are both reduced form air quality and exposure models based on average dispersion and atmospheric chemical transformation properties. Both models were used to estimate health impacts from air pollutants in the US Department of Energy's Retrospective Analysis of the Benefits and Impacts of US Renewable Portfolio Standards [123]. The impacts calculated within COBRA and AP2 are broadly consistent with the impacts calculated using full regional weather and air quality models, such as the modeling used to support the impact assessment of the Clean Power Plan [18, 39]. Due to computational limitations, reduced order modeling is preferred when evaluating the impacts of many individual plants.

Emissions of SO_2 and NO_x were derived for each power plant as described in Section 5.2.2. Unlike SO_2 and NO_x emissions, which are measured at the power plant stack and reported to the EPA, emissions of primary $PM_{2.5}$ are not directly measured and are thus derived from the literature [124, 125] as a function of plant class and US state. The Mercury and Air Toxics Standards (MATS) puts limits on power plant emissions of primary $PM_{2.5}$ [119], thus, to account for controls that may have been recently added to comply with MATS, the literature-based emission rate of primary $PM_{2.5}$ were adjusted down (when needed) to the MATS compliance level of 0.30 lb/MWh [89].

Mortality and morbidity impacts are presented separately as case counts and also monetized by the value of preventing a premature mortality (or the Value of Statistical Life, VSL) or preventing a morbidity outcome. The VSL is set at approximately $6 million in 2000 dollars in both COBRA and AP2, which is consistent with values used in the broader literature. However, COBRA reports its monetized values based on 2017 income levels and 2010 dollars, and thus is based on a VSL of $9.4 million (2010$). We multiplied AP2 values by 127%, the ratio of the 2010 Consumer Price Index (CPI) to the 2000 CPI [126] to inflate AP2 values to year 2010. The underlying income level assumptions were not updated for AP2. Note also that COBRA calculates health impacts based on population projections for 2017.

The COBRA model provides a high and low health impact estimate to account for differences in the epidemiological literature on the response to pollutant intake. The low estimate is based on epidemiological studies summarized in Krewski *et al.* [127], while the high estimate is based on epidemiological studies presented in Lepeule *et al.* [128]. Both sets of research are considered to have different strengths and weakness, and EPA states that is does not favor one result over the other [39].

Marginal health impacts (i.e., impact per ton of emissions) specific to pollutant and power plant were derived from the COBRA and AP2 model. In both models, marginal impacts by pollutant are calculated at the county level and applied to all power plants within each county. In COBRA the impacts are based on the weighted average impacts of all electric power plants within the county. As input, COBRA accepts county level emission changes and outputs changes to health impacts by county. In contrast, AP2 accepts county level emission changes as input, but provides only total dollar impacts summed across all counties. To find separate impacts from each power plant and pollutant using COBRA, three separate COBRA simulations were run for each county that contained a power plant. A specific reduction in emissions was entered into the COBRA model separately for SO_2, NO_x, and $PM_{2.5}$. In COBRA a reduction of 100 tons was typically used unless the total pollutant emissions from that county was less than 100 tons, in which case a value less than the total emission level was used. The results were then normalized to a per-ton basis. For the AP2 model, health impacts are already presented as marginal values specific to county of pollutant origin for SO_2, NO_x, and $PM_{2.5}$.

It is important to note a few limitations about this modeling effort. The impacts calculated here only account for operational emissions and do not include emissions associated with upstream activities such as fuel mining and transport. The emissions analyzed include only a subset of the total set of species emitted by power plants. For example, this analysis does not include the impacts of mercury emissions. Additionally, COBRA does not include health impacts of ozone exposure. COBRA had data available for the vast majority of counties and pollutants, though some power plant impacts were not included due to lack of data within COBRA. Finally, COBRA and AP2 are simplified representations of complicated natural processes such as atmospheric chemistry and transport as well as health impact functions, and while some variability in representation of these processes is accounted for by using multiple models and by the inclusion of multiple health impact functions within COBRA, there is always additional, unquantifiable uncertainty associated with modeling efforts such as this (see additional discussion of caveats within the COBRA model documentation [120]).

5.3.2 Results: health impacts

The aggregated results of the health impact modeling from COBRA are provided in **Table 4**. As described in the previous sections, the low and high estimates reflect different epidemiological studies used by the EPA and no one estimate is preferred over the other. The total monetary burden of health impacts from primary and secondary $PM_{2.5}$ from power plants covered by the Clean Power Plan in Ohio is \$8.1 billion in the low estimate and \$18.2 billion in the high estimate (2010\$). The AP2 model estimates the cost of these health impacts as \$5.4 billion. The non-CPP Plants have a health impact of \$12.2 million (COBRA low estimate) and \$27.6 million (COBRA high estimate), although these numbers are likely conservative given our less complete data set for the power plants excluded by the Plan.

The health estimates are in large part reflective of mortality associated with secondary formation of $PM_{2.5}$. Mortality estimates from 2015 emissions from Ohio plants subject to the Clean Power Plan are 942 (low estimate) and 2,133 (high estimate). Exposure to $PM_{2.5}$ is also associated with a range of cardiovascular and respiratory impacts, including non-fatal heart attacks, respiratory and cardiovascular hospital admissions, bronchitis, upper and lower respiratory symptoms, asthma emergency room visits and exacerbations, and restricted activity days and work loss days, all given in **Table 4**. While the impacts of ozone are not modeled in COBRA, we note that Driscoll *et al.* [40] found that a scenario similar to the draft Clean Power Plan would reduce ozone-related premature deaths by roughly 10% beyond the number of avoided premature deaths related to $PM_{2.5}$, and accounting for ozone reductions would more than double the number of avoided respiratory-related hospital admissions. While we cannot directly extrapolate from this model to Ohio, we can assume that the ozone impacts from NO_x would likely contribute to additional health burden from the plants shown in **Table 4**. Additionally, we should note that these estimates are likely conservative given that our models only take criteria air pollutants into account and we have not estimated human health impacts associated with the emissions of hazardous and toxic air pollutants such as mercury, arsenic and other heavy metals reported in Section 4.3. However, a number of these plants retired during the course of 2015. The cost of health

Table 5.2: Estimated $PM_{2.5}$ health burden from Ohio power plants, 2015 (COBRA model). Low and high estimates reflect two different epidemiological models used by the EPA.

Health impact	**Estimated impact**	
	Low	**High**
Cost of health burden ($Milllions)	8,062	18,232
Cost excluding now-retired plants ($Millions)	*6,211*	*14,045*
Adult mortality	942	2,133
Non-fatal heart attacks	117	1,085
Infant mortality	2	
Respiratory hospital admissions	272	
Cardiovascular hospital admissions	340	
Acute bronchitis	1,269	
Upper respiratory symptoms	23,115	
Lower respiratory symptoms	16,174	
Asthma ER visits	515	
Minor restricted activity days	670,103	
Work loss days	111,992	
Asthma exacerbations	24,534	

impacts of power plants still operational in 2016 is \$6.9 billion (COBRA low) and \$15.6 billion (COBRA high). The associated particulate matter-related mortality estimates for 2015 emissions from these plants is 807 (COBRA low) and 1,829 (COBRA high).

The majority of these health impacts are attributed to only a handful of power plants. The ten highest impact power plants are responsible for 90% of the estimated mortalities. The health burden of these ten high-impact plants are provided in **Figure 5.5**. The five estimates shown for each plant include the results of AP2, COBRA low estimates with and without primary $PM_{2.5}$, and COBRA high estimates with and without primary $PM_{2.5}$. Power plants do not report primary $PM_{2.5}$ emissions and these emissions were estimated based on power plant class, introducing some additional uncertainty. In aggregate, the modeled primary $PM_{2.5}$ is responsible for approximately 13% of the health impact estimates, although this fraction varies by plant. We show estimates excluding the health burden of primary $PM_{2.5}$ to illustrate the sensitivity of our results to these primary $PM_{2.5}$ estimates. As noted earlier, primary $PM_{2.5}$ estimates are capped at the recent MATS standard, which may underestimate some 2015 emissions.

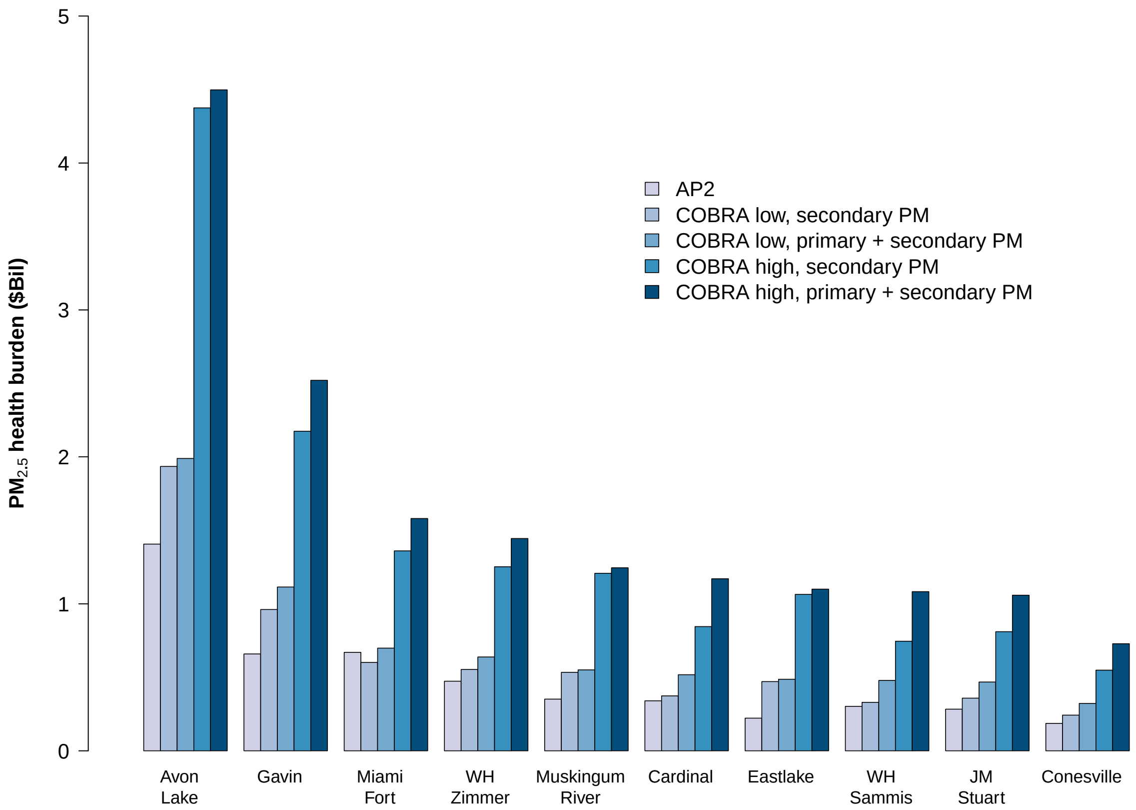


Figure 5.5: Bar chart of estimated cost of health burden for ten highest impact plants, by model. Estimates are from the models AP2 and COBRA, including high and low estimates from COBRA as well as results inclusive and exclusive of primary $PM_{2.5}$ emissions.

The COBRA and AP2 estimates show similar trends but different magnitudes, likely due to a mix of factors. Some differences should be expected given the sensitivity of results to underlying assumptions related to pollutant transport and transformation. Their health impact models are also informed by different epidemiological studies: AP2 uses a similar but slightly older set of studies than the low-estimate COBRA model. COBRA's population data are more recent than AP2 and are projected for the year 2017, which may contribute to larger magnitude impacts from COBRA. Finally, while the nominal dollar health burden for both studies has been adjusted to 2010$, the value of a statistical life used in COBRA incorporates income growth up to 2017, while AP2 uses a value from 2000 embedded in the model and could not be updated. These differences in underlying assumptions are consistent with the results, which have slightly lower estimates in health impacts from AP2, as would be expected from its dependence on older income and population data. However, the results are broadly consistent between these two models, and the results from the independent AP2 model help provide secondary verification for the COBRA results.

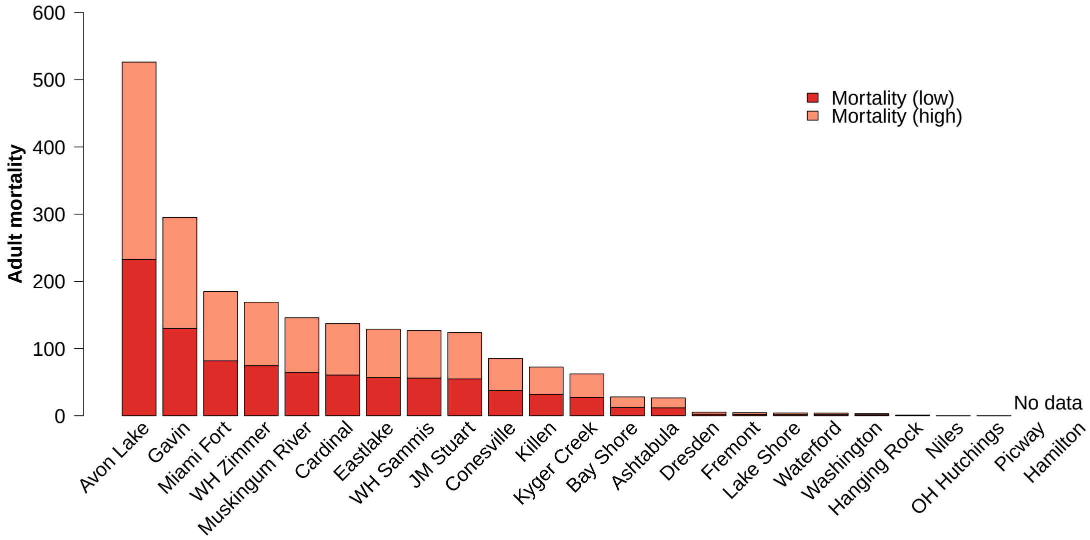


Figure 5.6: Bar chart of low and high mortality estimates for each power plant.

Figure 5.6 shows COBRA low and high estimates for mortality from each plant. Avon Lake has the most associated $PM_{2.5}$-related mortalities, with a low estimate of 232 and a high estimate of 526 early deaths attributable to criteria air pollutants emitted from its stack.[1] The magnitude of health impacts are a factor of both the pollutants emitted from the power plant and proximity to large populations, as well as atmospheric transport conditions.

The health impacts of these power plants are distributed over a broad area—so broad, in fact, that only 20% of the health impacts are contained within the state of Ohio. Estimated mortality in Ohio, by county, is mapped in **Figure 5.7**. Each circle represents a power plant, with the size corresponding with the total mortality impacts from that power plant. Each county is color-coded to reflect the aggregated health impacts from all of the CPP-covered power plants in Ohio, not just plants in that county. The blue outline designates areas that are non-attainment for the NAAQS 8-hour ozone standard, 24-hour $PM_{2.5}$ standard, 1-hour primary SO_2 standard, and/or three-month lead standard.[2]

These results are reflective of both proximity to power plant emissions, but also population density. Counties with a large population will have a larger number of people breathing polluted air and therefore may have a larger aggregate health burden than a county with similar air quality but a smaller population. An additional map showing the cost of this health burden in each county is given in Appendix .1, **Figure 2**. Out-of-state mortality estimates are highest in Pennsylvania (164 low, 371 high), New York (103 low, 234 high), Virginia (56 low, 127 high), New Jersey (49 low, 110 high), and Michigan (45 low, 105 high). Regional mortality estimates by county are mapped in **Figure 5.8**. An additional

[1] Effects of primary $PM_{2.5}$ are included in this estimate.

[2] The EPA has not updated NAAQS non-attainment areas to reflect the new ozone standard, and more area is likely to be out of attainment under this lower standard.

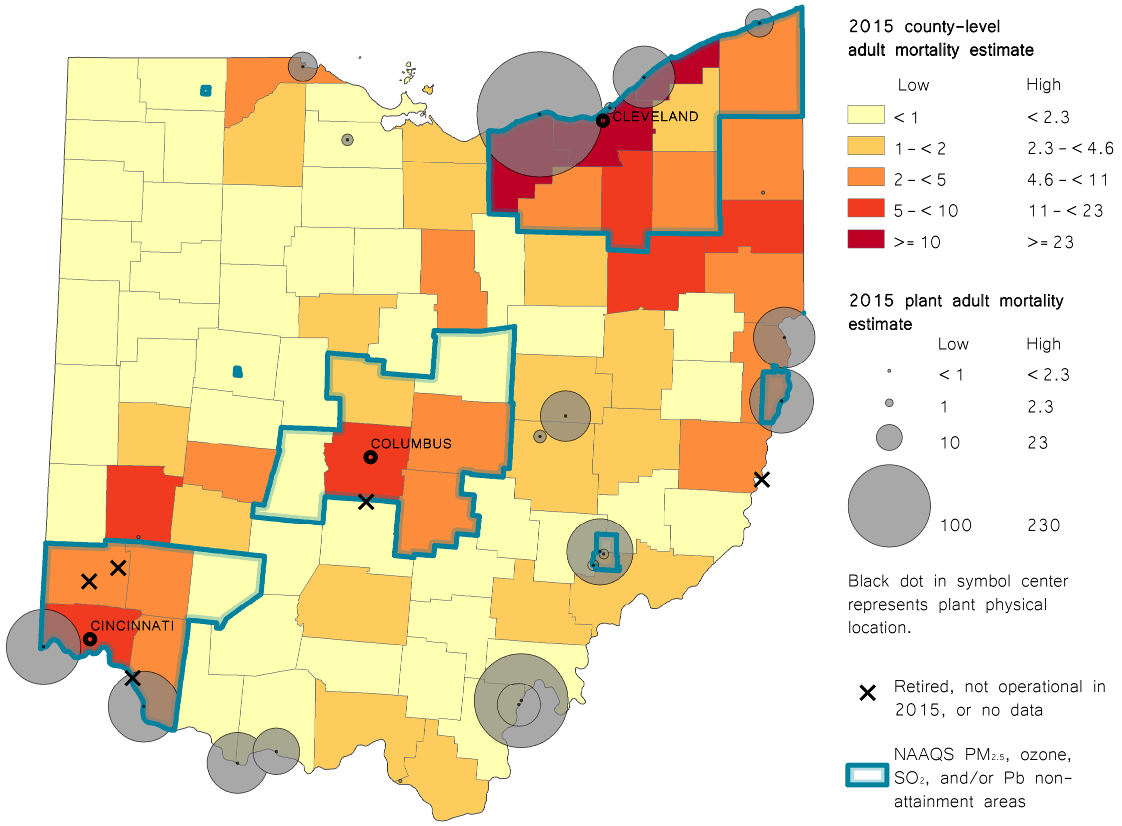


Figure 5.7: Estimated regional Ohio power plant $PM_{2.5}$ mortality impacts by county. Color indicates total mortality burden for each county. Circle size represents total mortality impacts for a plant, which extend far beyond the county where each plant is sited. Blue line designates NAAQS non-attainment areas.

map showing the estimated combined 2015 $PM_{2.5}$ mortality impacts of both Ohio and Pennsylvania power plants across both states is given in **Figure 3** in Appendix .1, and shows that the impacts of these power plants weigh heavily on some of the same counties, particularly in the Pittsburgh, Philadelphia and Cleveland areas.

Figure 5.9 provides a bar plot of estimated mortality by Ohio county for $PM_{2.5}$ impacts from 2015 power plant emissions. Cuyahoga, Lorain, Lake, Franklin and Summit counties have the highest cumulative health impacts, due to a combination of power plant proximity and population density.

Total mortality and morbidity health impacts per county from plants tend to be heavily weighted by the population in that county. To understand where the health burden might be high per capita, independent of the population density, we divide the estimated county-level cost of health impacts by county population.[3] The results give a range of costs of health burden per capita of approximately $61-476 (low estimate) and $138-1,075 (high estimate). The five counties with the highest per capita health burdens are Lorain, Jefferson, Lake, Meigs and Noble, which are all on the eastern side of the state and located either near a high-impact power plant or a few power plants in the same area. The retirement of Muskingum River reduces the per capita impacts on Noble County in particular, although it still ranks relatively high among counties even without this pollution. These results are shown in the map in **Figure** 5.10. This map highlights where the health burden is higher per person, on average, than in other areas, and therefore potential areas that may experience disproportionate impacts from these plants.

[3]Population data from American Community Survey.

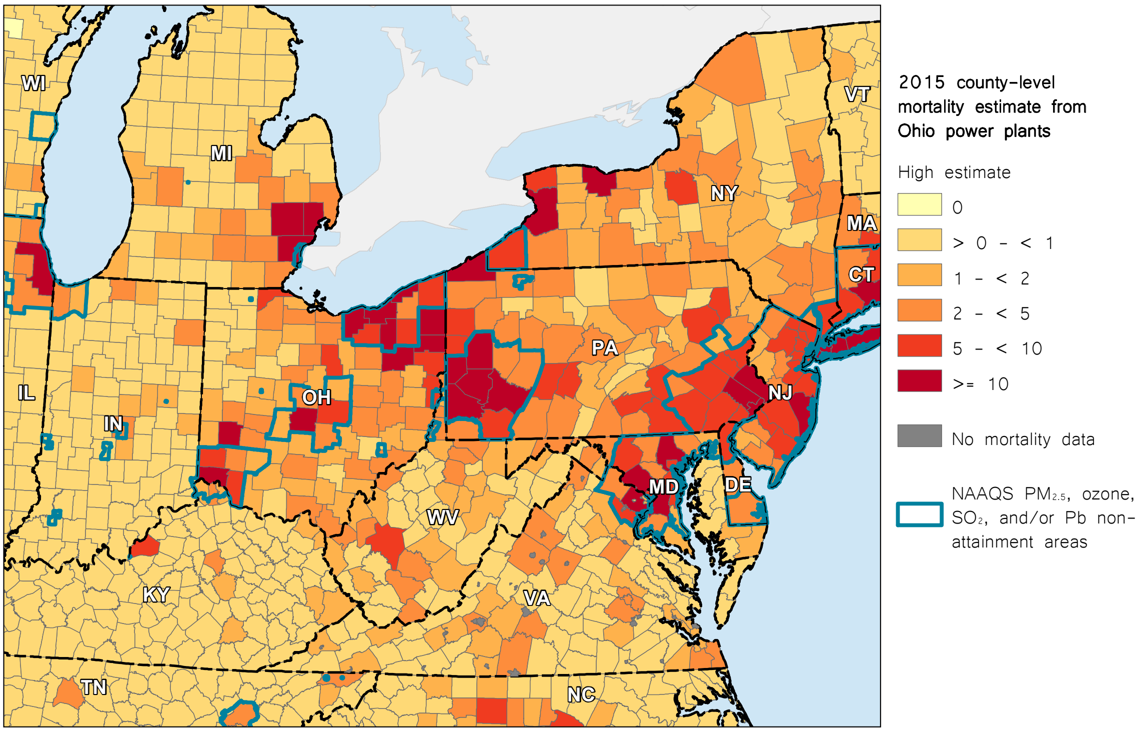


Figure 5.8: Estimated regional power plant $PM_{2.5}$ mortality impacts by county (high estimate). Color indicates health burden for each county. Blue line designates NAAQS non-attainment areas.

Figure 5.11 provides maps of the estimated cost of county level health burdens from the five highest impact plants. Once again, we see that emissions from each plant have impacts across the state, but in many cases the counties near the plant and with the highest populations show the highest burden of health impacts. The largest health burden from Avon Lake, for example, falls on its home county of Lorain, but the second highest burden falls on nearby Cuyahoga County, which is both next to Lorain County and is the most populated county in Ohio. Allegheny County in Pennsylvania suffers the third highest burden from Avon Lake. The coal plant Miami Fort's highest impacts are on its home county of Hamilton, second on Franklin County (a few counties away but home to Ohio's largest city, Columbus), and third on Cook County (home to Chicago) in Illinois. We show a separate visualization of the health impact data from these five power plants on a single map in Appendix .1 **Figure** 4.

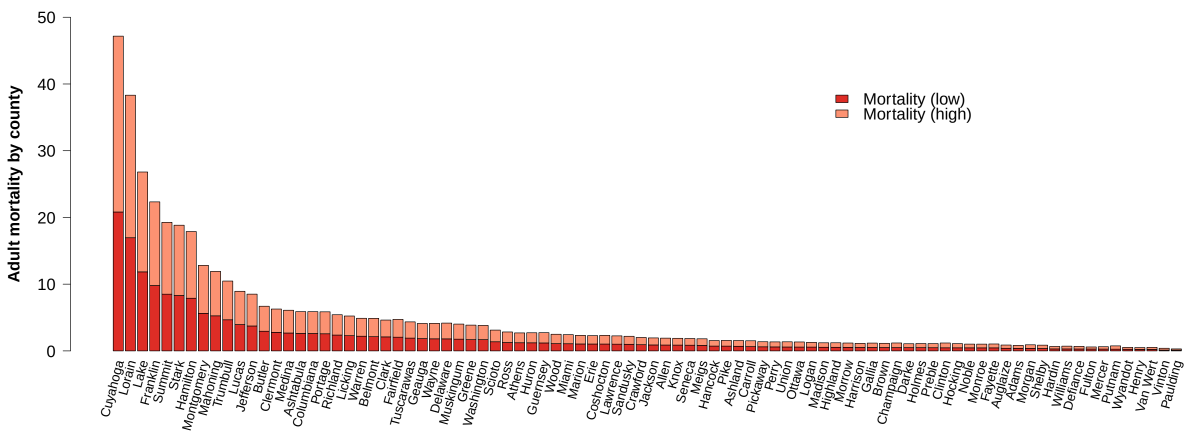


Figure 5.9: Bar chart of low and high estimates of mortality from primary and secondary $PM_{2.5}$ associated with all plants, by county.

We next look at asthma prevalence in each of these counties as a measure of underlying vulnerability. Pre-existing conditions like asthma are associated with an increased susceptibility to adverse health outcomes from exposure to air pollutants like $PM_{2.5}$ [49]. Adult asthma prevalence data are from the Ohio Department of Health's report on the *Impact of Chronic Disease in Ohio: 2015* [129]; data are from 2012 and available on the county or multi-county level. We note that asthma prevalence is self-reported, and therefore these data contain a significant amount of inherent uncertainty. However, these numbers can still provide insight into some underlying trends. In **Figure 5.12**, we map the adult asthma prevalence along with the per capita asthma exacerbations per county. Population data is retrieved from the US Census Bureau's American Community Survey [51]. We use the per capita value to ensure that both prevalence and exacerbations are provided as a rate per unit population. Lorain County has the highest per capita asthma exacerbations, and also has one of the highest rates of asthma prevalence, suggesting a disproportionate share of impacts on a particularly vulnerable population in this region. We give the total asthma exacerbations per county in Appendix .1 **Figure 5**. Population-weighted results more heavily weight urban areas like Cleveland, Columbus and Cincinnati, although Lorain is also the county with the third-highest set of *total* asthma exacerbations, after Allegheny in Pennsylvania and Cuyahoga County in Ohio. These results likely reflect the emissions from Avon Lake, which as noted earlier has the second highest total emissions of SO_2 in the country. Furthermore, Lorain County is designated non-attainment for $PM_{2.5}$ and ozone [37].

These data provide insight into which plants have the highest health and mortality impacts, and where those impacts are concentrated. The value of any given mitigation strategy,

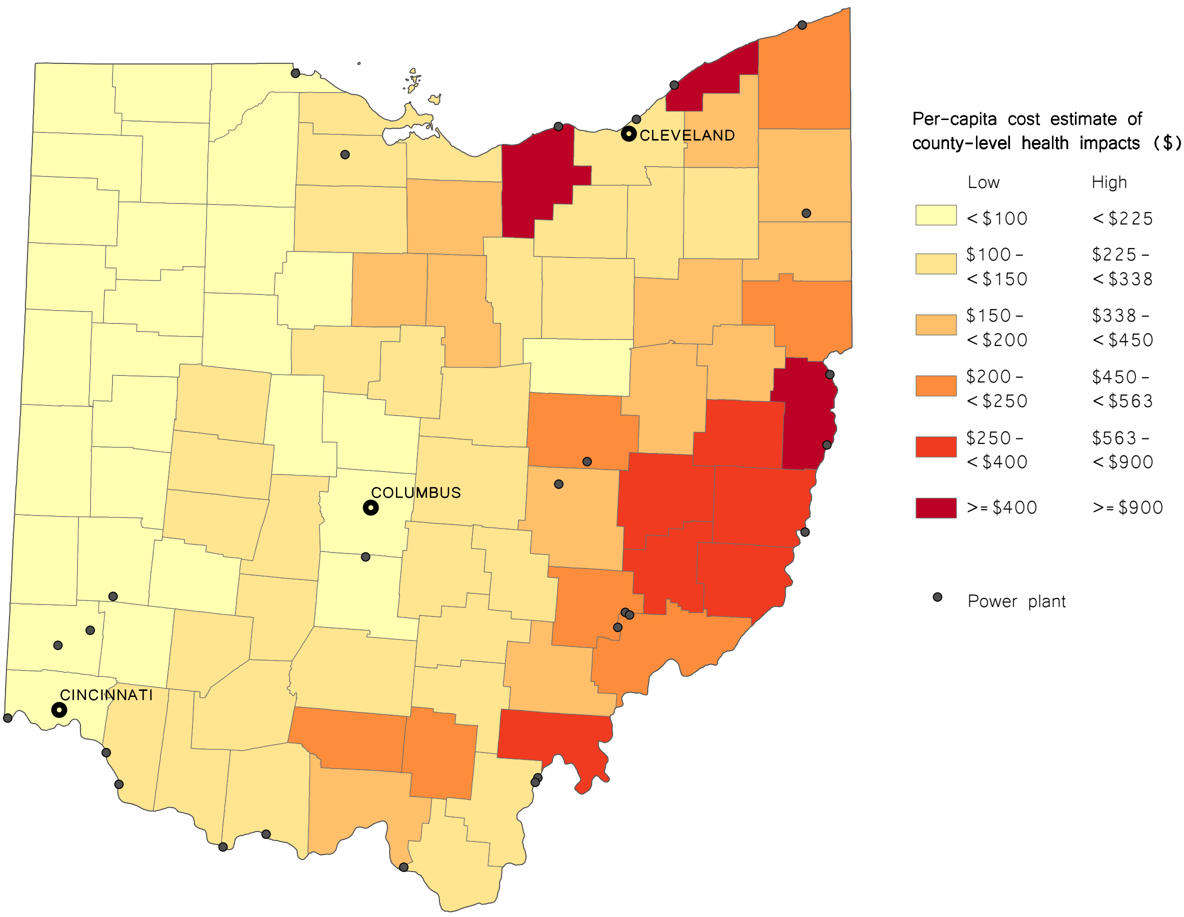


Figure 5.10: Map of estimated $PM_{2.5}$ health burden per capita by county, given in dollars (2010$).

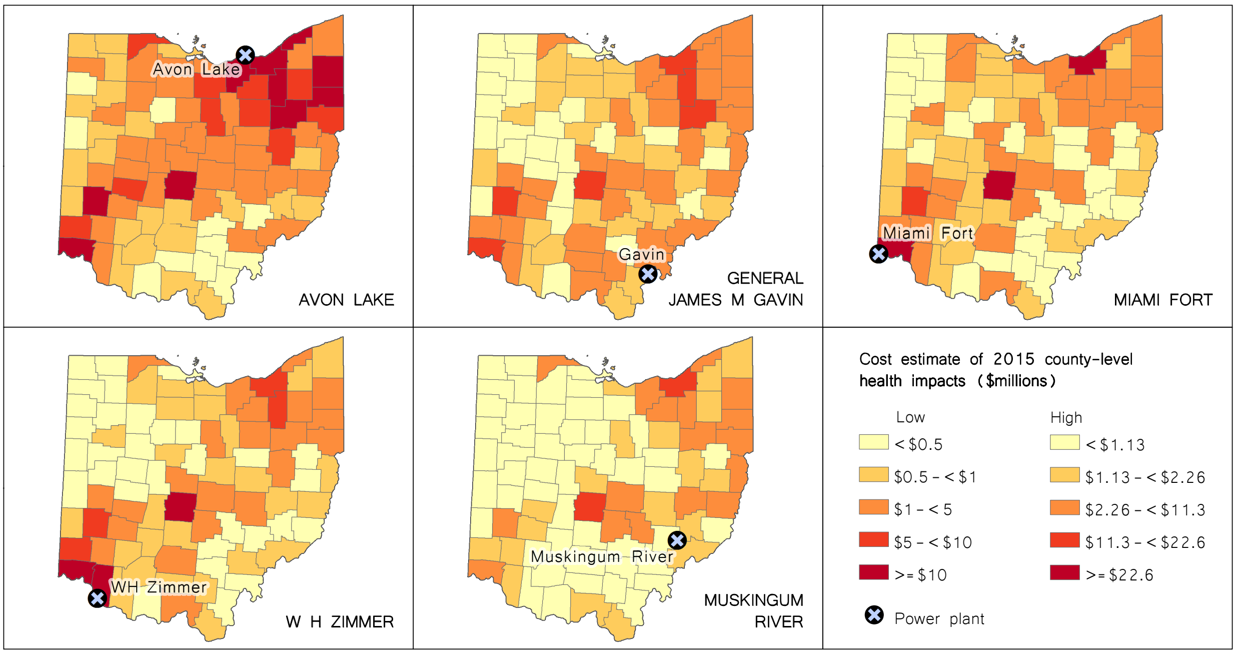


Figure 5.11: Estimated cost of health burden from the five plants with the highest 2015 impact.

however, will depend in large part on the rate of emissions or health impacts—or the rate of emission reductions and health impact reductions—per MWh of some alternative strategy. The primary objective under the Clean Power Plan is to reduce CO_2 emissions, and the Clean Power Plan sets a target for each state to reduce the rate of CO_2 emissions in pounds per MWh. A multi-pollutant approach to simultaneously reduce the health impact of power

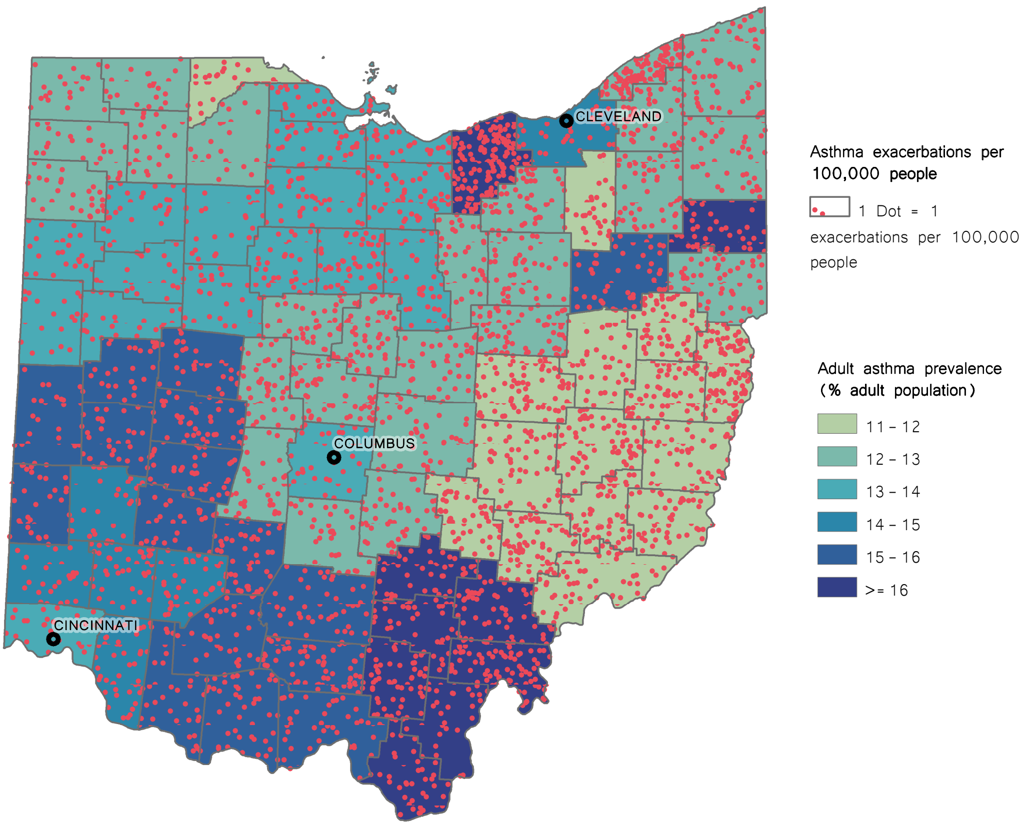


Figure 5.12: Asthma prevalence and asthma exacerbations per capita, by county.

plants would require simultaneously considering the health burden per MWh from each plant. **Figure 5.13a** provides a comparison of the total estimated cost of health burden and mass of CO_2 emissions from each plant. **Figure 5.13b** shows the intensity of estimated cost of health burden and mass of CO_2 emissions per MWh from each plant. The circle size reflects the total generation (GWh) from each plant in 2015. The plants with the highest total CO_2 emissions and aggregate $PM_{2.5}$ health burden are large coal plants; however a few smaller plants have a much higher rate of CO_2 emissions, health burden, or both per MWh. This last category is of particular interest, because it shows where emission reductions may help realize both climate and health benefits.

At the end of 2011, the EPA promulgated a new Mercury and Air Toxics Standards (MATS) for coal- and oil-fired power plants over 25 MW, giving these plants four years to reduce mercury and other toxic air pollutant emissions. These standards may lead to a reduction in SO_2 emissions from certain plants from 2015 levels following the installation of scrubbers and other emission reduction technologies. The EPA allows plants to meet an SO_2 emissions target of 1.5 lbs/MWh as an alternative compliance mechanism to the hydrogen chloride component of the MATS rule. To get a rough estimate of the impact of the MATS standard on health impacts from coal plants in Ohio, we re-ran the COBRA models assuming a maximum SO_2 emission rate of 1.5 lbs/MWh. In 2015, not a single coal plant in Ohio emitted SO_2 at or below this rate, according to EPA AMPD data [25]. Under these assumptions, aggregate mortality count from the COBRA models for the *non-retired* plants covered by the Clean Power Plan is reduced by 43% to 414 (low estimate) and 938 (high estimate). The impacts of this standard vary widely by plant, such as a projected 91% health reduction at Avon Lake, but only 9% at JM Stuart. Under these regulations (and again excluding retired plants), the five plants with the highest mortality impacts become Gavin (72 low, 163 high), WH Sammis (55 low, 124 high), Cardinal (50 low, 114 high), JM Stuart (50 low, 113 high), and Miami Fort (42 low, 95 high).

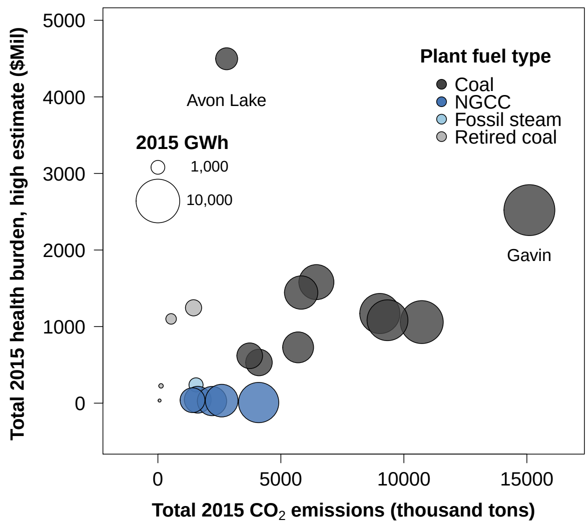


Figure 5.13a: 2015 cost of $PM_{2.5}$ health impacts from each power plant compared to total CO_2 emissions.

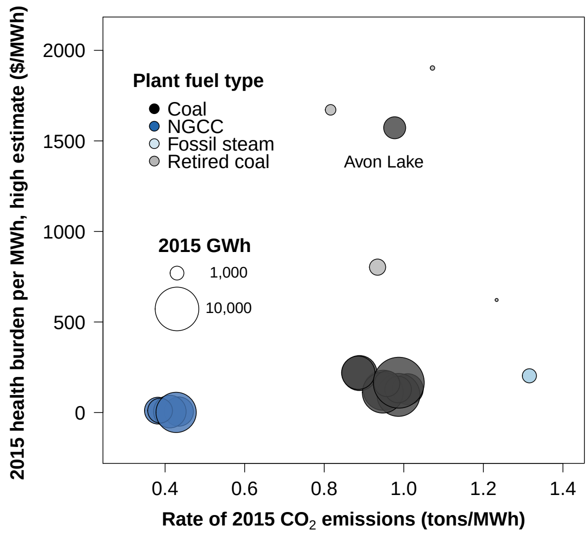


Figure 5.13b: Intensity of health impacts per MWh compared to intensity of CO2 emissions per MWh from each power plant in 2015.

Coal-fired plants dominate the estimated $PM_{2.5}$ health burden in this analysis, but the regional health impacts from natural gas-fired plants are not negligible. The estimated total mortality impacts from the five operational NGCC plants in Ohio in 2015 were 8 (low) and 18 (high), with corresponding health burden cost estimates of $67 and $152 million dollars. Furthermore, NO_x can also contribute to the formation of ozone, the health burdens of which are not reflected in the COBRA estimates.

6. Discussion and policy implications

Carbon mitigation strategies under the Clean Power Plan have the potential to simultaneously ameliorate some of the equity, health and environmental burdens and impacts from the Ohio power sector. In this report, we have 1) assessed vulnerability and cumulative environmental and health burden measures for populations living in close proximity to power plants, 2) analyzed environmental public health hazards attributable to power plant operations at these sites, including violations and toxic releases, and 3) aggregated criteria pollutant emissions and modeled the broader regional health impacts of primary and secondary particulate matter from fossil fuel combustion for electricity generation across the state. In doing so, we have characterized the environmental public health and equity dimensions of Ohio power generation to be regulated under the Clean Power Plan. Results from our analyses provide a useful baseline to identify policy pathways to increase potential co-benefits from the Clean Power Plan. Our results suggest that an integrated approach, rather than optimization over any one pollutant or metric, holds greater potential to realize human health and equity co-benefits of Clean Power Plan compliance.

The Clean Power Plan offers multiple strategies to meet greenhouse gas reduction targets, and many scenarios may enable the state of Ohio to achieve these goals. The incorporation of some of the environmental, health and equity data analyzed here may help identify pathways that simultaneously maximize public health benefits while ensuring that any compliance approach does not increase the burden of power generation on vulnerable and already overburdened populations. While compliance plans will not specify individual power plants to turn on or off, modeling of plant-specific generation and emissions under different scenarios can provide some insight into likely changes in power plant use and where shifts in emissions, hazards, burdens, and impacts may occur. The EPA specifically suggests that states consider a multi-pollutant strategy, which holds potential to reduce some of the toxic releases and public health burdens described in Sections 4 and 5 of this report. The EPA also requires that states not increase the burden of power generation on overburdened and vulnerable communities, which can be informed by the environmental justice analysis in Section 3 and environmental health hazards analysis in Section 4. We discuss the policy implication of these many data layers below.

6.1 Overburdened and vulnerable populations

The Clean Power Plan requires engagement with overburdened and vulnerable populations and the assurance that any compliance plan does not increase the burden on these communities. One potential pathway by which this burden could be inequitably shifted would be moving electricity generation from coal to existing NGCC plants, one of the EPA's three suggested compliance strategies—or to new planned NGCC plants under the New Source Complement. In Section 3 we found that all NGCC plants, both fossil steam plants, and all but two coal plants are located in communities with a higher fraction low income population than the state median. Four of the six planned NGCC plants are also above that median, and the other two plants just below it. Furthermore, two of these plants are in more urban areas than all but one active Clean Power Plan subject plant in Ohio. The summed populations living near both existing and planned NGCC plants are both above the median and higher than coal for metrics of low income, minority, less than high school education, and elderly populations. While many of the plants that rank highest on our Cumulative Vulnerability Index have been retired in recent years, most plants of all classes rank above the expected median value suggesting vulnerable communities living in proximity to many plants. Furthermore, in Section 4, we found that a potential co-benefit of reducing additional coal waste under the Clean Power Plan is to reduce or eliminate the use of impoundments with poor structural integrity, high hazard potential or near vulnerable communities. **These data suggest that a shift from coal to existing and planned NGCC may reduce many burdens associated with coal generation but potentially increase the demand on plants in low income and low socioeconomic status communities that already experience a cumulative burden of multiple environmental, health and social stressors.**

However, individual plants do not necessarily follow these trends, meaning that any compliance strategy would have to look at specifically where power plant generation is expected to increase or decrease. There is an opportunity here as well for reduced demand on both coal and NGCC plants in such vulnerable and overburdened populations, as well as at locations with large associated environmental health hazards like coal impoundments, toxic releases, groundwater contamination and histories of environmental violations. Clean Power Plan compliance strategies that emphasize renewables and efficiency, rather than increased generation at any fossil fuel plant, offer greater potential for ensuring that these burdens do not increase. The screening analysis offered in Section 3 also provides an approach to identify vulnerable communities for engagement during the development of any state plan, as well as potential areas to pursue efficiency projects under the Clean Energy Incentive Program.

6.2 Multi-pollutant strategies

The potential public health benefits of reducing co-pollutants under the Clean Power Plan are significant. Our models projected a mortality count of 940 (low estimate) and 2,100 (high estimate) associated with primary and secondary $PM_{2.5}$ resulting from combustion at Ohio power plants in 2015 alone, as well as health impacts ranging from acute bronchitis to asthma attacks and heart attacks. The monetary value of this health burden is estimated at \$5.4 billion (AP2), \$8.1 billion (COBRA low), and \$18.2 billion (COBRA high) in our three models—\$6.9 billion and \$15.6 billion if we exclude plants retired by the end of 2015. These aggregated burdens fall heaviest on Cuyahoga, Lorain, Lake, Franklin and Summit counties; the counties with the highest 2015 power plant $PM_{2.5}$ health burden per capita are Lorain, Jefferson, Lake, Meigs and Noble, although Noble faces somewhat less pollution in the coming years after the retirement of Muskingum River. The magnitudes of these estimates are likely conservative given that they do not reflect the additional health impacts of ozone and other toxic and hazardous air pollutant emissions. A number of Ohio power plants with the highest rates of pollutant emissions per MWh retired over the course of 2015, but some of the country's highest pollutant emitters—such as Avon Lake—remain online.

Public health benefits may be achieved under a Clean Power Plan scenario that prioritizes the reduction of co-pollutants like NO_x and SO_2 and toxic air pollutants; a more refined approach would target those SO_2 emissions with the highest health burden. A comparison of the rate of emissions and the rate of health burden per MWh, rather than just aggregate totals, can also identify where demand reduction projects might have the greatest impact for every MWh met with efficiency projects or renewable energy. The health impact per MWh, measured in dollars, ranged from $43 to $840 for coal plants alone in the COBRA low estimate ($97-$1900 high estimate) suggesting a large health benefit for every MWh reduced from specific plants. The total pollutant emissions and associated health burdens from each power plant provide insight into where to target the plants with the largest aggregate impacts, but some of the most effective alternatives may instead prioritize those locations where the rates of emissions and health burdens are highest. For example, the coal plant Gavin has the highest total emissions of CO_2, but only the fifth highest rate of CO_2 emissions per MWh; Gavin has the second highest total SO_2 emissions and total health impacts, but the ninth highest emission rate of SO_2 per MWh.

We also found the highest aggregated health burden fell in the northeast of Ohio and on counties with larger populations, but the highest per capita health burdens were located all along the eastern part of the state, particularly in or near counties with coal plants. While the populations and total health burdens may be higher elsewhere, these populations may face a disproportionate share of those health burdens per person. We also looked at background air quality across the state as well as background adult asthma prevalence, giving some initial insight into regions where health impacts from power plants may fall on populations with health vulnerability or existing environmental burden that may make them more susceptible to adverse health outcomes. Lorain County, near Cleveland, stood out for high total and per capita health impacts as well as high levels of background asthma and existing poor air quality, given that the county is out of attainment for both ozone and $PM_{2.5}$ under federal NAAQS standards. Lorain County, home to the second highest emitter of SO_2 in the country, therefore suffers a high health impact from power plant emissions on top of existing health and environmental burdens and vulnerabilities. These data suggest the need to account for both disparities in health burdens as well as cumulative health burden and background environmental and health burdens when seeking to optimize Clean Power Plan public health co-benefits.

6.3 Renewable energy and efficiency

Our mapping of existing generation in Ohio has focused primarily on coal, NGCC and fossil steam plants, given the current fuel mix of Ohio power generation (see **Figure 2.2**). However, renewables and energy efficiency can play a key role in reducing carbon emissions moving forward. Increased NGCC utilization is presented in the Clean Power Plan as a strategy to reduce direct carbon emissions from coal plants, but the direct carbon emissions from wind, solar and efficiency resources are negligible compared to NGCC generation, and these resources do not have the criteria pollutant emissions of fossil fuels. Furthermore, upstream methane emissions associated with the production, transmission, storage and distribution of natural gas erode some of the greenhouse gas emission reductions of switching from coal to natural gas [21, 130], even though these impacts are not directly considered under Clean Power Plan compliance, which focuses on combustion-related emissions. Methane is 86 times more potent than carbon dioxide on a 20-year timescale and approximately 34 times more potent on a 100-year time scale [131], and so this methane leakage greatly increases the climate impacts of using natural gas as a fuel.

The National Renewable Energy Laboratory estimates that Ohio has the economically competitive potential to generate 15.5 TWh per year from wind and 5.7 TWh per year from utility-scale PV, which would provide about 17% of Ohio's 2015 in-state generation of 122 TWh [29]; the total technical potential for renewable electricity generation is significantly higher, including 53 TWh [132] to 63 TWh [133] from rooftop solar; 165 TWh from wind [133]; and 3,796 TWh from utility-scale solar [133]. These numbers show significant potential for growth from 2015 generation levels of 1.2 TWh from wind and 162 GWh from all solar resources [29].

Actively pursuing efficiency strategies is shown to have greater public health benefits than strategies that simply aim to reduce CO_2 emissions [40]. Furthermore, deployment of efficiency and renewable energy technologies helps mitigate the risk of increased NGCC generation near vulnerable communities. Together, an emphasis on efficiency and renewables rather than natural gas for Clean Power Plan compliance is likely to yield greater climate, public health, and equity benefits.

6.4 Implications for retired plants

Our analysis includes a number of plants that retired after the baseline year of 2012, and more coal plants may move into retirement rather than comply with the MATS standards or the Clean Power Plan. We note that the populations near these recently retired plants are frequently low income, minority communities that rank high on numerous measures of cumulative burden. While this trend may be promising for reducing burdens on vulnerable communities, there are a few additional policy implications. First, both these and future retirement sites will likely still have on-site hazards like coal ash impoundments, and their proximity to vulnerable communities highlights the need to continue to carefully inspect and monitor such sites for environmental health hazards and contamination even if the power plant is no longer operational. Second, a number of coal plant sites (both with currently running and recently retired plants) are under consideration as potential NGCC sites. The cumulative burden screening results can help inform decisions to move forward on repowering such plants.

6.5 Additional considerations and limitations to approach

A number of additional considerations may help refine our broad portrait of the health, environment and equity dimensions of the Clean Power Plan, which necessarily included many approximations and estimates. Our environmental justice analysis focused on a set of specific vulnerability and burden indicators, but engagement with and feedback from communities living in the region of a plant can highlight whether any omitted indicators (e.g. local asthma prevalence or certain environmental burdens) are of importance to that community, or whether specific indicators are of more concern than others. Furthermore, we focused on populations in a three-mile radius, but there may be different priorities and concerns for those living closer to the plants or far beyond the three-mile radius, and community engagement should not necessarily be limited by the radius used in this proximity analysis. We note particularly that many of the health burdens reach far beyond this local area. We also did not address any economic or job concerns in the area, but these may be of particular importance to some communities. Speaking to local communities can also help identify whether specific spots are disproportionately burdened by a specific aspect of power plant operation, such as groundwater contamination concerns in areas where many inhabitants drink well water. Demographics and populations around these plants are continuously shifting as well and may not have been reflected in the most recent American Community Survey or other datasets used here.

Many of the plants themselves are undergoing shifts in fuels, utilization rates, and operating status which may affect the burden and impacts from these plants. The MATS standards, fuel prices, changes in population size and demand, and competition with new power generation sources will all affect power plant utilization, rate of toxic releases, and emissions in the coming years. Retirements or repowering at one site may also affect the use of other nearby plants. Furthermore, these changes as well as Clean Power Plan compliance may have an effect on the use of power plants not covered by the Clean Power Plan, which can be both modeled and monitored.

From a public health standpoint, we focused primarily on the impacts of $PM_{2.5}$ due to its large cumulative health burden and comparatively well-understood epidemiological impacts. However, this focus should not preclude the consideration of ozone, toxic air pollutants, heavy metals, and environmental health hazards from the plants themselves. The health risks from some of these hazards may be harder to model, but the estimated mortality rates and health burden of $PM_{2.5}$ should not overshadow the consideration of other environmental public health risks analyzed herein.

Any approach to Clean Power Plan compliance seeking to realize environmental health benefits will necessarily encounter trade-offs between certain emissions and burdens and others. There may particularly be a trade-off between reducing cumulative public health impacts and disproportionate burdens on individual communities near plants. Of particular note is the need to balance the reduction in cumulative burdens with the weight of disproportionate burdens put on certain populations. We have looked at some of these inequities for the state of Ohio, but any compliance plan that includes a multi-state approach also runs the potential risk of inequities between states, both in the populations near power generation as well as in the burden of air quality health impacts from that generation.

In many cases, renewable energy and efficiency projects may be most likely to reduce the many burdens from power generation, rather than switching load from one set of fossil generators to another. We did not look closely at when the power sector was emitting the most health-harming pollutants, but the inclusion of efficiency or renewable technologies that displace the highest-impact marginal emissions may help yield the greatest benefits [134]. These could be specific technologies that affect demand at the hours when the net emissions from the grid are the highest, or those that focus on making seasonal changes, such as advancing air-conditioning efficiency measures that reduce pollutant emissions in the hot summer months when ozone concentrations are typically highest.

6.6 Conclusions

In this report, we have integrated numerous layers of environmental, health and demographic information related to power plant operation in Ohio in relation to the Clean Power Plan. These data can help identify vulnerable populations near power plants, environmental hazards at those plants, and regional health impacts from power plant emissions. Under the Clean Power Plan, the State of Ohio has an opportunity to ameliorate some of the burdens of power generation, particularly on vulnerable communities. Doing so will require a balance between reducing total aggregated burdens and inequities in the distributions of these burdens on different populations. This report provides a baseline of the health, environment and equity dimensions of power generation from which state compliance plans can seek to identify strategies to Clean Power Plan compliance that also bring health and equity benefits to the State of Ohio.

Bibliography

[1] N. Middleton, O. Kolokotroni, D. Lamnisos, P. Koutrakis, and P. Yiallouros, “Prevalence of asthma and respiratory symptoms in 15–17 year-old Greek-Cypriots by proximity of their community of residence to power plants: Cyprus 2006–07,” *Public Health*, vol. 128, no. 3, pp. 288–296, 2014.

[2] X. Liu, L. Lessner, and D. O. Carpenter, “Association between residential proximity to fuel-fired power plants and hospitalization rate for respiratory diseases,” *Environmental Health Perspectives*, vol. 120, no. 6, p. 807, 2012.

[3] S. Ha, H. Hu, J. Roth, H. Kan, and X. Xu, “Associations between residential proximity to power plants and adverse birth outcomes,” *American Journal of Epidemiology*, vol. 182, no. 3, pp. 215–224, 2015.

[4] S.-W. Hu, Y.-J. Chan, H.-T. Hsu, K.-Y. Wu, G.-P. ChangChien, R.-H. Shie, and C.-C. Chan, “Urinary levels of 1-hydroxypyrene in children residing near a coal-fired power plant,” *Environmental Research*, vol. 111, no. 8, pp. 1185–1191, 2011.

[5] A. Di Ciaula, “Emergency visits and hospital admissions in aged people living close to a gas-fired power plant,” *European Journal of Internal Medicine*, vol. 23, no. 2, pp. e53–e58, 2012.

[6] Ohio Power Siting Board. Power siting cases. [Online]. Available: http://www.opsb.ohio.gov/opsb/

[7] EPA, “EJ screening report for the Clean Power Plan,” U.S. Environmental Protection Agency, Tech. Rep. Docket: EPA–HQ–OAR–2013–0602, 2015.

[8] J. K. Boyce and M. Pastor, “Clearing the air: incorporating air quality and environmental justice into climate policy,” *Climatic Change*, vol. 120, no. 4, pp. 801–814, 2013.

[9] D. R. Faber and E. J. Krieg, “Unequal exposure to ecological hazards: environmental injustices in the Commonwealth of Massachusetts.” *Environmental Health Perspectives*, vol. 110, no. Suppl 2, p. 277, 2002.

[10] EPA. (2016) Toxic Release Inventory. [Online]. Available: https://www.epa.gov/toxics-release-inventory-tri-program

[11] J. I. Levy, J. D. Spengler, D. Hlinka, D. Sullivan, and D. Moon, “Using CALPUFF to evaluate the impacts of power plant emissions in Illinois: model sensitivity and implications,” *Atmospheric Environment*, vol. 36, no. 6, pp. 1063–1075, 2002.

[12] J. I. Levy, L. K. Baxter, and J. Schwartz, “Uncertainty and variability in health-related damages from coal-fired power plants in the United States,” *Risk Analysis*, vol. 29, no. 7, pp. 1000–1014, 2009.

[13] M. L. Bell, K. Ebisu, R. D. Peng, J. Walker, J. M. Samet, S. L. Zeger, and F. Dominici, “Seasonal and regional short-term effects of fine particles on hospital admissions in 202 US counties, 1999–2005,” *American Journal of Epidemiology*, vol. 168, no. 11, pp. 1301–1310, 2008.

[14] M. J. Strickland, L. A. Darrow, M. Klein, W. D. Flanders, J. A. Sarnat, L. A. Waller, S. E. Sarnat, J. A. Mulholland, and P. E. Tolbert, “Short-term associations between ambient air pollutants and pediatric asthma emergency department visits,” *American Journal of Respiratory and Critical Care Medicine*, vol. 182, no. 3, pp. 307–316, 2010.

[15] M. L. Bell, A. Zanobetti, and F. Dominici, “Who is more affected by ozone pollution? A systematic review and meta-analysis,” *American Journal of Epidemiology*, 2014.

[16] M. A. McGeehin and M. Mirabelli, “The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States.” *Environmental Health Perspectives*, vol. 109, no. Suppl 2, p. 185, 2001.

[17] V. Barros, C. Field, D. Dokke, M. Mastrandrea, K. Mach, T. Bilir, M. Chatterjee, K. Ebi, Y. Estrada, R. Genova *et al.*, *Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate ChangeB: regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, 2015.

[18] EPA, "Carbon pollution emission guidelines for existing stationary sources: Electric utility generating units," U.S. Environmental Protection Agency, Final Rule FR Vol. 80 No. 205, August 2015. [Online]. Available: http://www.gpo.gov/fdsys/pkg/FR-2015-10-23/pdf/2015-22842.pdf

[19] EPA. (2016) EJSCREEN: Environmental justice screening and mapping tool share. [Online]. Available: http://www2.epa.gov/ejscreen

[20] M. Whitaker, G. A. Heath, P. O'Donoughue, and M. Vorum, "Life cycle greenhouse gas emissions of coal-fired electricity generation," *Journal of Industrial Ecology*, vol. 16, no. s1, pp. S53–S72, 2012.

[21] A. Brandt, G. Heath, E. Kort, F. O'Sullivan, G. Pétron, S. Jordaan, P. Tans, J. Wilcox, A. Gopstein, D. Arent *et al.*, "Methane leaks from North American natural gas systems," *Science*, vol. 343, no. 6172, pp. 733–735, 2014.

[22] O. Schneising, J. P. Burrows, R. R. Dickerson, M. Buchwitz, M. Reuter, and H. Bovensmann, "Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations," *Earth's Future*, vol. 2, no. 10, pp. 548–558, 2014.

[23] S. Ghosh, K. Crist, and M. Kim, "Assuring Ohio's competitiveness in a carbon-constrained world: A collaboration between ohio university and the ohio state university," Ohio University and The Ohio State University. Prep. for the Ohio Department of Development., Tech. Rep., 2011.

[24] EIA. (2015) Energy-related carbon dioxide emissions at the state level, 2000-2013. [Online]. Available: http://www.eia.gov/environment/emissions/state/analysis/pdf/table3.pdf

[25] EPA. (2015) Air Markets Program Data. [Online]. Available: http://ampd.epa.gov/ampd/

[26] EPA. (2015) Clean Power Plan state tables. [Online]. Available: https://blog.epa.gov/blog/wp-content/uploads/2015/08/State-tables-tab-1.pdf

[27] EPA, "CO2 emission performance rate and goal computation technical support document for CPP final rule," U.S. Environmental Protection Agency, Tech. Rep. EPA-HQ-OAR-2013-0602, 2015.

[28] EPA, "Clean Power Plan technical support document emission performance rate goal computation appendix 1-5," U.S. Environmental Protection Agency, Tech. Rep., 2015.

[29] EIA. (2016) Electricity data browser. [Online]. Available: https://www.eia.gov/electricity/data/browser/

[30] F. Dominici, R. D. Peng, M. L. Bell, L. Pham, A. McDermott, S. L. Zeger, and J. M. Samet, "Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases," *JAMA*, vol. 295, no. 10, pp. 1127–1134, 2006.

[31] A. J. Cohen, H. Ross Anderson, B. Ostro, K. D. Pandey, M. Krzyzanowski, N. Künzli, K. Gutschmidt, A. Pope, I. Romieu, J. M. Samet *et al.*, "The global burden of disease due to outdoor air pollution," *Journal of Toxicology and Environmental Health, Part A*, vol. 68, no. 13-14, pp. 1301–1307, 2005.

[32] C. A. Pope III, R. T. Burnett, M. J. Thun, E. E. Calle, D. Krewski, K. Ito, and G. D. Thurston, "Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution," *JAMA*, vol. 287, no. 9, pp. 1132–1141, 2002.

[33] M. Franklin, A. Zeka, and J. Schwartz, "Association between PM2. 5 and all-cause and specific-cause mortality in 27 US communities," *Journal of Exposure Science and Environmental Epidemiology*, vol. 17, no. 3, pp. 279–287, 2007.

[34] ATSDR. (1999) Toxicological profile: Mercury. [Online]. Available: http://www.atsdr.cdc.gov/toxprofiles/tp46.pdf

[35] PA-DEP, "Commonwealth of Pennsylania Department of Environmental Protection Bureau of Air Quality 2009 ambient air quality monitoring and emission trends report," Pennsylvania Department of Environmental Protection Bureau of Air Quality, Tech. Rep., 2009. [Online]. Available: http://www.dep.state.pa.us/dep/deputate/airwaste/aq/aqm/aqreport/AnnualReport2009.pdf

[36] EPA. (2016) Air trends. [Online]. Available: https://www3.epa.gov/airtrends/

[37] EPA. (2015) The green book nonattainment areas for criteria pollutants. [Online]. Available: https://www3.epa.gov/airquality/greenbook/

[38] EPA. (2016) Air Quality Index (AQI) basics. [Online]. Available: https://airnow.gov/index.cfm?action=aqibasics.aqi

[39] EPA, "Regulatory impact analysis for the Clean Power Plan final rule," U.S. Environmental Protection Agency, Tech. Rep. EPA 452-R-15-003, August 2015. [Online]. Available: http://www2.epa.gov/sites/production/files/2015-08/documents/cpp-final-rule-ria.pdf

[40] C. T. Driscoll, J. J. Buonocore, J. I. Levy, K. F. Lambert, D. Burtraw, S. B. Reid, H. Fakhraei, and J. Schwartz, "US power plant carbon standards and clean air and health co-benefits," *Nature Climate Change*, vol. 5, no. 6, pp. 535–540, 2015.

[41] J. I. Levy, A. M. Wilson, and L. M. Zwack, "Quantifying the efficiency and equity implications of power plant air pollution control strategies in the United States," *Environmental Health Perspectives*, pp. 743–750, 2007.

[42] J. I. Levy, S. L. Greco, S. J. Melly, and N. Mukhi, "Evaluating efficiency-equality tradeoffs for mobile source control strategies in an urban area," *Risk Analysis*, vol. 29, no. 1, pp. 34–47, 2009.

[43] N. Fann, H. A. Roman, C. M. Fulcher, M. A. Gentile, B. J. Hubbell, K. Wesson, and J. I. Levy, "Maximizing health benefits and minimizing inequality: incorporating local-scale data in the design and evaluation of air quality policies," *Risk Analysis*, vol. 31, no. 6, pp. 908–922, 2011.

[44] J. I. Levy, S. L. Greco, and J. D. Spengler, "The importance of population susceptibility for air pollution risk assessment: a case study of power plants near Washington, DC," *Environmental Health Perspectives*, vol. 110, no. 12, p. 1253, 2002.

[45] P. L. DeFur, G. W. Evans, E. A. C. Hubal, A. D. Kyle, R. A. Morello-Frosch, and D. R. Williams, "Vulnerability as a function of individual and group resources in cumulative risk assessment," *Environmental Health Perspectives*, pp. 817–824, 2007.

[46] R. Morello-Frosch, M. Zuk, M. Jerrett, B. Shamasunder, and A. D. Kyle, "Understanding the cumulative impacts of inequalities in environmental health: implications for policy," *Health Affairs*, vol. 30, no. 5, pp. 879–887, 2011.

[47] C. for Disease Control and Prevalence. BRFSS prevalence & trends data. [Online]. Available: http://www.cdc.gov/brfss/brfssprevalence/index.html

[48] D. W. Dockery and C. A. Pope, "Acute respiratory effects of particulate air pollution," *Annual Review of Public Health*, vol. 15, no. 1, pp. 107–132, 1994.

[49] C. A. Pope III and D. W. Dockery, "Health effects of fine particulate air pollution: lines that connect," *Journal of the Air & Waste Management Association*, vol. 56, no. 6, pp. 709–742, 2006.

[50] Office of Environmental Health Hazard Assessment and California Enviornmental Protection Agency. (2014, November) California communities environmental health screening tool, version 2 (CalEnviroScreen 2.0). Guidance and screening tool. [Online]. Available: http://oehha.ca.gov/ej/ces2.html

[51] U. C. Bureau, "American Community Survey (ACS)," US Census Bureau, Tech. Rep., 2008-2012. [Online]. Available: https://www.census.gov/programs-surveys/acs/

[52] A. Y. Liu, F. C. Curriero, T. A. Glass, W. F. Stewart, and B. S. Schwartz, "The contextual influence of coal abandoned mine lands in communities and type 2 diabetes in Pennsylvania," *Health & Place*, vol. 22, pp. 115–122, 2013.

[53] EPA, "National Ambient Air Quality Standards for ozone; final rule," U.S. Environmental Protection Agency, Tech. Rep., 2015. [Online]. Available: https://www.gpo.gov/fdsys/pkg/FR-2015-10-26/pdf/2015-26594.pdf

[54] EPA. (2016) AirData. [Online]. Available: https://www3.epa.gov/airdata/

[55] EPA, "United States Environmental Protection Agency air quality system site description report," U.S. Environmental Protection Agency (EPA), Tech. Rep. AMP380, 2014.

[56] EIA. (2016) Form EIA-923 detailed data. [Online]. Available: https://www.eia.gov/electricity/data/eia923/

[57] EIA. (2016) Form EIA-860 detailed data. [Online]. Available: https://www.eia.gov/electricity/data/eia860/

[58] C. J. Santhanam, R. R. Lunt, S. L. Johnson, C. B. Cooper, P. S. Thayer, and J. W. Jones, "Health and environmental impacts of increased generation of coal ash and FGD sludges. report to the committee on health and ecological effects of increased coal utilization," *Environmental Health Perspectives*, vol. 33, p. 131, 1979.

[59] G. Bartov, A. Deonarine, T. M. Johnson, L. Ruhl, A. Vengosh, and H. Hsu-Kim, "Environmental impacts of the Tennessee Valley Authority Kingston coal ash spill. 1. Source apportionment using mercury stable isotopes," *Environmental Science & Technology*, vol. 47, no. 4, pp. 2092–2099, 2012.

[60] EPA. (2016) Coal ash basics. [Online]. Available: https://www.epa.gov/coalash/coal-ash-basics

[61] P. J. Borm, "Toxicity and occupational health hazards of coal fly ash (CFA). A review of data and comparison to coal mine dust," *Annals of Occupational Hygiene*, vol. 41, no. 6, pp. 659–676, 1997.

[62] S. Landsberger, J. Cerbus, and S. Larson, "Elemental characterization of coal ash and its leachates using sequential extraction techniques," *Journal of Radioanalytical and Nuclear Chemistry*, vol. 192, no. 2, pp. 265–274, 1995.

[63] EPA, "Administrative order and agreement on consent in the matter of TVA Kingston fossil fuel plant release site," U.S. Environmental Protection Agency, Tech. Rep. CERCLA-04-2009-3766, 2009.

[64] Tennessee State Government, "Environment and conservation issues $ 11.5 million penalty to TVA for Kingston coal ash spill," Tennessee State Government, Tech. Rep., 2010. [Online]. Available: https://tn.gov/news/28888

[65] A. D. Lemly and J. P. Skorupa, "Wildlife and the coal waste policy debate: Proposed rules for coal waste disposal ignore lessons from 45 years of wildlife poisoning," *Environmental Science & Technology*, vol. 46, no. 16, pp. 8595–8600, 2012.

[66] EIP, “Factsheet on Kingston ash spill,” Environmental Integrity Project, Tech. Rep., 2009. [Online]. Available: http://www.environmentalintegrity.org/pdf/newsreports/TVA_2008TRI_Kingston%20Ash%20Spill%202009128.pdf

[67] L. S. Ruhl, G. S. Dwyer, H. Hsu-Kim, J. C. Hower, and A. Vengosh, “Boron and strontium isotopic characterization of coal combustion residuals: validation of new environmental tracers,” *Environmental Science & Technology*, vol. 48, no. 24, pp. 14 790–14 798, 2014.

[68] L. Ruhl, A. Vengosh, G. S. Dwyer, H. Hsu-Kim, and A. Deonarine, “Environmental impacts of the coal ash spill in Kingston, Tennessee: an 18-month survey,” *Environmental Science & Technology*, vol. 44, no. 24, pp. 9272–9278, 2010.

[69] L. Ruhl, A. Vengosh, G. S. Dwyer, H. Hsu-Kim, A. Deonarine, M. Bergin, and J. Kravchenko, “Survey of the potential environmental and health impacts in the immediate aftermath of the coal ash spill in Kingston, Tennessee,” *Environmental Science & Technology*, vol. 43, no. 16, pp. 6326–6333, 2009.

[70] EPA. (2015) Frequent questions about the coal ash disposal rule. [Online]. Available: FrequentQuestionsabouttheCoalAshDisposalRule

[71] Ohio EPA, “Fact sheet: Ground water in ohio,” Ohio Environmental Protection Agency, Tech. Rep., 2014. [Online]. Available: http://epa.ohio.gov/Portals/28/documents/gwqcp/gwfactsht.pdf

[72] Ohio EPA, “Ohio integrated water quality monitoring and assessment report,” Ohio Environmental Protection Agency, Tech. Rep., 2012. [Online]. Available: http://epa.ohio.gov/portals/35/tmdl/2012IntReport/IR12SectionMfinal.pdf

[73] EPA, “Regulatory impact analysis for EPA’s proposed RCRA regulation of coal combustion residues (CCR) generated by the electric utility industry,” U.S. Environmental Protection Agency, Tech. Rep., 2010.

[74] A. D. Lemly, “An urgent need for an EPA standard for disposal of coal ash,” *Environmental Pollution*, vol. 191, pp. 253–255, 2014.

[75] US District Court for the Western District of Pennsylvania, “Commonwealth of Pennsylvania: Department of Environmental Protection v. Firstenergy Generation Corp.” 2012. [Online]. Available: http://www.environmentalintegrity.org/news_reports/documents/LittleBlueRun-FirstEnergyComplaint.pdf

[76] M. Hargraves and W. Harris, “Assessment of dam safety coal combustion surface impoundments (task 3) final report: Duke Energy W.C. Beckjord Station,” Prep. for Lockheed Martin, Tech. Rep., 2010.

[77] R. Lowenstein and M. Hargraves, “Assessment of dam safety coal combustion surface impoundments (task 3) final report: American Electric Power Cardinal Power Plant,” Prep. for Lockheed Martin, Tech. Rep., 2009.

[78] EPA. (2016) Information request responses from electric utilities. [Online]. Available: https://archive.epa.gov/epawaste/nonhaz/industrial/special/fossil/web/html/index-3.html

[79] EPA. (2016) Coal combustion residuals impoundment assessment reports. [Online]. Available: https://archive.epa.gov/epawaste/nonhaz/industrial/special/fossil/web/html/index-4.html

[80] EPA. (2016) Frequent questions on coal ash impoundment assessments. [Online]. Available: https://www3.epa.gov/epawaste/nonhaz/industrial/special/fossil/coalash-faqs.htm#13

[81] M. Hargraves, “Assessment of dam safety coal combustion surface impoundments (task 3) final report: American Electric Power Muskingum River Power Plant,” Prep. for Lockheed Martin, Tech. Rep., 2010.

[82] ATSDR. (2007) Toxicological profile: Arsenic. [Online]. Available: http://www.atsdr.cdc.gov/toxprofiles/tp2.pdf

[83] N. E. Lauer, J. C. Hower, H. Hsu-Kim, R. K. Taggart, and A. Vengosh, “Naturally occurring radioactive materials in coals and coal combustion residuals in the United States,” *Environmental science & technology*, vol. 49, no. 18, pp. 11 227–11 233, 2015.

[84] F. Ogundare and O. Adekoya, “Gross alpha and beta radioactivity in surface soil and drinkable water around a steel processing facility,” *Journal of Radiation Research and App. Sciences*, vol. 8, no. 3, pp. 411–417, 2015.

[85] ASTDR. (2012) Toxicological profile: Manganese. [Online]. Available: http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=102&tid=23

[86] ATSDR. (2010) Toxicological profile: Boron. [Online]. Available: http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=453&tid=80

[87] EPA. (2016) Drinking water contaminant human health effects information. [Online]. Available: https://www.epa.gov/dwstandardsregulations/drinking-water-contaminant-human-health-effects-information

[88] EIP. (2015) Ashtracker. [Online]. Available: http://ashtracker.org/

[89] EPA, “Regulatory impact analysis for the final mercury and air toxics standards,” U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Health and Environmental Impacts Division, Research Triangle Park, NC, Tech. Rep. EPA-452/R-11-011, 2011.

[90] NIH. (2016) Dioxins. [Online]. Available: https://www.niehs.nih.gov/health/topics/agents/dioxins/

[91] Tennessee Valley Authority, "Regulatory submittal for Kingston fossil plant," U.S. Environmental Protection Agency, Tech. Rep., 2009. [Online]. Available: https://archive.epa.gov/pesticides/region4/kingston/web/pdf/approved-offsite-ash-disposal-options-plan.pdf

[92] J. M. Norton, S. Wing, H. J. Lipscomb, J. S. Kaufman, S. W. Marshall, and A. J. Cravey, "Race, wealth, and solid waste facilities in North Carolina," *Environmental Health Perspectives*, pp. 1344–1350, 2007.

[93] EIA, "Natural gas 1998: Issues and trends," U.S. Energy Information Administration, Tech. Rep., 1999. [Online]. Available: http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/natural_gas_1998_issues_trends/pdf/it98.pdf

[94] P. L. Spath and M. K. Mann, "Life cycle assessment of a natural gas combined-cycle power generation system," National Renewable Energy Laboratory, Tech. Rep., 2000.

[95] M. D. Avakian, B. Dellinger, H. Fiedler, B. Gullet, C. Koshland, S. Marklund, G. Oberdörster, S. Safe, A. Sarofim, K. R. Smith *et al.*, "The origin, fate, and health effects of combustion by-products: a research framework." *Environmental Health Perspectives*, vol. 110, no. 11, p. 1155, 2002.

[96] EPA. (2016) Enforcement and compliance history online. [Online]. Available: https://echo.epa.gov/?redirect=echo

[97] M. L. Bell, R. D. Peng, and F. Dominici, "The exposure-response curve for ozone and risk of mortality and the adequacy of current ozone regulations," *Environmental Health Perspectives*, pp. 532–536, 2006.

[98] M. Jerrett, R. T. Burnett, C. A. Pope III, K. Ito, G. Thurston, D. Krewski, Y. Shi, E. Calle, and M. Thun, "Long-term ozone exposure and mortality," *New England Journal of Medicine*, vol. 360, no. 11, pp. 1085–1095, 2009.

[99] J. Kim, H. Kim, and J. Kweon, "Hourly differences in air pollution on the risk of asthma exacerbation," *Environmental Pollution*, vol. 203, pp. 15–21, 2015.

[100] A. M. Neophytou, M. J. White, S. S. Oh, N. Thakur, J. M. Galanter, K. K. Nishimura, M. Pino-Yanes, D. G. Torgerson, C. R. Gignoux, C. Eng *et al.*, "Air pollution and lung function in minority youth with asthma in the GALA II & SAGE II studies," *American Journal of Respiratory and Critical Care Medicine*, 2016.

[101] J. De Gouw, D. Parrish, G. Frost, and M. Trainer, "Reduced emissions of CO2, NOx, and SO2 from US power plants owing to switch from coal to natural gas with combined cycle technology," *Earth's Future*, vol. 2, no. 2, pp. 75–82, 2014.

[102] X. Zhu, Y. Liu, Y. Chen, C. Yao, Z. Che, and J. Cao, "Maternal exposure to fine particulate matter (PM2. 5) and pregnancy outcomes: a meta-analysis," *Environmental Science and Pollution Research*, vol. 22, no. 5, pp. 3383–3396, 2015.

[103] M. A. Shepherd, G. Haynatzki, R. Rautiainen, and C. Achutan, "Estimates of community exposure and health risk to sulfur dioxide from power plant emissions using short-term mobile and stationary ambient air monitoring," *Journal of the Air & Waste Management Association*, vol. 65, no. 10, pp. 1239–1246, 2015.

[104] ASTDR. (1998) Toxicological profile: Sulfur dioxide. [Online]. Available: Available:http://www.atsdr.cdc.gov/toxprofiles/tp116.pdf

[105] G. M. Ghanbari, B. Heibati, K. Naddafi, I. Kloog, C. G. Oliveri, R. Polosa, and M. Ferrante, "Evaluation of chronic obstructive pulmonary disease (COPD) attributed to atmospheric O3, NO2, and SO2 using Air Q model (2011-2012 year)," *Environmental Research*, vol. 144, no. Pt A, pp. 99–105, 2015.

[106] C. Amancio and L. Nascimento, "Association of sulfur dioxide exposure with circulatory system deaths in a medium-sized city in Brazil," *Brazilian Journal of Medical and Biological Research*, vol. 45, no. 11, pp. 1080–1085, 2012.

[107] H. Gong, P. A. Lachenbruch, P. Harber, and W. S. Linn, "Comparative short-term health responses to sulfur dioxide exposure and other common stresses in a panel of asthmatics," *Toxicology and Industrial Health*, vol. 11, no. 5, pp. 467–487, 1995.

[108] J. Balmes and J. Fine, "Symptomatic bronchoconstriotion after short-term inhalation of sulfur dioxide," *Journal of Occupational and Environmental Medicine*, vol. 31, no. 4, pp. 302–314, 1989.

[109] A. G. Barnett, G. M. Williams, J. Schwartz, A. H. Neller, T. L. Best, A. L. Petroeschevsky, and R. W. Simpson, "Air pollution and child respiratory health: a case-crossover study in Australia and New Zealand," *American Journal of Respiratory and Critical Care Medicine*, vol. 171, no. 11, pp. 1272–1278, 2005.

[110] R. T. van Strien, J. F. Gent, K. Belanger, E. Triche, M. B. Bracken, and B. P. Leaderer, "Exposure to NO2 and nitrous acid and respiratory symptoms in the first year of life," *Epidemiology*, vol. 15, no. 4, pp. 471–478, 2004.

[111] J. Heinrich, E. Thiering, P. Rzehak, U. Krämer, M. Hochadel, K. M. Rauchfuss, U. Gehring, and H.-E. Wichmann, "Long-term exposure to NO2 and PM10 and all-cause and cause-specific mortality in a prospective cohort of women," *Occupational and Environmental Medicine*, 2012.

[112] P. E. Sheffield, J. Zhou, J. L. C. Shmool, and J. E. Clougherty, "Ambient ozone exposure and children's acute asthma in New York City: a case-crossover analysis," *Environmental Health*, vol. 14, no. 1, p. 25, 2015.

[113] M. Choi, F. C. Curriero, M. Johantgen, M. E. C. Mills, B. Sattler, and J. Lipscomb, "Association between ozone and emergency department visits: an ecological study," *International Journal of Environmental Health Research*, vol. 21, no. 3, pp. 201–221, 2011.

[114] J. I. Halonen, T. Lanki, P. Tiittanen, J. V. Niemi, M. Loh, and J. Pekkanen, "Ozone and cause-specific cardiorespiratory morbidity and mortality," *Journal of Epidemiology and Community Health*, 2009.

[115] M. L. Bell, A. McDermott, S. L. Zeger, J. M. Samet, and F. Dominici, "Ozone and short-term mortality in 95 US urban communities, 1987-2000," *JAMA*, vol. 292, no. 19, pp. 2372–2378, 2004.

[116] EH&E, "Emission of hazardous air pollutants from coal-fired power plants," Environmental Health & Engineering, for the American Lung Association, Needham, MA, Tech. Rep., 2011.

[117] WHO. (1946) Constitution of the world health organization. [Online]. Available: http://apps.who.int/gb/bd/PDF/bd47/EN/constitution-en.pdf?ua=1

[118] E. D. Amster, M. Haim, J. Dubnov, and D. M. Broday, "Contribution of nitrogen oxide and sulfur dioxide exposure from power plant emissions on respiratory symptom and disease prevalence," *Environmental Pollution*, vol. 186, pp. 20–28, 2014.

[119] EPA, "National emission standards for hazardous air pollutants from coal- and oil-fired electric utility steam generating units and standards of performance for fossil-fuel-fired electric utility, industrial-commercial-institutional, and small industrial-commercial-institutional steam generating units," U.S. Environmental Protection Agency, Tech. Rep., 2012. [Online]. Available: https://www.gpo.gov/fdsys/pkg/FR-2012-02-16/pdf/2012-806.pdf

[120] EPA, "User's manual for the Co-Benefits Risk Assessment (COBRA) screening model version: 2.61," U.S. Environmental Protection Agency, Washington, DC, Tech. Rep., 2014.

[121] N. Z. Muller, R. Mendelsohn, and W. Nordhaus, "Environmental accounting for pollution in the United States economy," *The American Economic Review*, pp. 1649–1675, 2011.

[122] NRC, "Hidden costs of energy: Unpriced consequences of energy production and use," National Research Council, Washington, DC, Tech. Rep., 2010. [Online]. Available: http://www.nap.edu/catalog/12794/hidden-costs-of-energy-unpriced-consequences-of-energy-production

[123] R. Wiser, G. Barbose, J. Heeter, T. Mai, L. Bird, M. Bolinger, A. Carpenter, G. Heath, D. Keyser, J. Macknick *et al.*, "A retrospective analysis of the benefits and impacts of US renewable portfolio standards," Lawrence Berkeley National Laboratory and National Renewable Energy Laboratory, Tech. Rep. NREL/TP-6A20-65005, 2016.

[124] H. Cai, M. Wang, A. Elgowainy, and J. Han, "Updated greenhouse gas and criteria air pollutant emission factors and their probability distribution functions for electricity generating units," Argonne National Laboratory, Tech. Rep., 2012.

[125] H. Cai, M. Wang, A. Elgowainy, and J. Han, "Updated greenhouse gas and criteria air pollutant emission factors of the US electric generating units in 2010," Tech. Rep., 2013.

[126] U. BLS, "Table 24. Historical consumer price index for all urban consumers (cpi-u): U. S. city average, all items," U.S. Bureau of Labor Statistics, Tech. Rep., February 2016. [Online]. Available: http://www.bls.gov/cpi/cpid1602.pdf

[127] D. Krewski, M. Jerrett, R. Burnett, R. Ma, E. Hughes, Y. Shi, M. Turner, C. Pope III, G. Thurston, E. Calle *et al.*, *Extended Follow-up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality*. Health Effects Institute, 2009.

[128] J. Lepeule, F. Laden, D. Dockery, and J. Schwartz, "Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009," *Environmental Health Perspectives*, vol. 120, no. 7, p. 965, 2012.

[129] C. A. Hornbeck, J. Kollman, T. J. Payne, and H. L. Sobotka, "The impact of chronic disease in Ohio: 2015," Ohio Department of Health, Tech. Rep., 2015.

[130] R. A. Alvarez, S. W. Pacala, J. J. Winebrake, W. L. Chameides, and S. P. Hamburg, "Greater focus needed on methane leakage from natural gas infrastructure," *Proceedings of the National Academy of Sciences*, vol. 109, no. 17, pp. 6435–6440, 2012.

[131] G. Myhre, D. Shindell, F. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J. Lamarque, D. Lee, B. Mendoza *et al.*, "Anthropogenic and natural radiative forcing," *Climate Change*, vol. 423, 2013.

[132] P. Gagnon, R. Margolis, J. Melius, C. Phillips, and R. Elmore, "Rooftop solar photovoltaic technical potential in the United States: A detailed assessment," National Renewable Energy Laboratory, Tech. Rep., 2016.

[133] A. Brown, P. Beiter, D. Heimiller, C. Davidson, P. Denholm, J. Melius, A. Lopez, D. Hettinger, D. Mulcahy, and G. Porro, "Estimating renewable energy economic potential in the United States: Methodology and initial results," National Renewable Energy Laboratory, Tech. Rep., 2015.

[134] E. M. Krieger, J. A. Casey, and S. B. Shonkoff, "A framework for siting and dispatch of emerging energy resources to realize environmental and health benefits: Case study on peaker power plant displacement," *Energy Policy*, vol. 96, pp. 302–313, 2016.

Appendix .1. Additional figures

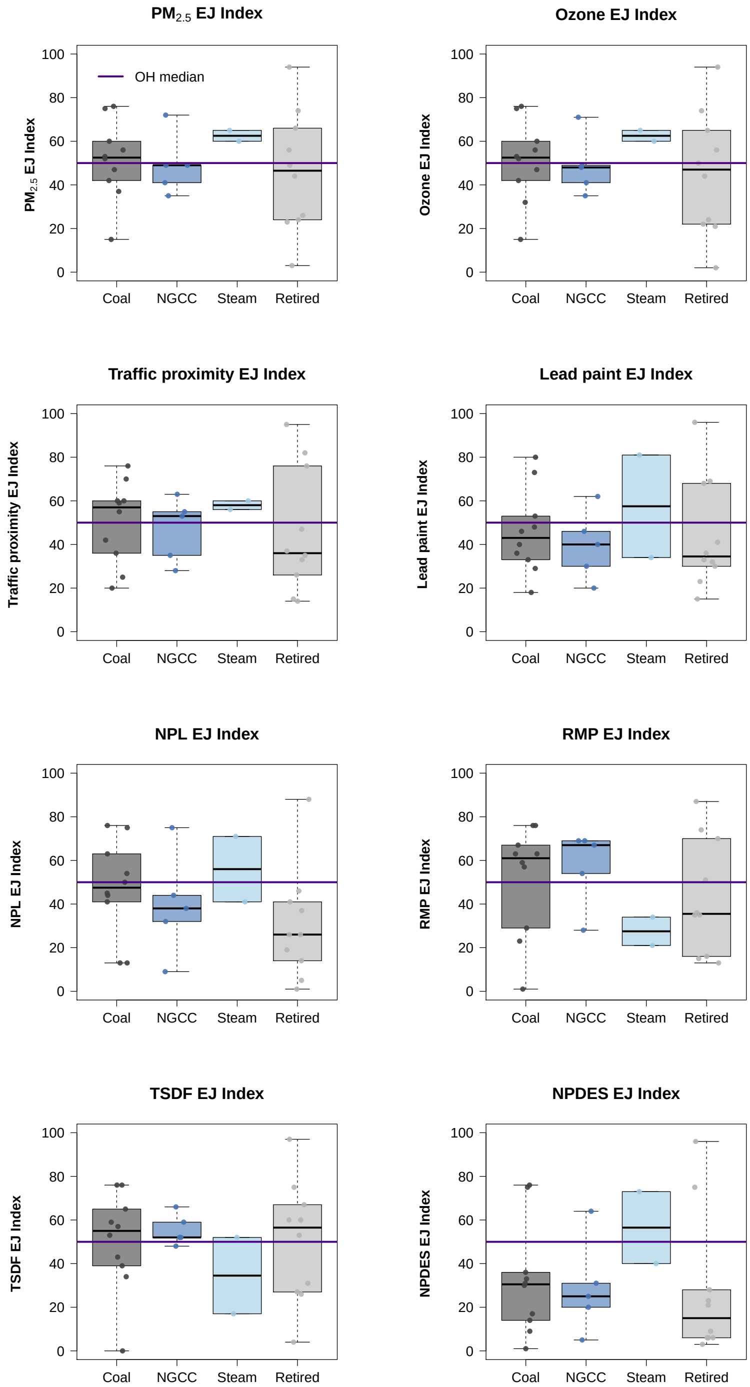


Figure 1: Box plot of EPA environmental justice indices for environmental indicators in regions near power plants. The EJ Index gives a demographically-weighted value for each indicator. Purple line indicates state median. Indicators include average 24-hour $PM_{2.5}$ concentration, average 8-hour ozone concentration, traffic proximity, lead paint in houses, national priorities list (Superfund) sites (NPL), facilities with chemical risk management plans (RMP), hazardous waste, treatment and disposal facilities (TSDF), and National Pollutant Discharge Elimination System sites reflecting water discharges (NPDES).

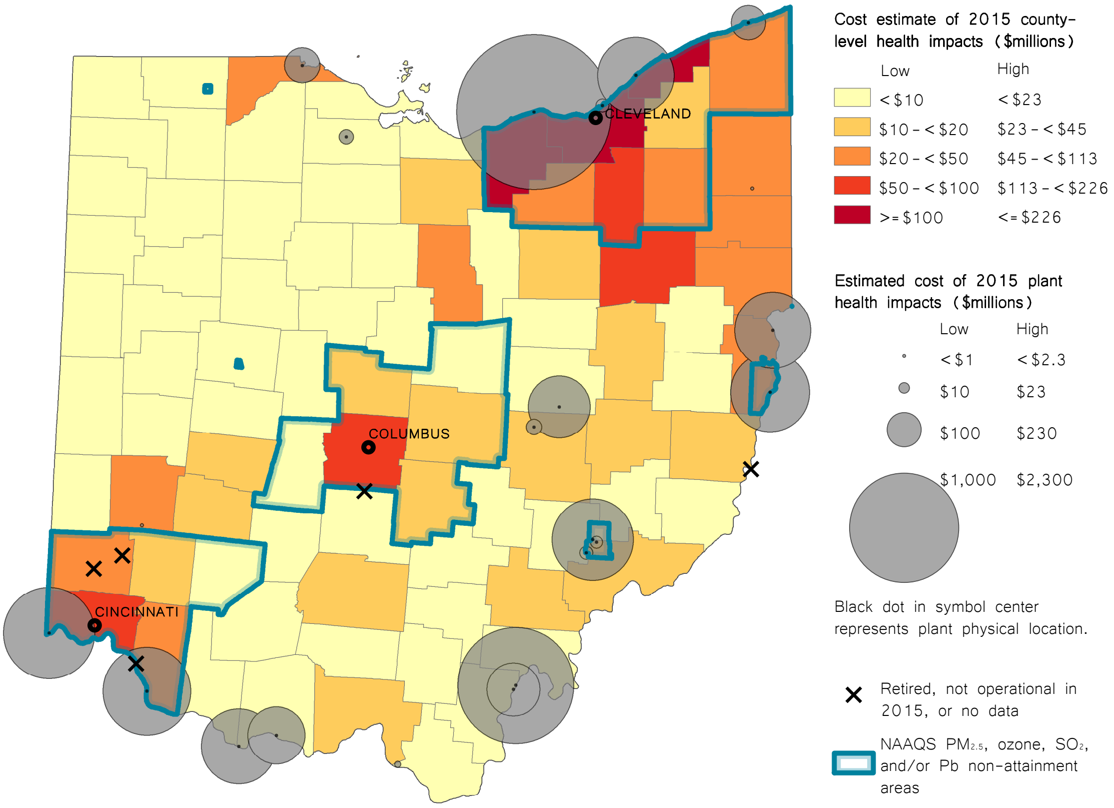


Figure 2: Costs of health impacts from Ohio power plants, by county.

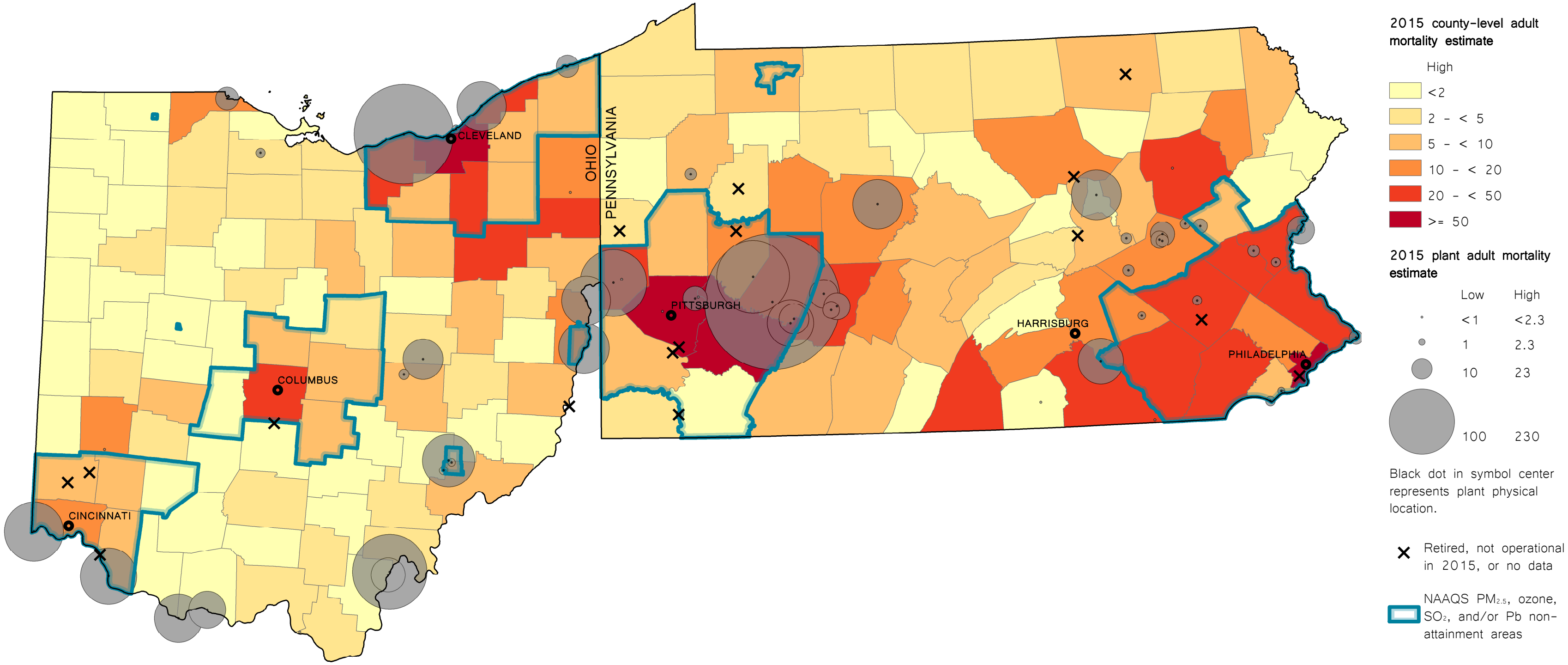


Figure 3: $PM_{2.5}$ mortality impact estimates, by county, associated with combined Ohio and Pennsylvania power plant emissions in 2015. Circle size represents nationwide mortality impacts from each plant. Blue outlines indicate regions where air quality is designated as non-attainment under NAAQS.

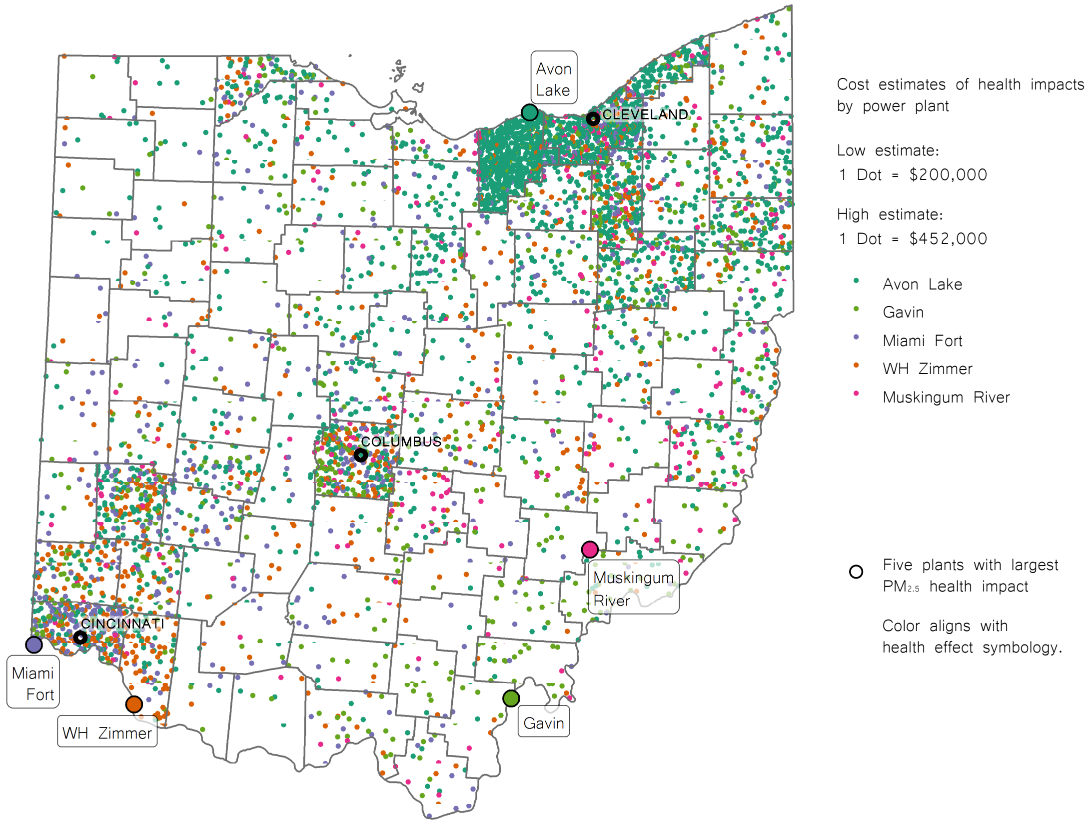


Figure 4: Dot map of health burden costs for five high impact plants, by county. Dots represent intensity of health impacts, not individual incidents.

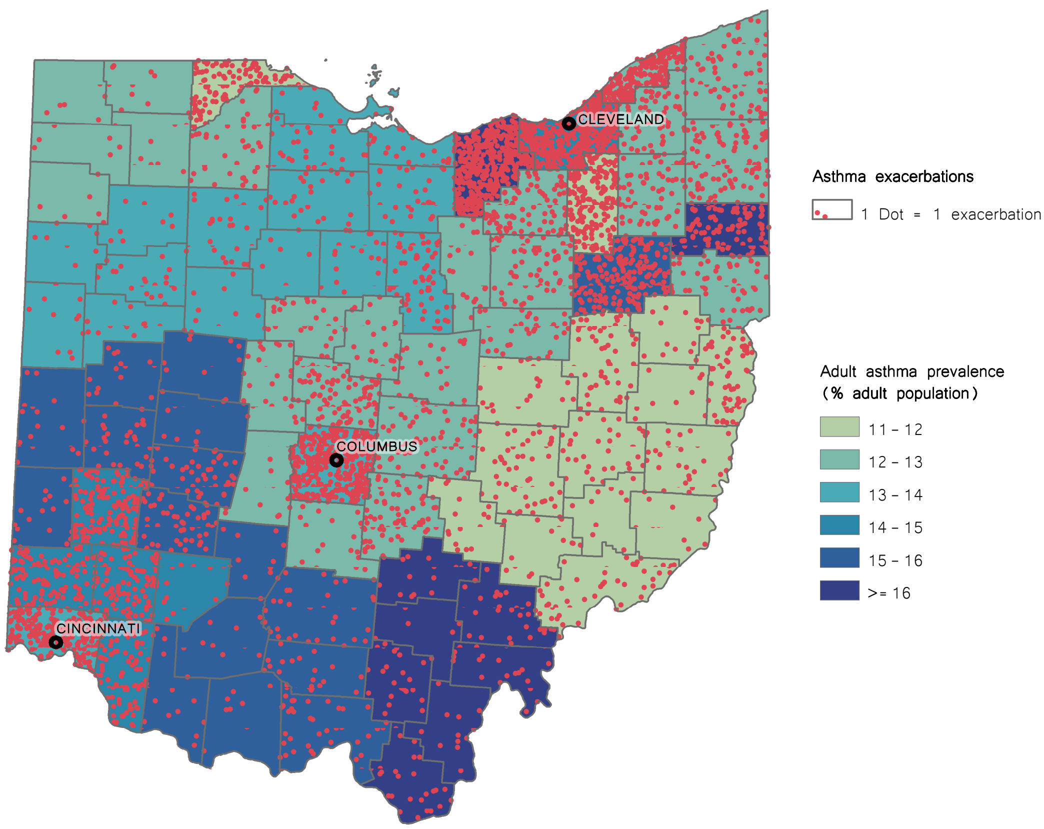


Figure 5: Asthma prevalence and total asthma exacerbations, by county.

Appendix .2. Reference tables

Table 1: Cross-reference for power plant names used in this report.

ORISPL ID	Report name	Clean Power Plan name
2835	Ashtabula	FirstEnergy Ashtabula
2836	Avon Lake	Avon Lake
2878	Bay Shore	FirstEnergy Bayshore
2828	Cardinal	Cardinal
2840	Conesville	Conesville
55350	Dresden	Dresden Energy Facility
2837	Eastlake	FirstEnergy Eastlake
55701	Fremont	Fremont Energy Center
8102	Gavin	General James M Gavin
2917	Hamilton	Hamilton
55736	Hanging Rock	Hanging Rock Energy Facility
2850	JM Stuart	JM Stuart
6031	Killen	Killen Station
2876	Kyger Creek	Kyger Creek
2838	Lake Shore	FirstEnergy Lake Shore
2832	Miami Fort	Miami Fort
57822	Middletown Coke	Middletown Coke Company LLC
2872	Muskingum River	Muskingum River
2861	Niles	Niles
2848	OH Hutchings	OH Hutchings
2843	Picway	Picway
2864	RE Burger	FirstEnergy R E Burger
55397	Washington	Washington Energy Facility
55503	Waterford	AEP Waterford Facility
2830	WC Beckjord	Walter C Beckjord
2866	WH Sammis	FirstEnergy W H Sammis
6019	WH Zimmer	W H Zimmer
	Report name	**Ohio Power Siting Board name**
	Carroll County	Carroll County Energy Generation Facility
	Lordstown	Clean Energy Future–Lordstown
	Middletown Energy	Middletown Energy Center
	Oregon	Oregon Clean Energy Center
	Rolling Hills	Rolling Hills Generating Station Combined-Cycle Conversion
	South Field	South Field Energy

Table 2: Indicators, sources and data years used in screening analysis.

Indicator name	Type	Description	Source	Data years
Minority	Demographic	Percent of population other than white, non-hispanic	EJSCREEN, ACS, US Census	2008-2012
Low income	Demographic	Percent of population in households with income below or equal to twice the federal poverty level	EJSCREEN, ACS, US Census	2008-2012
Less than high school	Demographic	Percent of population over age 25 without a high school diploma	EJSCREEN, ACS, US Census	2008-2012
Linguistic isolation	Demographic	Percent of population in households where those over age 14 speak a language other than English and speak English less than "very well"	EJSCREEN, ACS, US Census	2008-2012
Under age 5	Demographic	Percent of population under age 5	EJSCREEN, ACS, US Census	2008-2012
Over age 64	Demographic	Percent of population over age 64	EJSCREEN, ACS, US Census	2008-2012
Low birthweight	Health	Percent of babies born below 2500 g	ACS	2008-2012
Disability	Health	Percent of population with one or more of six difficulties: hearing, vision, cognitive, ambulatory, self-care, or independent living	ACS	2008-2012
Cancer prevalence	Health	Percent of population with a cancer diagnosis of any kind	ACS	2012
Adult uninsurance	Health	Percent of adult population over 18 without health insurance	ACS	2008-2012
Asthma	Health	Percent of adults reporting they currently have asthma	OH Dept. Health	2012-2014

Table 3: Indicators, sources and data years used in screening analysis.

Indicator name	Type	Description	Source	Data years
Average $PM_{2.5}$	Environmental	Annual average $PM_{2.5}$ in $\mu g/m^3$	EJSCREEN	2011
Average ozone	Environmental	Summer average 8-hour ozone concentration in ppb	EJSCREEN	2011
Traffic proximity	Environmental	Count of vehicles at major roads within 500m divided by m	EJSCREEN	2011
Lead paint	Environmental	Percent of housing built before 1960	EJSCREEN	2008-2012
RMP Proximity	Environmental	Count of facilities with Risk Management Plans (RMP) for chemical spills within 5km, divided by km	EJSCREEN	2013
TSDF Proximity	Environmental	Count of hazardous waste treatment, storage and disposal facilities (TSDF) within 5km, divided by km	EJSCREEN	2013
NPL Proximity	Environmental	Count of proposed or listed National Priorities list (NPL) sites, Superfund program, within 5km, divided by 5 km	EJSCREEN	2013
NPDES Proximity	Environmental	Count of major direct water dischargers in National Pollutant Discharge System (NPDES) within 5km, divided by 5km	EJSCREEN	2013
$PM_{2.5}$ exceedances	Environmental	Number of days $PM_{2.5}$ exceeded 35 $\mu g/m^3$ 2013-2015	EPA	2013-2015
Ozone exeedances	Environmental	Number of days ozone exceeded 70 ppb in air management district 2013-2015	EPA	2013-2015
NAAQS non-attainment	Environmental	Designated non-attainment area for 2008 ozone, 2012 $PM_{2.5}$, or 2010 SO_2 standard under NAAQS	EPA	Multiple

Table 4: Estimated $PM_{2.5}$ health burden from highest impact Ohio power plants, 2015 (COBRA high model unless otherwise indicated).

Health impact	Avon Lake	Gavin	Miami Fort	WH Zimmer	Muskingum River	Cardinal	Eastlake	WH Sammis	JM Stuart	Conesville
$Millions health burden (high)	4,498	2,521	1,581	1,446	1,245	1,171	1,100	1,083	1,059	729
$Millions health burden (low)	1,989	1,115	699	639	551	518	487	479	468	322
$Millions health burden (AP2)	1,407	659	670	473	352	340	222	302	283	340
Adult mortality (high)	526	295	185	169	146	137	129	127	124	85
Adult mortality (low)	232	130	82	75	64	61	57	56	55	38
Non-fatal heart attacks (high)	270	150	96	87	74	68	64	63	63	43
Non-fatal heart attacks (low)	29	16	10	9	8	7	7	7	7	5
Respiratory hosp. admissions	67	38	24	22	18	17	16	15	16	11
Cardiovascular hosp. admissions	85	47	30	27	23	21	20	20	20	14
Acute bronchitis	312	176	115	104	86	79	73	73	74	50
Upper respiratory symptoms	5,681	3,213	2,097	1,901	1,574	1,445	1,332	1,332	1,344	918
Lower respiratory symptoms	3,975	2,248	1,460	1,331	1,102	1,011	932	932	943	643
Asthma ER visits	130	71	44	40	35	33	31	30	29	20
Minor restricted activity days	164,715	93,923	58,864	53,690	46,179	42,608	38,986	39,317	38,814	26,697
Work loss days	57,509	15,709	9,853	8,985	7,719	7,116	6,500	6,566	6,490	4,461
Asthma exacerbations	6,033	3,411	2,211	2,014	1,672	1,536	1,414	1,416	1,425	975