The Clean Power Plan in Pennsylvania

Analyzing power generation for health and equity

Prepared for NextGen Climate America
by PSE Healthy Energy

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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

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Contact

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

Executive summary

The Clean Power Plan provides Pennsylvania 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 the Clean Power Plan. We first assess the socioeconomic and environmental health burdens and hazards for populations living near plants regulated under the Clean Power Plan. We then model the potential public health impacts of fine particulate matter attributable to combustion at Pennsylvania's power plants. Our findings point to where carbon emission reductions may have the greatest public health benefits, and help identify where increased or decreased power generation may add to or alleviate burdens on vulnerable communities.

The Environmental Protection Agency's (EPA) Clean Power Plan 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, the geographic and demographic distribution and the scale of these benefits may vary widely depending on the manner in which these carbon dioxide (CO_2) emissions standards are implemented in each state.

Historically, power generation has been associated with numerous environmental health burdens that disproportionately affect vulnerable and already overburdened communities. Power plants are often located near low income and minority populations, which are both more likely to experience a cumulative burden of multiple socioeconomic and environmental stressors, such as poor air quality and proximity to hazardous waste facilities, and to be more susceptible to experiencing 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 suggests that states consider the emissions of multiple pollutants beyond CO_2 when developing their Clean Power Plan compliance approach.

The Clean Power Plan gives states 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. The EPA provided an initial analysis of the nationwide public health benefits from reductions in co-pollutant emissions under the Clean Power Plan [1], along with an initial proximity analysis of populations living within three miles of regulated power plants to identify potentially vulnerable and overburdened communities [2]. In this report, we model the regional health burden associated with emissions from each power plant covered by the Clean Power Plan in Pennsylvania 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 fine particulate matter ($PM_{2.5}$) attributable to Pennsylvania power plant emissions is responsible for thousands of premature deaths a year and tens of thousands of incidents of respiratory symptoms, asthma exacerbations and other health effects. The majority of these particulate matter health impacts are attributed to coal plants. **Reducing CO_2 emissions in Pennsylvania 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. Pennsylvania power plants are located disproportionately in low income and minority communities, particularly natural gas combined cycle plants. Populations living near many of these plants are further burdened by multiple socioeconomic, health and environmental stressors. **Increasing use of existing natural gas combined cycle plants for Clean Power Plan compliance may increase generation and associated hazards near already overburdened and vulnerable communities. Renewables and energy efficiency do not carry that same risk, and can help to displace existing fossil fuel pollution.**

3. Pennsylvania power plants are associated with numerous environmental health hazards in nearby communities in addition to their air pollution impacts. Examples include coal ash impoundments at coal plants, and higher rates of environmental statute violations at natural gas combined cycle plants—particularly near state-designated Environmental Justice Areas. **Engagement with local communities can give insight into these and other environmental health concerns near power plants that may be ameliorated by reduced fossil reliance under the Clean Power Plan.**

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

1. 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, and recently retired).

2. We analyze specific environmental health hazards at power plants, including coal ash impoundments, toxic releases on- and off-site, groundwater well-monitoring, and power plant compliance, including violations of federal environmental statutes.

3. We analyze historic 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 Pennsylvania 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 are in many cases burdened with a disproportionate share of environmental health hazards, such as proximity to traffic and hazardous facilities, and have a larger share of socioeconomic and health vulnerabilities, such as large low income populations and high disability prevalence. These vulnerabilities, combined with other environmental stressors, are associated with these populations being more susceptible to impacts from exposures to environmental hazards attributable to power plants. While exposure to primary and secondary air pollutants from power generation affects populations over hundreds of miles, the scientific literature suggests that populations that live near all types of fossil generation sites are at higher risk of experiencing adverse health outcomes [3, 4, 5, 6, 7].

Building on the EPA 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.). Demographic measures of populations living within three miles of each power plant class, including percent low income and minority, are shown in **Figure 1**.

Our results indicate that populations living within three miles of both coal and natural gas power plants subject to the Clean Power Plan have a larger percentage of low income residents than either the state median or the state average and this trend is most pronounced for natural gas combined cycle plants. Populations within three miles of natural gas combined cycle plants have a five times larger share of racial/ethnic minority residents than the state median. These populations are 44% minority, compared to a state median of 9% and state average of 21%. Furthermore, **half of the affected power plants are located within three miles of a region designated as an Environmental Justice Area by the Pennsylvania Department of Environmental Protection** (PA DEP) [8].

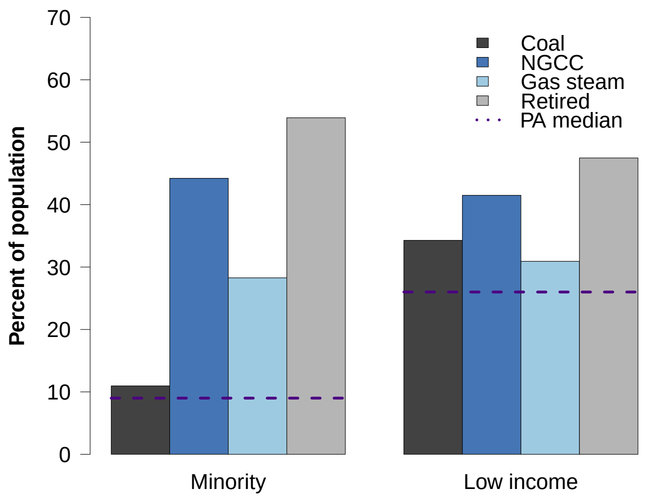

Figure 1: Demographics of populations that live within three miles of Clean Power Plan subject power plants, compared to the state median.

This report creates an aggregate demographic, environmental and health index by averaging percentile rankings for eighteen different indicators (e.g. low income, access to health care, air quality) to reflect cumulative burden for populations living near affected power plants (the "Cumulative Vulnerability Index"). This aggregate metric, shown for the 15 highest-ranking plants in **Figure 2**, reveals that four of the five power plants that rank highest for cumulative vulnerability of adjacent communities are natural gas combined cycle (the fifth has retired since the EPA baseline year of 2012).

Our 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 rulemaking. Ideally, it will also be used to inform approaches to decrease environmental hazard and human health impact burdens on these populations. **A State Plan that relies on increasing electricity generation at existing natural gas plants, rather than replacing coal generation with energy efficiency or renewable generation, for example, may have the potential to increase the utilization of plants located near disproportionately low income and minority populations.**

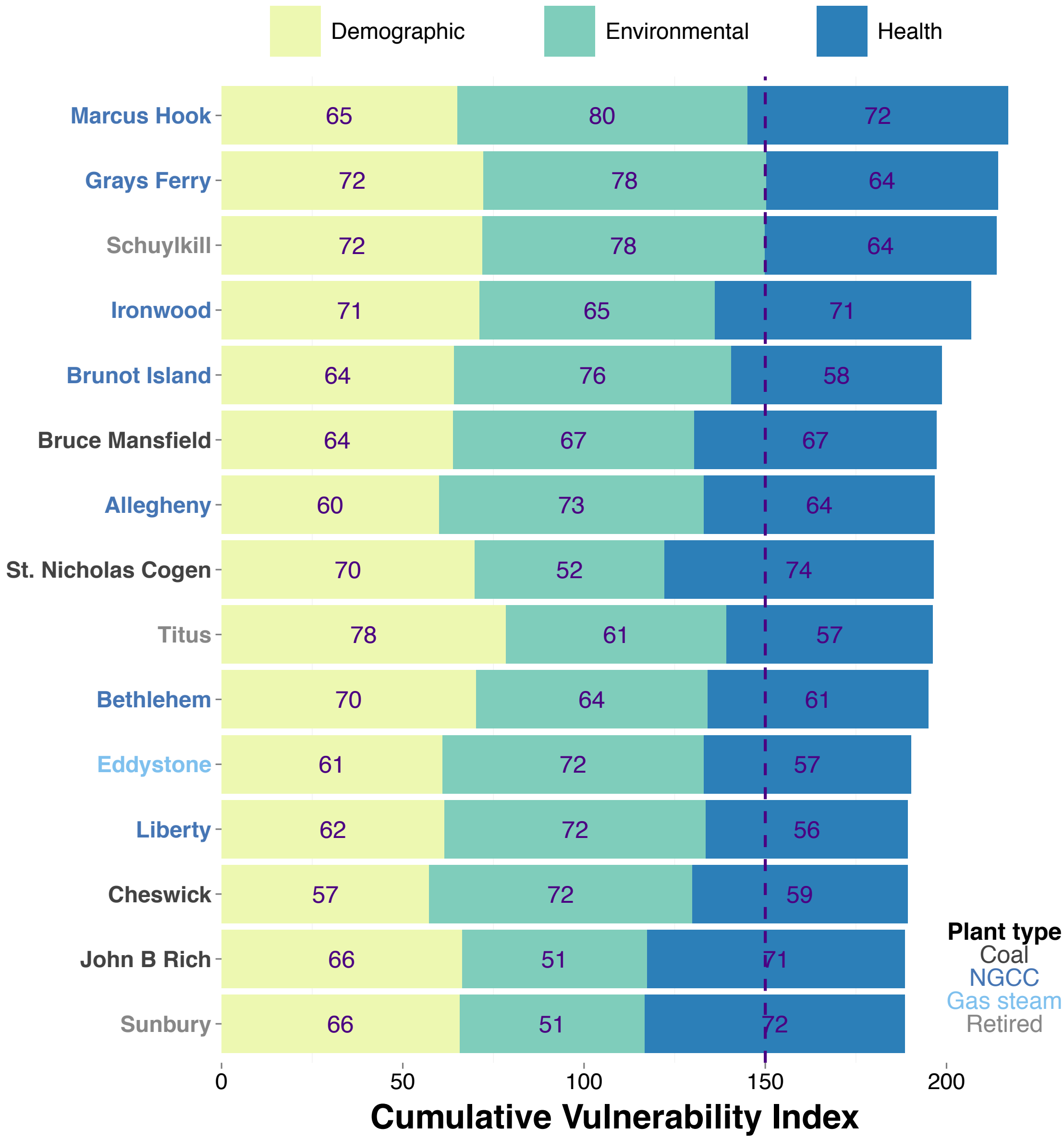

Figure 2: Cumulative Vulnerability Index reflecting aggregate demographic, environmental and health burdens for populations living within three miles of the 15 highest-ranked power plants. A median score on all indicators would give an Index score of 150 (purple dashed line). 14 of these plants (all except Sunbury) are located within three miles of a state-designated Environmental Justice Area.

Table 1: Inspections and violations of federal environmental statutes, 2011-2015. Total violations/inspections and average number of violations/inspections per plant near (< 3 mi.) or not near (> 3 mi.) an Environmental Justice (EJ) Area. 2015 or prior retired plants excluded.

	Total 2011-2015	Average per plant	Average per EJ Area plant	Average per non-EJ Area plant
VIOLATIONS				
Coal	58	2.42	2.80	2.14
NGCC	43	2.69	4.22	0.71
Gas steam	5	2.50	4.00	1.00
INSPECTIONS				
Coal	193	8.04	7.60	8.36
NGCC	62	3.88	5.11	2.29
Gas steam	14	7.00	9.00	5.00

This report also examines environmental health hazards at the sites of power plants subject to the Clean Power Plan by analyzing both power plant inspections and violations of federal statutes, including the Clean Air Act, the Clean Water Act, the Resource Conservation and Recovery Act, and the Safe Drinking Water Act. In our analysis, we find that the largest total number of violations is associated with coal plants, but the highest average number of violations per plant is associated with natural gas combined cycle plants, as shown in **Table 1**. This trend is exacerbated near Environmental Justice Areas, where natural gas combined cycle plants show a 1.5 times higher average number of violations than coal.

Compliance and violations

- Coal received more violations and inspections than other plants.
- Within three miles of a state-designated Environmental Justice Area, natural gas combined cycled plants had a 1.5 times higher rate of violations than coal plants.
- For violations received during a noncompliance period, 33% of natural gas combined cycle plants and 44% of coal plants received at least one violation for contamination.
- Inspection rates at plants near Environmental Justice Areas are nearly 1.5 times higher for coal than natural gas combined cycle.

Additionally, natural gas combined cycle plants received less than half the number of average inspections compared to coal. The environmental hazards associated with these violations could potentially be reduced or eliminated through reduced demand on these facilities under the Clean Power Plan. But these data also underscore the need for careful, consistent and more frequent inspections of power generation sites, especially in disproportionately vulnerable communities. **The majority of plants are located near low income populations, and similarly the total number of violations received between 2011-2015 were primarily in low income areas,** as shown in **Figure 3**. We find numerous human health hazards associated with coal plants in particular, including multiple plants with coal ash impoundments designated with a high hazard potential and/or poor structural integrity by EPA contractors. These results indicate elevated risks of groundwater and soil contamination, including at six plants in or near Environmental Justice Areas.

From well-monitoring data near coal ash impoundments, high levels of toxic releases of heavy metals, persistent bioaccumulative toxins and other health-harming contaminants were found to exceed allowable levels of lead, 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 impoundments' existence were not available, the use of wells for drinking water by rural residents is cause for concern with regards to exceedances above MCL and health advisory standards.

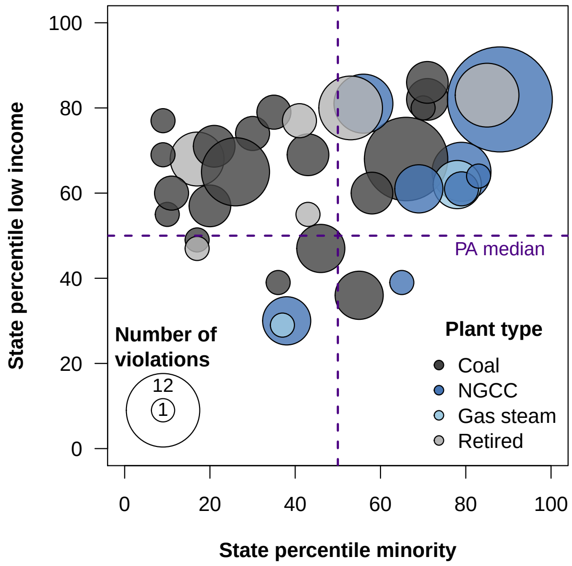

Figure 3: Total 2011-2015 violations for each plant (circle size) plotted by the state percentile for low income and minority populations of the surrounding community.

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 power plants or new power plants sited in vulnerable or historically burdened areas, there is a risk of increasing the burden 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 is needed to provide insight into whether demand, and associated health burdens, are likely to increase near any given population.

Air pollutant emissions and public health

Our models suggest that fine particulate matter ($PM_{2.5}$) attributable to Pennsylvania power plant emissions is responsible for thousands of premature deaths a year and tens of thousands of incidents of respiratory symptoms, asthma exacerbations and other health effects. Consideration of health-damaging criteria pollutants when developing carbon reduction strategies can help reduce or eliminate some of these health burdens. Such multi-pollutant 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 Pennsylvania 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 can contribute to a wide range of cardiovascular and respiratory health impacts, particularly among members of already-vulnerable populations (e.g. low income, minority, the elderly, and those with pre-existing diseases).

Power plants that burn coal waste have a higher rate of CO_2 emissions per MWh than any other plant class, a lower rate of NO_x emissions than non-waste burning coal plants, and relatively high rates of SO_2 emissions. 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 of emissions for all pollutants examined. 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 two different estimates of impacts (low and high) based on two different underlying epidemiological studies. We find that particulate matter associated with pollution from power plant operations in Pennsylvania in 2015 contributes to an estimated 1000 (low estimate) or 2300 (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 \$5.9 billion (AP2), \$8.9 billion (COBRA low estimate), and \$20 billion (COBRA high estimate). Approximately 90% of these $PM_{2.5}$ health impacts are attributable to the ten highest-impact plants.

The mortality estimates for each county are mapped in **Figure 4**. 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 level. Important to note is that 70% of the human health impacts from power generation occur outside of Pennsylvania—and similarly, electricity generation outside the state releases pollutant emissions that contribute to poor air quality in Pennsylvania. Finally, while the aggregate health impacts shown in **Figure 4** are heavily weighted 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.

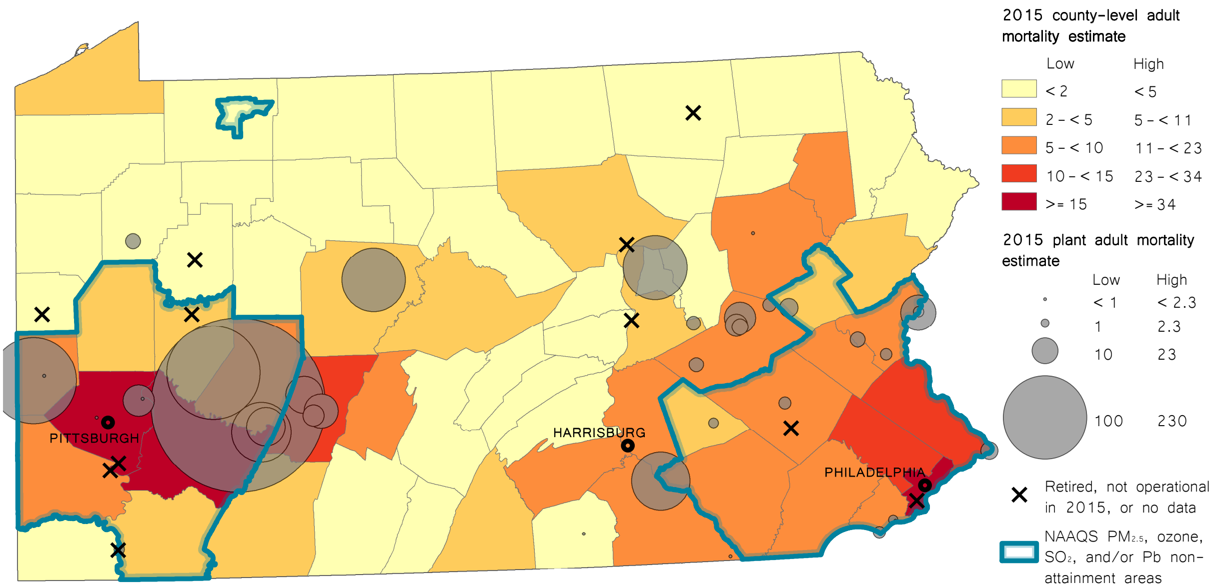

Figure 4: Modeled $PM_{2.5}$ mortality impacts by county from 2015 Pennsylvania power plant emissions. Circle size represents each plant's nationwide mortality impact (70% of which are out of state). Blue outlines indicate non-attainment areas for ozone, $PM_{2.5}$, SO_2 or lead under National Ambient Air Quality Standards.

We compare emissions totals and rates to health impacts in **Figures** 5a and 5b. In **Figure** 5a 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.

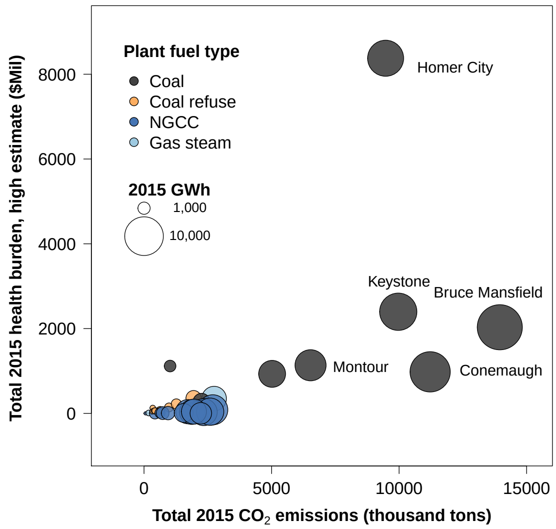

Figure 5a: 2015 cost of $PM_{2.5}$ health impacts from each power plant compared to total CO_2 emissions.

In **Figure** 5b we compare the rate of CO_2 emissions per MWh to the intensity of this health burden in cost per MWh. This plot highlights where an individual measure to reduce electricity generation may have the greatest climate and public health co-benefits. Our health burden modeling only assesses the health impacts of primary and secondary $PM_{2.5}$, but 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.

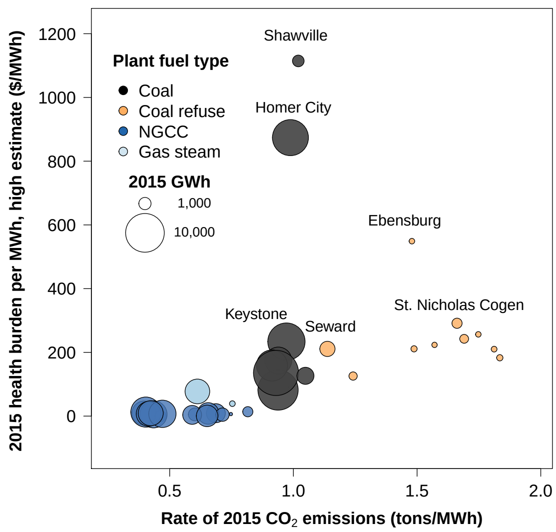

Figure 5b: Intensity of health impacts per MWh compared to intensity of CO2 emissions per MWh from each power plant in 2015.

Figure 5

Legacy from retired plants

The list of power plants covered by the Clean Power Plan includes nine power plants that were running in 2012, but which have since been retired, and more are expected to retire in coming years. Many of these retired plants have legacy environmental hazards, such as coal ash impoundments at two of these sites, and are located near vulnerable communities, highlighting a need for ongoing monitoring and careful assessment at sites under consideration for repowering with natural gas.

The communities living within three miles of these nine retired plants rank particularly high for multiple socioeconomic, health and environmental hazard burdens. 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 if retirements continue under the Clean Power Plan. 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.

Moving forward

Approaches to Clean Power Plan compliance that integrate health, environment and equity measures hold potential to mitigate climate change, improve public health, and alleviate disproportionate cumulative environmental burdens on vulnerable populations all at the same time.

A multi-pollutant strategy that simultaneously 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 Pennsylvania. Integration of climate, health, and equity factors will require careful consideration of the many dimensions of these issues, including considerations of aggregate versus per-capita power plant impacts and hazards, as well as where these impacts and hazards are disproportionately occurring.

There are many potential strategies for Clean Power Plan compliance. These approaches could include shifting the generation from coal to existing natural gas combined cycle plants, or increasing energy efficiency and ramping up generation from renewables like wind and solar, or a combination of these strategies. Given the presence of vulnerable communities near existing natural gas combined cycle generation, an emphasis on renewables and efficiency, rather than increased 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 gas, and potentially provide tradable emission reductions in a regional compliance scheme.

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. Taken together, the data presented in this analysis provide a baseline of the environmental health and equity burdens associated with power generation in Pennsylvania and can be used to measure potential changes in these burdens when the state considers approaches to Clean Power Plan compliance and other energy regulations.

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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
EDDIE Enterprise Data Dissemination Informatics Exchange
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
MMBtu Million British Thermal Units
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 nitrogen 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 Plant Location
PA DEP Pennsylvania Department of Environmental Protection
PAH polycyclic aromatic hydrocarbon
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 Pennsylvania. 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 [2, 9, 10]. These plants are also often associated with the production and on-site disposal of toxic and hazardous contaminants [11], and studies have found that living near plants is associated with elevated incidence of poor health outcomes [4, 5, 7]. 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 [12, 13]. 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 [13, 14, 15, 16]. 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 [17], which frequently have the least resilience to adapt to a changing climate [18].

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 [19]. 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 [2, 20], 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 a Pennsylvania 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 Pennsylvania. 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 Pennsylvania 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 Pennsylvania.

2. Background: Pennsylvania 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 [19]:

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 Pennsylvania, the power sector is the largest contributor to statewide greenhouse gas emissions [24] and includes some of the largest point sources of criteria air pollutants in the United States [25]. Pennsylvania has been directed under the Clean Power Plan to reduce the emission rate of CO_2 from affected electricity generation by one third from the 2012 rate (1,642 lbs CO_2/MWh to 1,095 lbs CO_2/MWh) [19, 26]. The total mass (lbs) of CO_2 emissions is expected to fall by approximately 23%, 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 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.

[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% [21]. Lifecycle methane emissions from the natural gas sector are more uncertain but high rates of leakage above production fields (see: [22, 23]) may greatly erode climate benefits of switching from coal to natural gas.

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

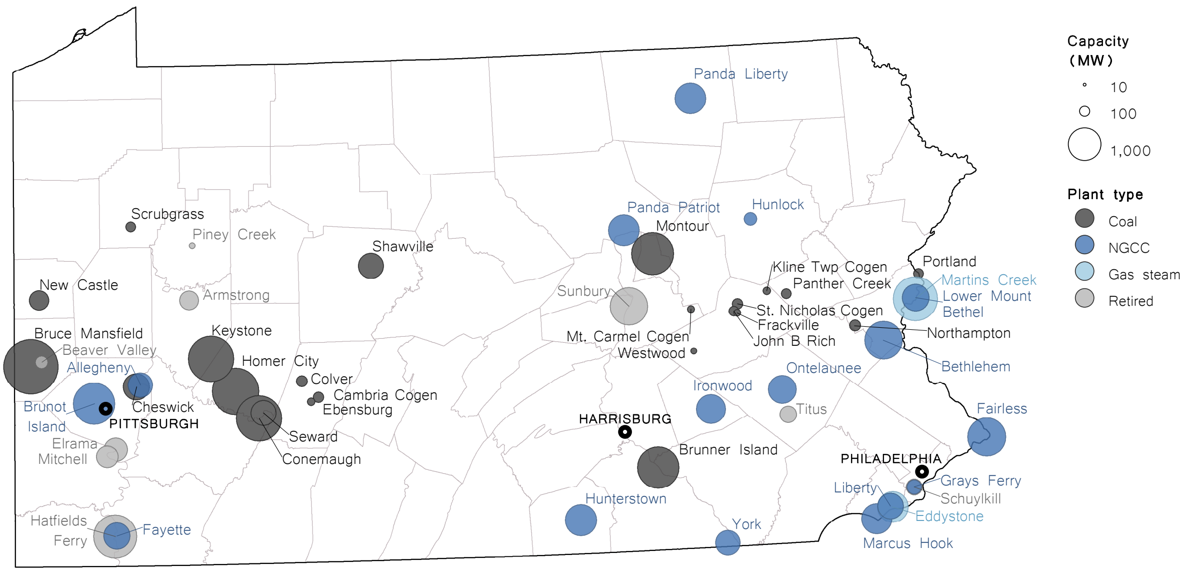

Figure 2.1: Map of power plants in Pennsylvania regulated by the Clean Power Plan. Classification reflects plant status at the end of 2015. Circle size is proportional to plant capacity in MW.

The Clean Power Plan covers all generation from in-state regulated plants, even for electricity net-exporter states like Pennsylvania. Fifty plants fall under the Clean Power Plan in Pennsylvania, including 31 coal plants, 16 NGCC plants,[3] and three fossil steam plants.[4] Since 2012, eight of the CPP-regulated coal plants and one fossil steam plant have retired;[5] a few of these sites are under consideration for repowering as NGCC plants. **Figure 2.1** shows a map of all of the plants covered by the Clean Power Plan in Pennsylvania, their capacity in megawatts (MW), and classification at the end of 2015 (coal, NGCC, fossil steam, or retired)[6] (data source: [28, 29]). 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 and subsequent name changes.

Net generation in Pennsylvania by fuel type, from the years 2012 to 2015, is shown in **Figure 2.2**.[7] Coal provided 39% of electricity generation in Pennsylvania in 2012, but dropped to 30% by 2015. Natural gas generation increased from 24% to 28%, and nuclear generation from 34% to 37%, during this same time period. The remainder of the energy generation mix is made up primarily of wind, hydropower, biomass, and some petroleum liquids and coke (data source: [30]).

Current power generation in Pennsylvania contributes to poor air quality across the state through both primary pollutant emissions and secondary atmospheric formation of ozone

[3] Two of these natural gas plants, Panda Liberty and Panda Patriot, are slated to come on line in 2016 but as such do not have any historic generation or emission data associated with them.

[4] Fossil steam plants include both oil- and gas-fired steam plants, but the two remaining fossil steam plants in Pennsylvania are gas steam and referred to as such in the following text.

[5] An additional three coal plants are in some state of conversion, in one case only burning oil in 2015 (Portland) [29] and in another two cases likely undergoing conversion to NGCC (Shawville, New Castle) although the exact status could not be determined. We maintain the coal classification for these plants but note them when they arise.

[6] The power plant capacity is reflective of MW designated active by the EPA in 2012 [28]. We note that two plants (Portland, Shawville) are not expected to burn coal in 2016; Portland is running primarily on oil and Shawville is expected to undergo a conversion to natural gas. Furthermore, Beaver Valley was active in 2015 but retired by the end of the year so classified as retired here.

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

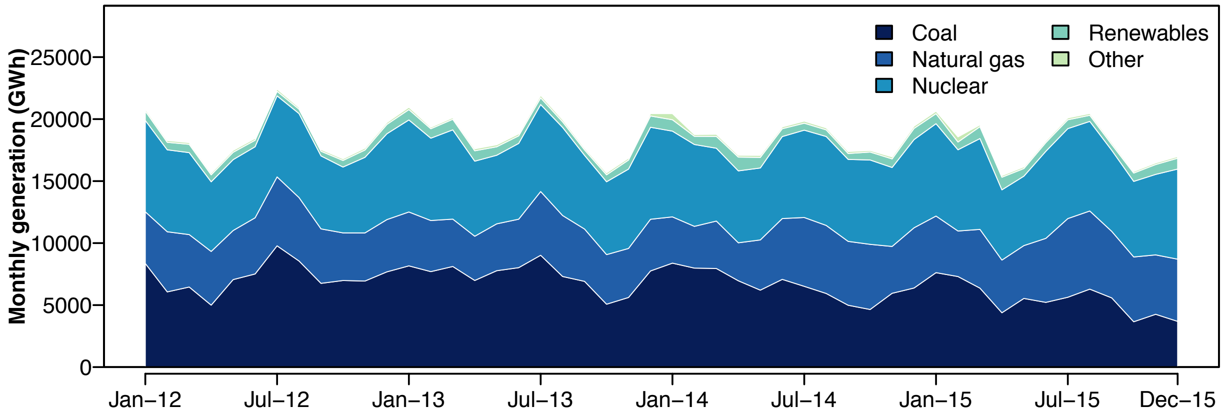

Figure 2.2: Historic electricity generation in Pennsylvania, by fuel type, 2012-2015.

and particulate matter (PM). Adverse health outcomes associated with these pollutants include cardiovascular and respiratory disease [31], lung cancer [32, 33], and premature death [34], 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 [35], 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 Pennsylvania has largely improved since 2000 [36, 37], with variations across individual sites and years. However, many communities in Pennsylvania still live in locations where air pollutant concentrations exceed federal National Ambient Air Quality Standards (NAAQS). In Pennsylvania, multiple regions are designated as non-attainment for 8-hour ozone, 24-hour $PM_{2.5}$,[8] lead (rolling three month average), and sulfur dioxide (SO_2) [38]. 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.[9] 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 [39]. 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 Pennsylvania 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.

Of all of the possible environmental health and equity co-benefits of power sector carbon

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

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

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 nitrogen 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 [1]. 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 [1]. 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 [1], concluding that carbon standards for power plants (under draft Clean Power Plan assumptions) 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 in Pennsylvania and 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 cumulative 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 Pennsylvania.

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 Pennsylvania. 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 [2, 9, 10] 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 worsened 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 Pennsylvania tends to be more elevated in low income and minority communities compared to higher income and white communities. According to the State's Enterprise Data Dissemination Informatics Exchange (EDDIE) database, the average asthma prevalence among Pennsylvania adults (2012-2014) is 10%. However, it is 9% for white, non-Hispanic populations, 13% for non-white populations, 15% for those that make less than $25,000 annually, and only 8% for those that earn $25,000 to $50,000 annually. The prevalence is 7% for those with a college degree, and 11% for those with less than high school education [47]. State hospitalization rates for asthma are six times higher for blacks than whites [48].

Elevated concentrations of particulate matter are associated with higher rates of asthma attacks and related hospital visits [49]. 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 [50]. 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 [2, 19]. 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 Section 5. Furthermore, additional insight may be gained by deeper analysis of populations living within a closer radius, particularly in more dense urban areas. 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.

Multiple indicators can be used to identify a potentially vulnerable or overburdened community. The State of Pennsylvania considers Environmental Justice Areas to be census tracts with "a poverty rate of 20% or greater or a non-white population of 30% or greater" [8]. 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 [20]. 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 [51]. 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.

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 a cumulative burden of some of the indicators discussed above. It is therefore useful to look at both the aggregated values 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 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 health insurance coverage for children under age six. We aggregate cumulative burdens across all plants and compare these aggregate results to the EPA's Demographic Index and to Pennsylvania-designated Environmental Justice Areas. We also integrate additional data on regional air quality.

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 [2]. 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 [20].

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

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 [20]. 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 [52] and the Pennsylvania Department of Health from the EDDIE platform [47]. Health data were available at the minor civil division level in Pennsylvania. 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 [53]. 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 Pennsylvania:

- **Uninsurance rate:** percent of children under age six 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 [2, 20], which also uses American Community Survey data from 2008-2012 [52]. 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 [13, 14, 15, 16]. These demographic indicators include [2, 20]:

- **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 [2]:

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

The State of Pennsylvania Department of Environmental Protection (PA DEP) uses a different formula, as described earlier, and designates Environmental Justice Areas as those where 20% or more of the population lives in poverty and/or 30% or more of the population is minority (non-white). In parts of this analysis, we use geospatial data from the state of Pennsylvania to identify these regions [8].

3.2.3 Environmental data

The environmental data used in this environmental justice screening analysis come primarily from the EPA's EJSCREEN analysis [2, 20]. These indicators include:

- **Average PM:** average 24-hour $PM_{2.5}$ concentration ($\mu g/m^3$);
- **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 [38]. However, the NAAQS non-attainment areas have not been updated to reflect the 2015 update to the ozone standard [54], 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 Pennsylvania for 2013-2015, aggregated from EPA's AirData website [55]. For each monitor, located using the EPA site description report [56], 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 35 $\mu g/m^3$ 24-hour $PM_{2.5}$). Not all of the monitors collect data every day, however, and

[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."

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 Pennsylvania. 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 [29, 57]. We refer to the two non-retired fossil steam plants as gas steam because their primary fuel is natural gas. We designated nine plants (eight coal, one oil steam) as retired since 2012. We include these plants in their own category in our analysis, both to analyze trends in retirements and because some of these sites are under consideration 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.

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 Pennsylvania.

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 black line in each individual 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 itself 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 solid dark purple line indicates the *state median* value, where this median represents the middle value for all census blocks in Pennsylvania. For example, the median percent low income population is 26%, meaning that in 50% of census blocks, less than 26% of the population is low income. The dashed lavender line indicates the *state average* population fraction of low income inhabitants, which at 30% 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.

Our results indicate a wide distribution of indicators for each plant class. Human populations living within three miles of NGCC plants range from 6% to 61% minority. However,

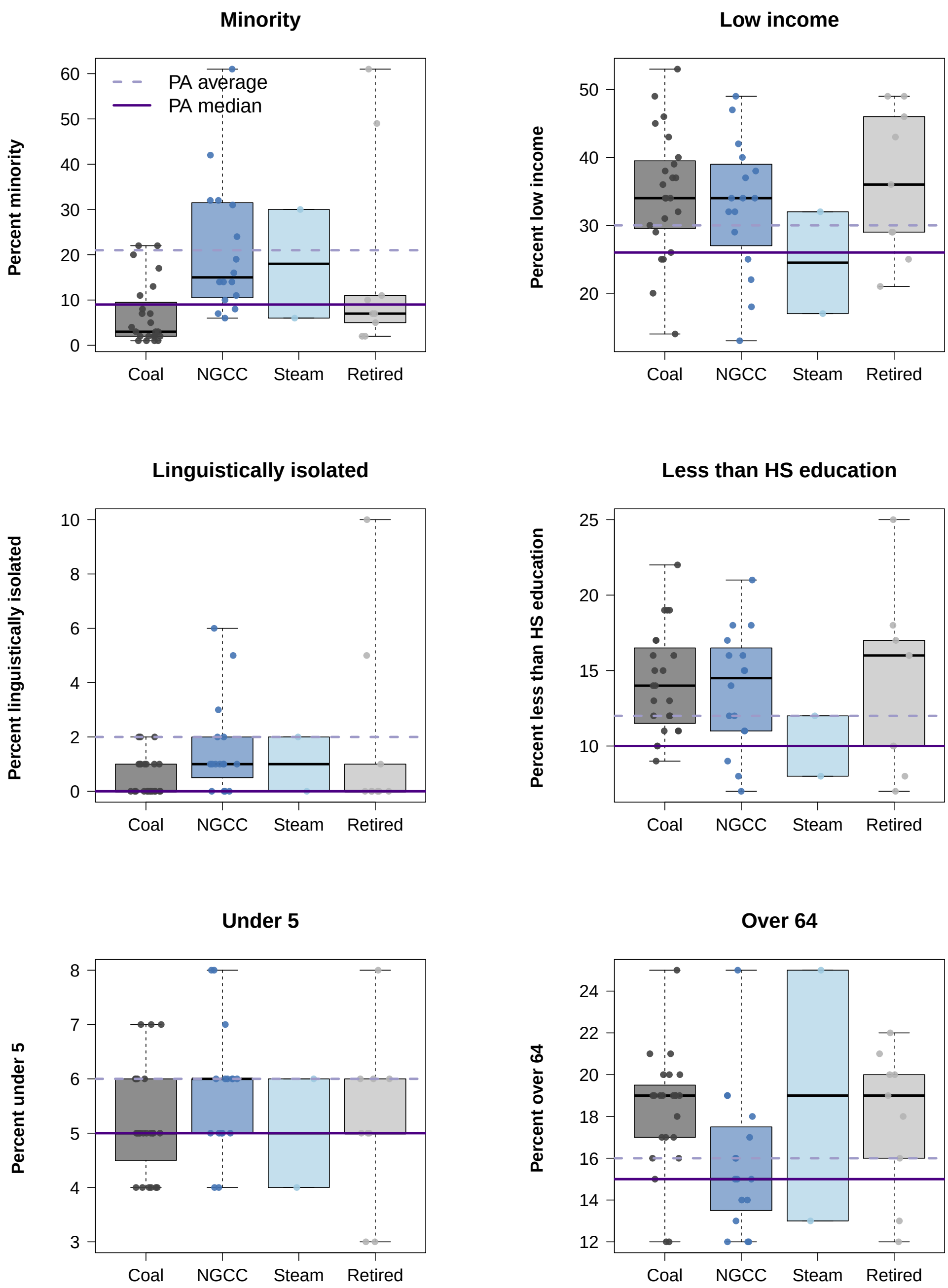

Figure 3.1: Box plot of demographic indicators for populations near Pennsylvania power plants, by plant class. Solid dark purple line indicates the median value of census blocks in Pennsylvania. Dashed lavender line represents the state average. Each dot represents the indicator value for the population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

more than 80% of these plants are in communities with a larger proportion of minorities than the state median. In contrast, only 26% of the communities living in proximity to coal plants are in regions where the proportion of minorities is above the state median. Every NGCC plant has a higher minority concentration living nearby than 61% of coal plants; 38% of NGCC plants have a higher minority concentration living near them than any coal plant. These data suggest that a shift in generation from coal to existing NGCC may be likely to increase generation near minority communities, although it depends on the specific shift in plant use.

More than 75% of communities around coal, NGCC, gas steam and retired plants are located in communities with a larger percentage of low income inhabitants than the state median. A majority of these communities are also above the median for less than high school education and linguistic isolation measures. The percent of the population under age 5 and over age 64 show a broad distribution in each plant class, but there is a larger proportion of older communities near coal than NGCC plants, and a larger proportion of communities with children under five near NGCC than coal plants. A shift from coal generation to existing NGCC plants under the Clean Power Plan may in general increase generation close to populations with a different set of vulnerabilities, such as a larger fraction of minorities and young children. However, the broad distribution for each indicator suggests that individual plants must be taken into account: a shift in generation from one plant to another could easily be a shift from a less vulnerable community to a more vulnerable one, or vice versa.

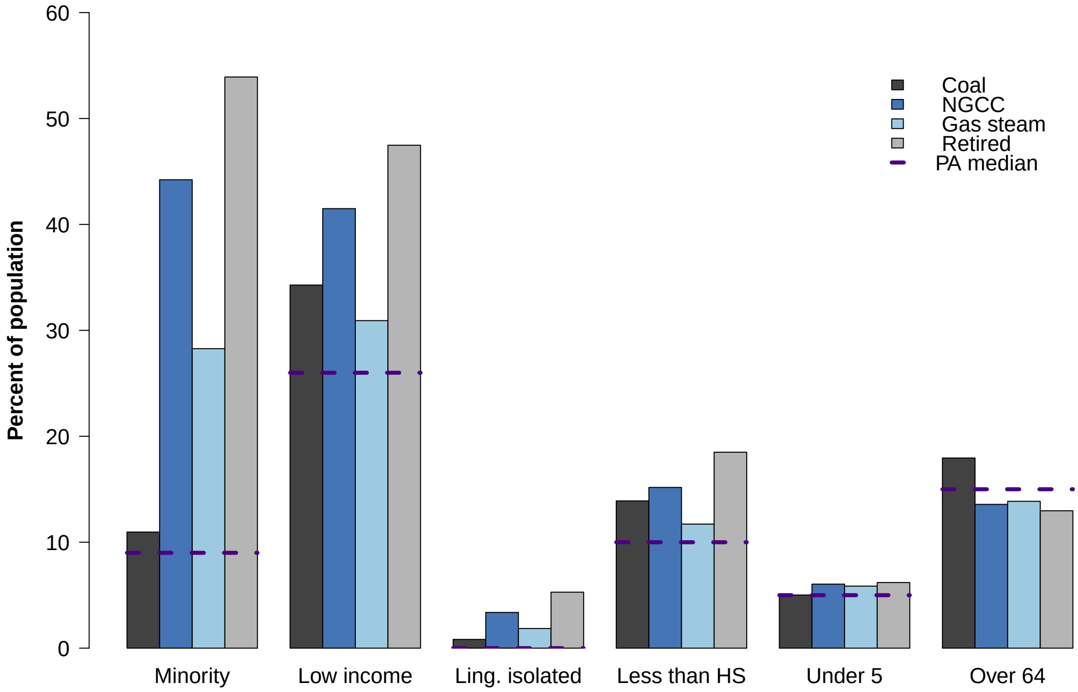

Figure 3.2: Bar chart of demographic indicators for total statewide population living within three miles of a Pennsylvania power plant, by plant class.

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 Pennsylvania's 12.8 million inhabitants, 202,000 reside within three miles of a coal plant, 887,000 within three miles of a NGCC plant, 92,000 near a gas steam plant, and 596,000 within three miles of a plant retired between 2012 and 2015. To calculate the population-weighted value for each indicator we multiply each metric (e.g., percent minority) by the total population living around each plant, and then sum the results by plant class (**Figure 3.2**). The picture changes from the previous one. We parse out these percentages for populations living near NGCC, coal, steam, or retired plants, and compare the results to the state median.

The data in **Figure 3.2** indicate that the total aggregate population living near power plants scores higher than the state median on every demographic vulnerability indicator except the percent of the population over age 64. The population living near NGCC plants is on average 44% minority, compared to a state median of 9% and a state average of

21%. The minority percentage of populations living near coal plants is above the median, but much lower than the minority percentage of populations living in proximity to NGCC plants, suggesting that a shift from coal to NGCC under the Clean Power Plan may increase the utilization of plants near communities of color. All near-power plant populations have a higher percentage of low income residents than the state median of 26% or the state average of 30%, but even more so for NGCC plants than coal. We see similar results for linguistically isolated populations and those without a high school education, but more mixed indicators for the population percentage under five years of age. Coal plants, in particular, have a higher percentage of people over 64 years nearby. This is of concern as the elderly are often more vulnerable to numerous health hazards than younger healthy adults.

The aggregate population living near retired plants has higher percentages of individuals identified as low income, minority, linguistically isolated, with low level of educational attainment, and/or under age five, than for any other class of plants. 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 need to continue to monitor these plants and their associated hazards, including but not limited to waste disposal sites, after retirement. Some of these risks, 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 showing the state percentile for minority populations living in proximity to each plant by the state percentile[4] low income population living in proximity to each plant. The 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. A number of the NGCC plants are located in areas of relatively high population density (as indicated by the larger circle size) with a larger proportion of low income and minority inhabitants than the state median. The average number of inhabitants living within three miles of a NGCC plant is 55,000 (median 21,000), while the average number living within three miles of a coal plant is 8,500 (median 5,800). Again, we note the potential here for a shift from coal generation under the Clean Power Plan to potentially increasing generation at very urban plants in low income and minority communities. Of the ten non-retired plants with the largest nearby populations, seven are NGCC, two coal, and one gas steam. The nine non-retired plants with the smallest populations living nearby are all coal (the tenth is NGCC). The 15 plants with the largest non-minority population nearby are all coal, and the five plants with the largest minority percentages nearby are NGCC, although there are three coal plants in the top ten buffer areas with the highest minority percentages. The overall trend suggests coal plants are located in relatively rural areas, which tend to have predominantly white populations, while more of the natural gas plants are in urban areas, which tend to have a larger share of non-white inhabitants. Of the ten plants with the highest low income percentages nearby (excluding retired plants), six are coal and four are NGCC. We also note that the coal plants are almost all older than the NGCC plants, suggesting that power plant siting within the last decade and a half has tended towards urban, minority areas (although demographics may have been somewhat different at time of siting).

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

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

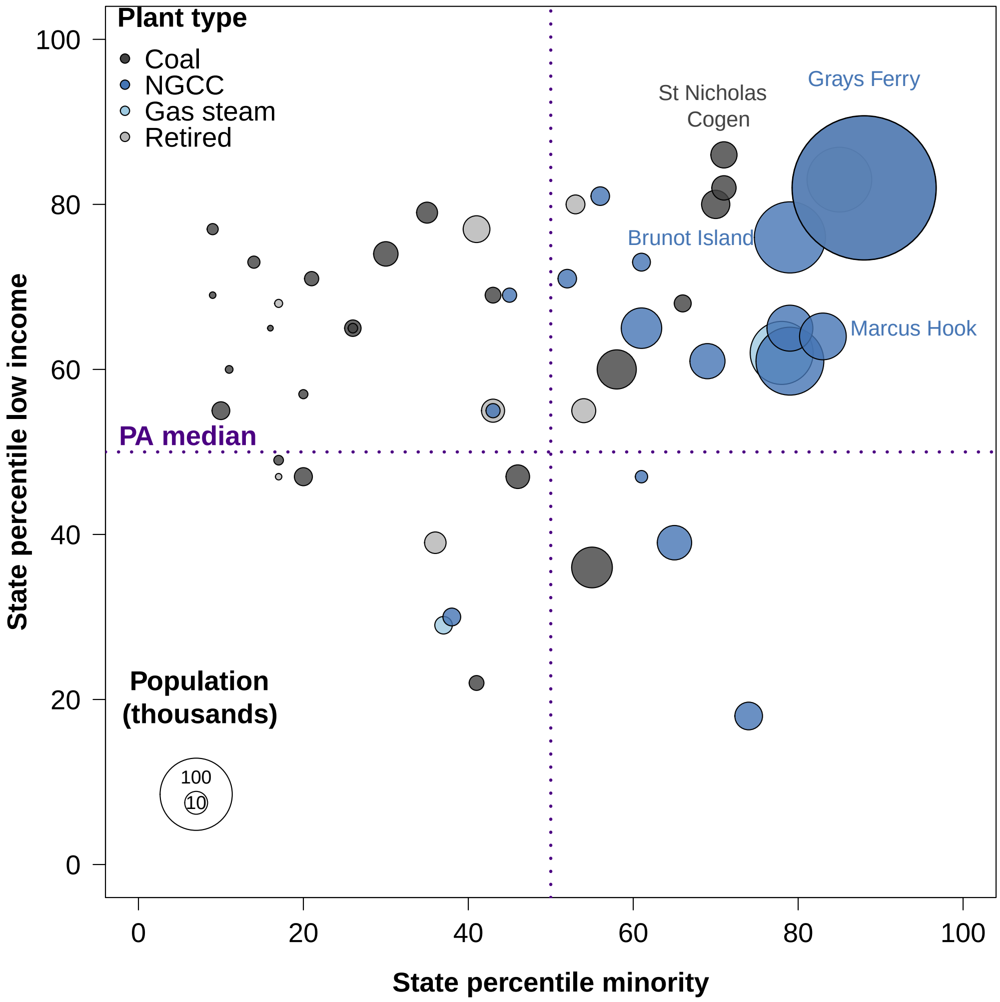

Figure 3.3: Bubble chart of state percentile rankings for low income and minority percentage for populations living within three miles of each power plant, by plant class. Circle size represents the number of inhabitants living within three miles of each plant. Purple line represents the state median.

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 **Figure 3.3**, but also includes the percentile rankings for each area compared to EPA Region 3 (Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia) and the US as a whole. The results suggest that Region 3 has a higher percentage minority population but lower percentage low income population than Pennsylvania alone, and the US as a whole has higher percentage of minority and 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 integrate environmental burdens on communities living near power plants. A box plot of the EPA's EJ Index for each indicator is

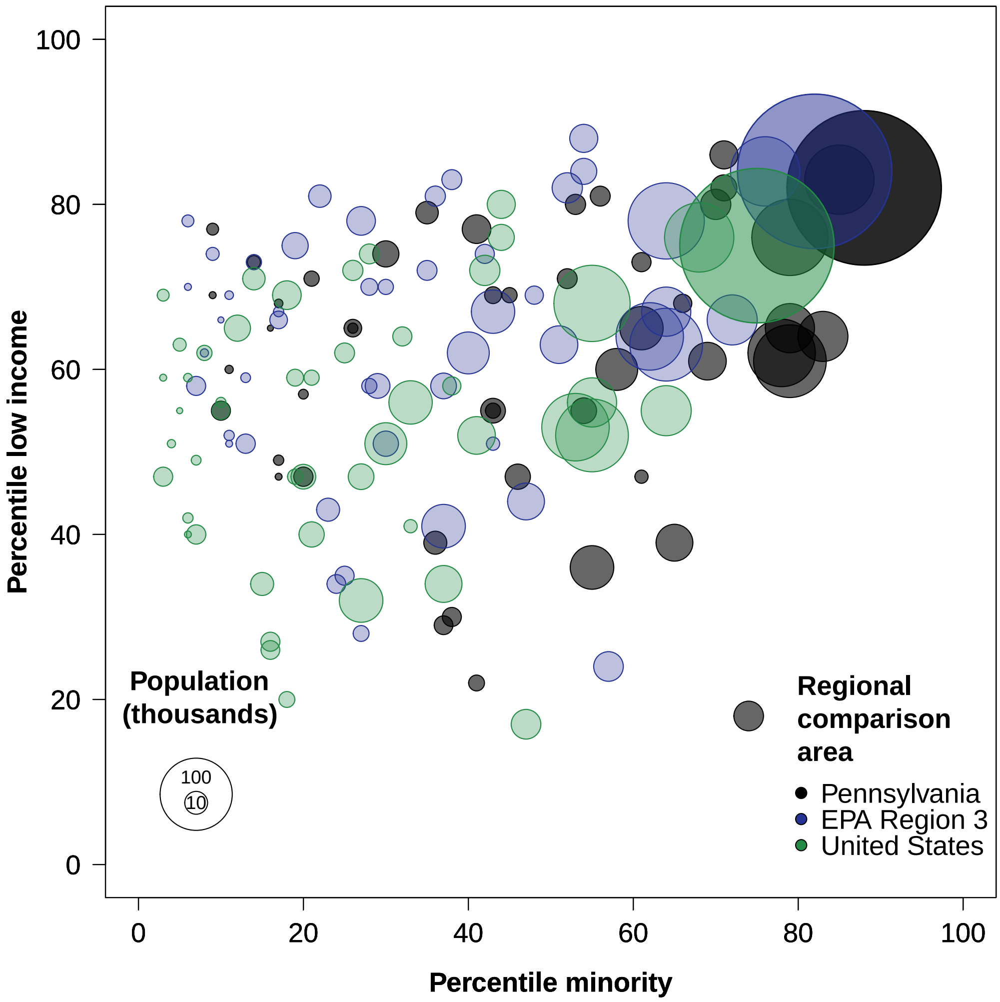

Figure 3.4: Bubble chart comparing percentile rankings of each plant against low income and minority demographics for Pennsylvania, EPA Region 3, and the US. Circle size corresponds with number of inhabitants living within three miles of each plant.

shown in **Figure 3.5**. The calculation for this Index, shown in Equation 3.3, weights each indicator by population size and percentage minority and low income population. 50% indicates a median value. EJ Index areas around NGCC plants and gas steam plants rank high for traffic proximity, likely due to their more urban locations, as noted earlier. These and other indicators are likely correlated, but also are examples of the potential for cumulative environmental burdens on the same population. The gas plants on average score higher than coal on most of these indicators (which also holds true for most of the non-weighted environmental indicators given in **Figure 1** in Appendix .1), due to a combination of demographic indicators and inherent variations in the environmental indicators, but overall, the indicator results have a relatively wide distribution.

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 Pennsylvania 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.

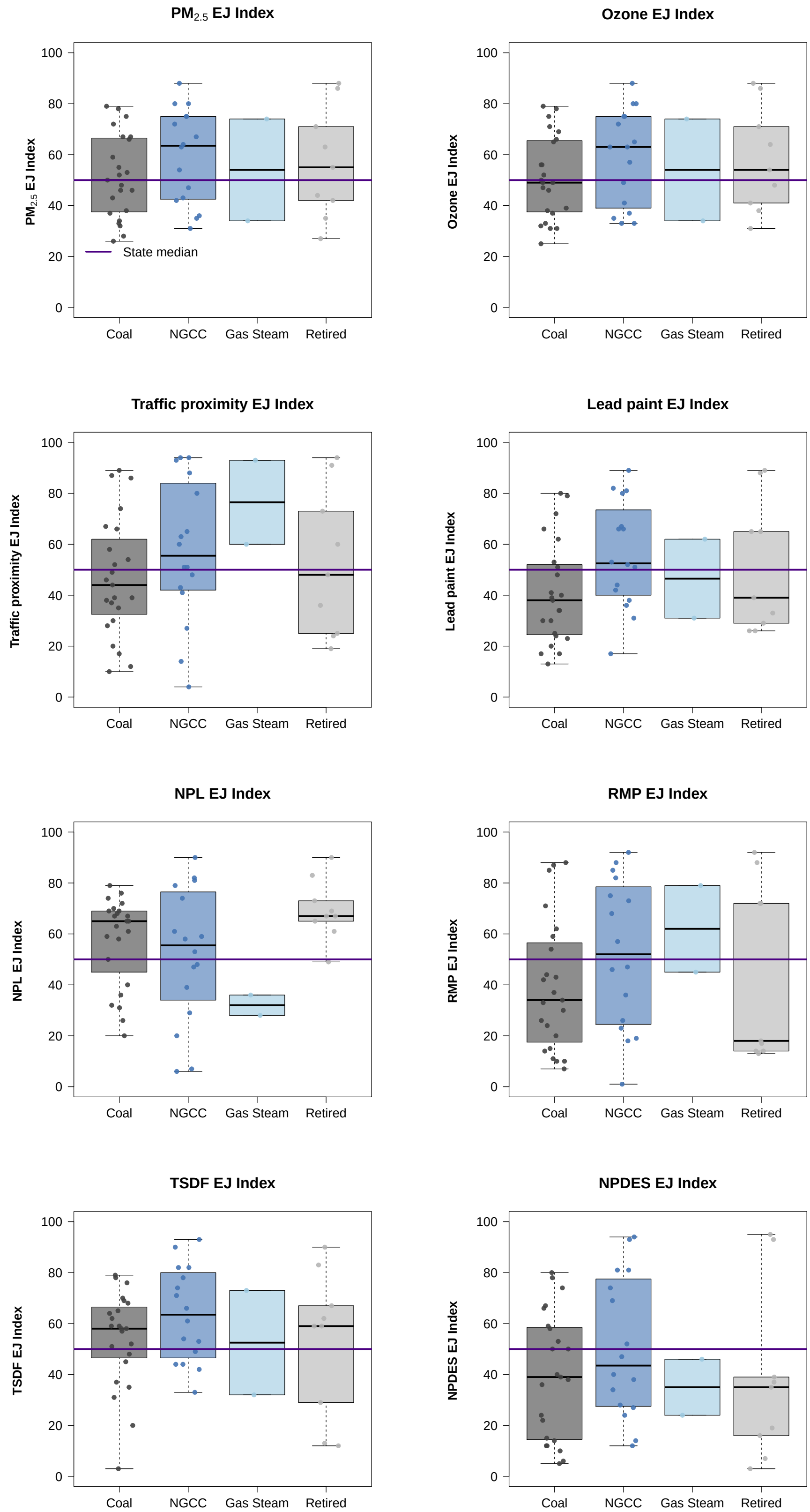

Figure 3.5: Box plot comparing EJ Indices for populations near power plants, by plant class. Each dot reflects the population living near a power plant. The EJ Index gives a demographically-weighted value for each indicator. The purple lines indicate the median at 50%. Indicators include average 24-hour $PM_{2.5}$ 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).

Three counties in Pennsylvania are designated non-attainment for $PM_{2.5}$ and 17 counties designated non-attainment for ozone. Ten of 16 NGCC plants are located in ozone non-attainment areas, while only six of 23 coal plants are located in ozone non-attainment areas. Four of the NGCC plants are located in $PM_{2.5}$ non-attainment areas but only one coal plant is similarly located.

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 25 over a three-year period, compared to 19 days for coal plants. The average number of $PM_{2.5}$ exceedance days was 22 for NGCC and 16 for coal. In aggregate, these data suggest the potential that increasing emissions at NGCC plants could increase NO_x emissions in areas with poor air quality. However, as with all indicators, there are a wide range of values for plants in each fuel class and a careful State Plan could target NO_x and SO_2 emission reductions in these areas instead. We note that the full regional impacts of any emissions stretch 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 need to model 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 low birthweight and disability above the state median, and all but three NGCC plants are located in communities with slightly higher cancer rates than the state median. The population-weighted results are given in a bar plot in **Figure 3.7**. When population-weighted, the prevalence of low birthweight births and of disability near NGCC and gas steam plants increases in comparison with coal and with the median, which suggests an increase in the value of these indicators in urban areas near regulated plants. Once again, 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.

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 socioeconomic 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 Pennsylvania, we aggregated PA DEP Environmental Justice Area designations [8], the EPA's

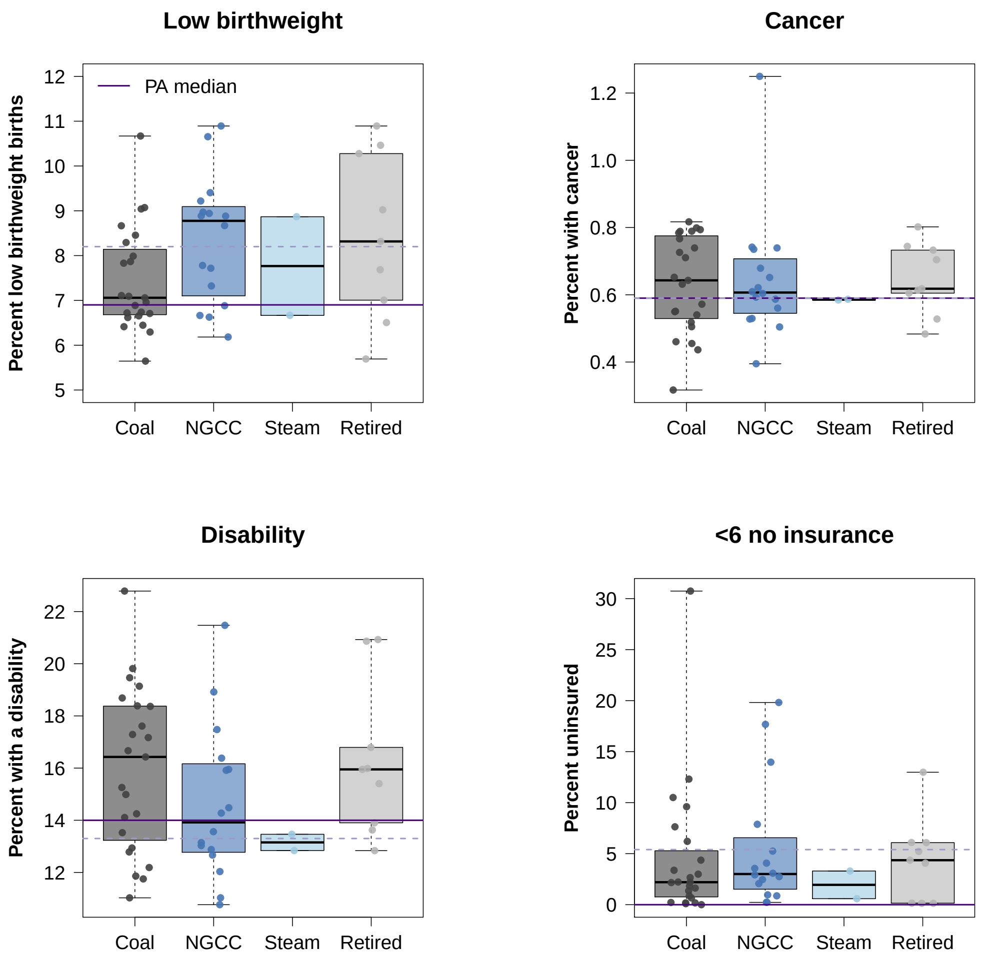

Figure 3.6: Box plot comparing health indicators for populations near Pennsylvania power plants, by plant class. Solid dark purple line indicates the median value of census blocks within Pennsylvania. Each dot reflects the population living around each power plant.

Demographic Index, and our own vulnerability indicators. We developed a Cumulative Vulnerability 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 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, 18 of the 19 highest ranked plants from a cumulative burden perspective are also located within a Pennsylvania-designated Environmental Justice Area, or have such a community within a three-mile buffer of the plant, as indicated by an asterisk next to their name in **Figure** 3.8. However, there are a number of plants near these communities (there are 25 plants total within three miles of an Environmental Justice Area) that rank lower down the list. Nineteen of the plants with an Environmental Justice Area nearby are in the top 25 of this ranking. The remaining six plants are all in relatively rural areas (<10,000 population in a three-mile radius) and all have much higher proportions of low income populations than minority populations; these areas were likely designated Environmental Justice Areas due to poverty levels rather than minority populations. Fifteen of the communities

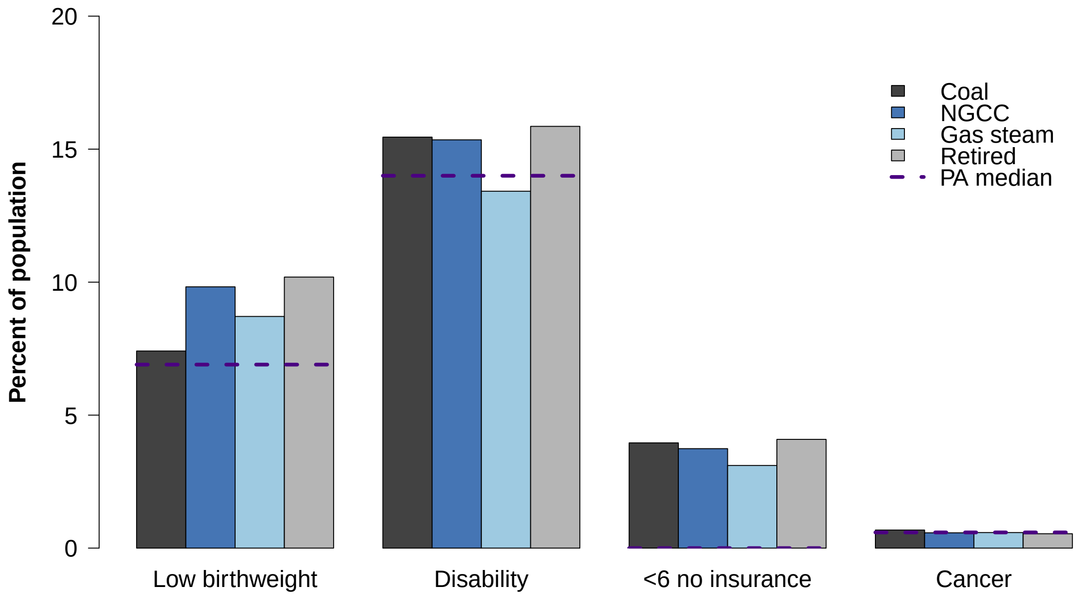

Figure 3.7: Bar chart comparing indicators for total statewide population living within three miles of Pennsylvania power plants, by plant class. Indicators include prevalence of low birthweight births, disability rates, percent of children under six without health insurance, and cancer prevalence.

living near plants are above the 70th percentile for the EPA's Demographic Index, and 14 of these are rank among the highest 20 on our Cumulative Vulnerability Index in **Figure 3.8**, suggesting relatively good agreement between all approaches but also the relative benefit of using additional environmental and health indicators to prioritize certain plants. Six of the top 25 plants on this list have been retired since 2012, but remain of interest due to both proposed repowering projects (e.g. Sunbury and Hatfields Ferry) and remaining coal ash impoundments and other hazards that are left behind when a plant retires.

These results suggest that while there is some similarity in these three 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.

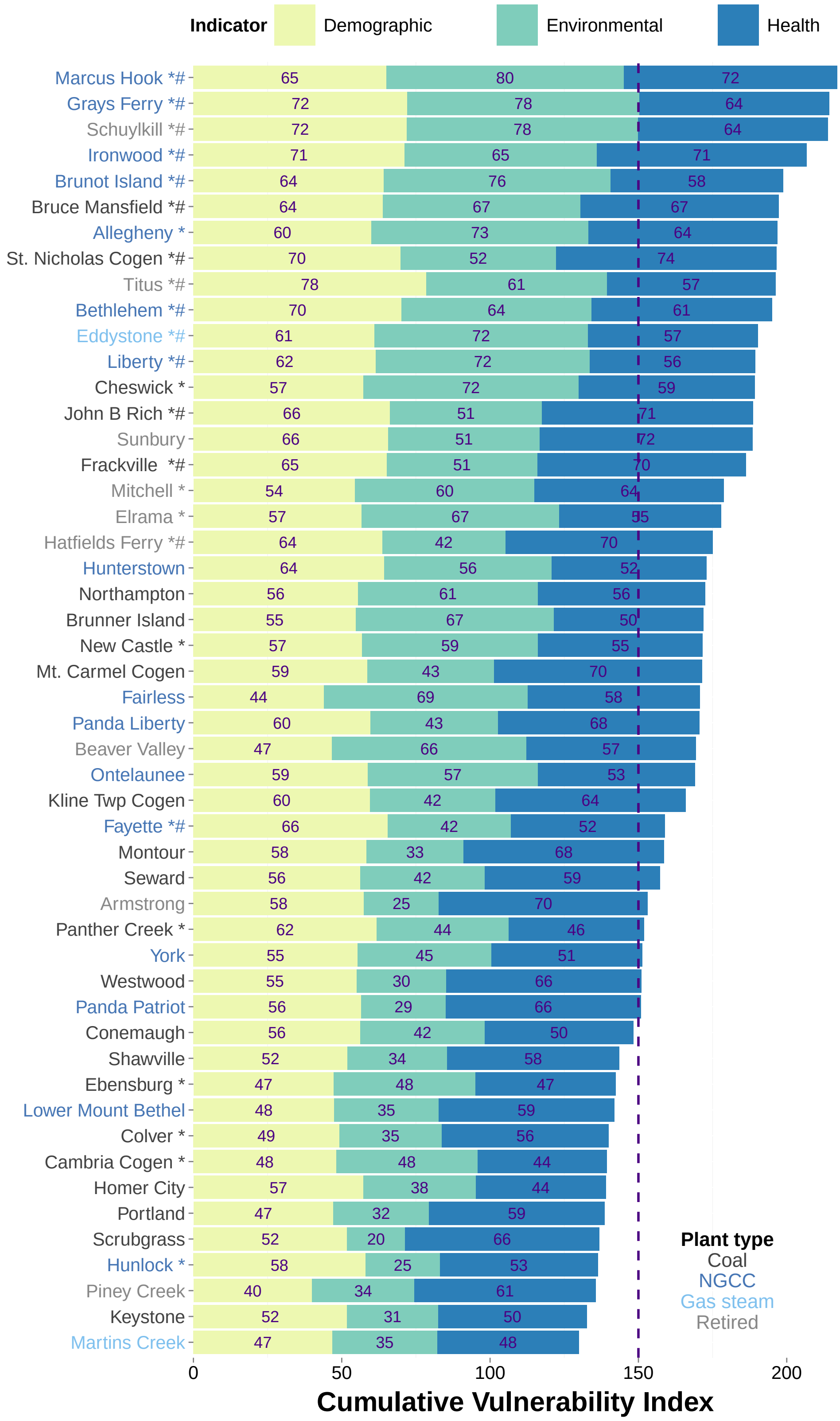

Figure 3.8: Cumulative Vulnerability Index of demographic, environmental and health indicators reflecting cumulative socioeconomic and environmental hazard burden for populations living within three miles of each power plant in Pennsylvania. Each color represents a class of indicators (demographic, environmental, 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 near state-designated Environmental Justice Areas are designated with *. Plants above the 70th percentile of 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 Pennsylvania. 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 Pennsylvania. 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 can also 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. Groundwater is a primary source of residential water usage for rural residents in Pennsylvania, with nearly one million wells servicing over three million rural residents, primarily in the western and eastern regions of the state [71].

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 [72], 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" [73]. 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 PA DEP, 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 [74]. 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 [73].

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 [75]; and 2) 2014 Impoundment Assessment [76]. 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 [77]:

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 [76].

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 conjunction with Environmental Justice Areas designated by the PA DEP in **Figure 4.1**.

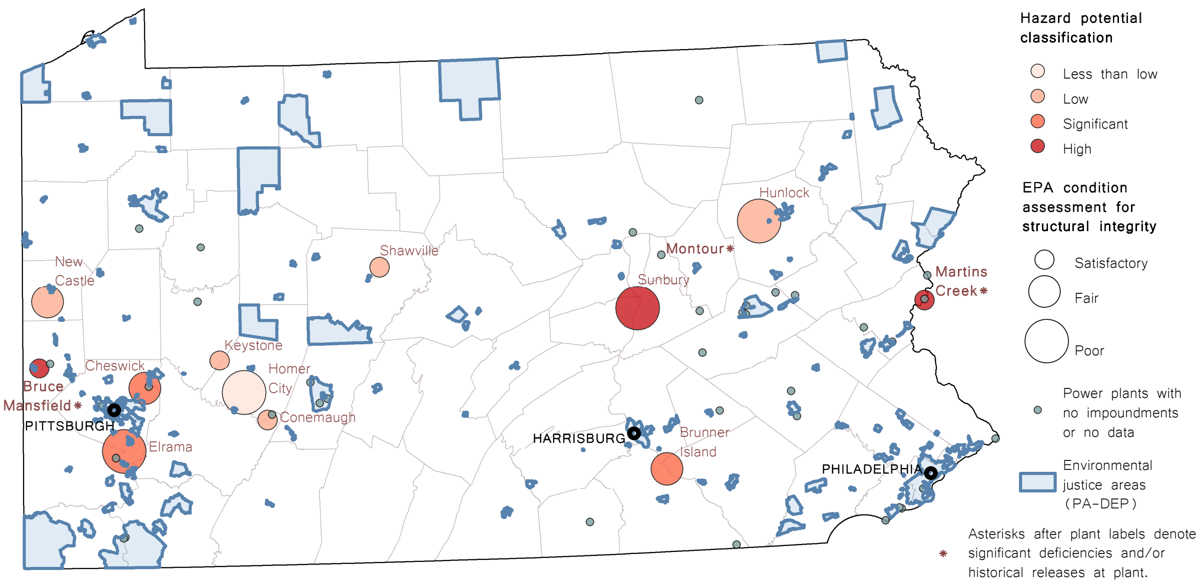

Figure 4.1: Map of coal ash impoundments at power plants, indicating hazard potential, structural integrity condition, and historical spills or unpermitted releases, from 2009-2014 (using available data). Circle size indicates EPA condition assessment of the structural integrity of impoundments; larger 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. Shaded, non-circular areas indicate Environmental Justice Areas. Names with * are plants with significant deficiencies and/or historical releases of pollution.

The plants with historical releases and/or significant deficiencies at their coal ash impoundments included Martins Creek, Bruce Mansfield, and Montour. Martins Creek had a historical release of about 100 million gallons of fly ash in 2005 [75], although we note that this plant has subsequently closed its coal-fired units and now only burns natural gas and oil.

Of the 14 plants that have coal ash impoundments in Pennsylvania, six are located within three miles of an Environmental Justice area, three have a high hazard potential, three have significant hazard potential, and four have a poor condition assessment rating (**Figure 4.1**).

The plants within three miles of an Environmental Justice Area, including retired facilities, are Cheswick, Bruce Mansfield, Hatfields Ferry, Hunlock, New Castle and Elrama. The bottom ash settling ponds at Elrama coal plant have a significant hazard potential rating and a poor structural integrity condition assessment rating. The residual waste ash basin at Sunbury coal plant had both a high hazard potential and poor structural integrity condition. The site has a closure plan for this impoundment, but it is not yet approved.

In **Table 4.1**, we show six plants with the most severe hazard potential classification or EPA condition assessment ratings. Of these, the Bruce Mansfield, Hunlock (now NGCC) and Elrama (retired) plants are within a three-mile radius of a PA DEP-defined Environmental Justice Area. Operating near an Environmental Justice Area 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 (temporarily or permanently stored) one or more of the following: fly ash, bottom ash, boiler slag, flue gas desulfurization emission control residuals, and other residuals [75]. The Homer City and Sunbury plants also contributed sludge from waste water treatment, cooling towers, and/or industrial waste treatment to their on-site impoundments, and Homer City further adds plant runoff sediments, leachate solids, anthracite, sand activated carbon filters, demineralizer resins, fireclay brick, sandblasting material, paint chips, asphalt, concrete, stones, rocks, bricks, and asbestos [75]. 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) [76]. Plants that received a poor structural integrity condition assessment rating include Sunbury (one impoundment), Homer City (four impoundments), Hunlock (two impoundments), and Elrama (one impoundment), as shown in **Table 4.1**. However, there are other impoundments that we do not have conclusive data on, and therefore cannot assess the potential associated environmental health hazards. Furthermore, we only addressed impoundments located within three miles of a power plant, but in some cases impoundments may be located further away yet still pose risks to the communities living near those sites.

Understanding plant location and management can provide insight for continued safe operations. For example, if Sunbury's Basin 1 were to at any point fail, its contents would drain directly to the Susquehanna River via the Pennsylvania Canal or Rolling Green Run, with the Dauphin Municipal Water Authority's intake stream 22 miles downstream [78]. While Homer City has not had a failure or release from its recycle ponds, the site has no emergency warning or action plan, and no available hydrologic or structural and/or seepage analysis as of the assessment date [79].

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 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

Table 4.1: Coal ash impoundments with highest hazard potential, based on EPA structural integrity condition assessment and/or historical releases for available 2009-2014 data.

Site	Impoundment	Start year	Hazard potential rating	EPA structural integrity assessment	Historical releases	Near EJ area	Size
Bruce Mansfield	Little Blue Run Dam	1975	High	N/A, de-commissioned	Several seeps; recommended subsurface investigation	Yes	84,300 acre-ft
	North LDS Pond	1975	Significant	Satisfactory			46 acre-ft
	South LDS Pond	1975	Significant	Satisfactory			42 acre-ft
	West HDS Pond	1975	Significant	Satisfactory			45 acre-ft
Brunner Island	Ash Basin 6	1981	Significant	Fair		Yes	2,600 acre-ft
	Equalization Pond	1993	—				5 acre-ft
	Industrial Waste Treatment Basin	1973	—				20 acre-ft
Chewsick	Emergency Ash Pond	1970	Significant	Fair		Yes	0.4 acre
	Bottom Ash Recycle Pond	1970	Significant	Fair			0.6 acre
Elrama	SPD-1 and -2	1952	Significant	Poor		Yes	Each pond 2 acres, max depth 25 ft
Homer City	Ash Recycle Ponds 1, 2, 3, and 4	1973	Less than low	Poor		No	4, 5, 5, and 5 acre-ft
Hunlock	East and West Basins	Mid 1960s	Low	Poor		Yes	Each 90 acre-ft
Martins Creek	Ash Basin 1	1974	—	Satisfactory		No	300 acre-ft
	Ash Basin 2	—	Low				
	Ash Basin 3	—	—				
	Ash Basin 4	1989	High	Satisfactory	100M+ gallon fly ash spill, 2005		39 acre-ft
Montour	Ash Area 3 Leachate Runoff Basin	1980	Less than low			No	11 acre-ft
	Ash Basin No. 1	1968	Low		Minor seeps, abatement underway (2007)		5,070 acre-ft
	Detention Basin	1968	Less than low		Minor seepage west side berm (2004)		53 acre-ft
	Silo Runoff Pond	1980	Less than low				1 acre-ft
	Stormwater Basin	1968	Less than low				13 acre-ft
Sunbury	Residual Waste Ash Basin No. 1	1949	High	Poor		No	1,139 acre-ft

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, 80]. Both total arsenic levels and dissolved arsenic levels are considered in this report. Lead is a likely human carcinogen and is known to impair cognitive function, especially among young children. High exposure to lead levels can lead to brain and kidney damage and even death [81]. 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, 82]. Boron has acute and chronic effects at large doses, including impacting the stomach, liver, kidney, and brain, and excessive amounts can be deadly [83].

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 [84], 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) or 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: water well-monitoring

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 [85]. 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" [85], (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 of the facilities subject to the Clean Power Plan as of this report; only 11 plants out of the 50 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: Seward, Portland, Mitchell, Bruce Mansfield, Hunlock, Homer City, Hatfields Ferry, Fern Valley, Elrama, Conemaugh, and Cheswick, available at the Ashtracker website [85]. Data are most recent for 2014, and 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, lead, manganese and selenium. 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 Pennsylvania 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. Seward had the greatest number of exceedances of any facility studied, with 1,179 exceedances between 2010 and 2014, out a total 5,876 samples recorded—20% of all samples for Seward were in exceedance. Of those, 259 (22%) were above MCLs, 183 (16%) were above DWAs, 729 (62%) were above LHAs and less than 1% were above CHA levels. Elrama, now retired, operated as a separate entity than its disposal site Fern Valley, which received Elrama's coal fly ash between 1989 to 2003. The site was overfilled in 2002 and shutdown in 2007 after numerous PA DEP citations. Though Fern Valley existed to receive Elrama's coal combustion waste, results for Fern Valley were excluded from Elrama since waste disposal to Fern Valley did not occur during 2010-2014 .

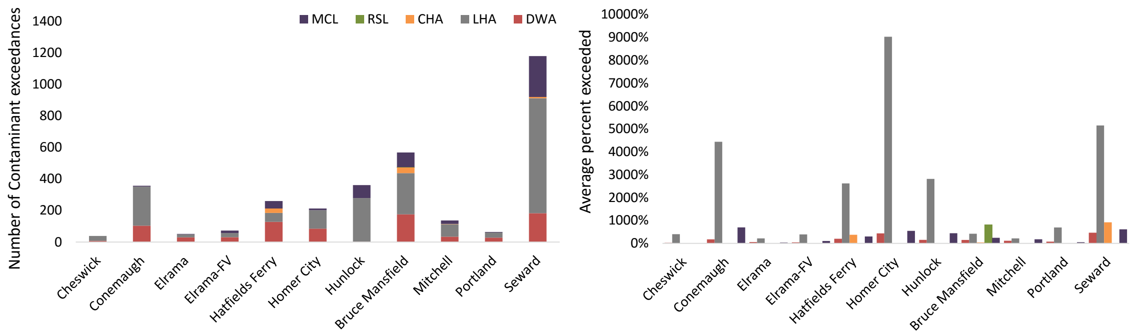

Figure 4.2: Contaminant exceedances by plant, for sample recordings within a three-mile radius of the power plant, 2010-2014. (Left) Total exceedances. (Right) Average percentage above designated level. Colors indicate advisory or regulatory level attributed to exceedances. Levels include: Drinking Water 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 2015 include Elrama, Hatsfield, and Mitchell. Elrama-FV (Elrama Fern Valley disposal site) no longer receives coal ash. Bruce Mansfield had no data within the three-mile radius of the plant.

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. Homer City, Seward and Connemaugh had the highest average LHA exceedances, at 9,030%, 5,151%, and 4,440%, respectively. The RSL was exceeded the least. Where there is geographic and hydrological overlap between high and frequent observations of LHA exceedances 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 except Cheswick. The highest average MCL reading was from Conemaugh, at 696%.

Exceedances of the EPA MCLs for arsenic, selenium, and lead (0.01 mg/L, 0.05 mg/L, and 0.015 mg/L, respectively) are shown in **Figure 4.3**, along with manganese exceedances of the LHA and boron exceedances of the CHA. These exceedances 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.

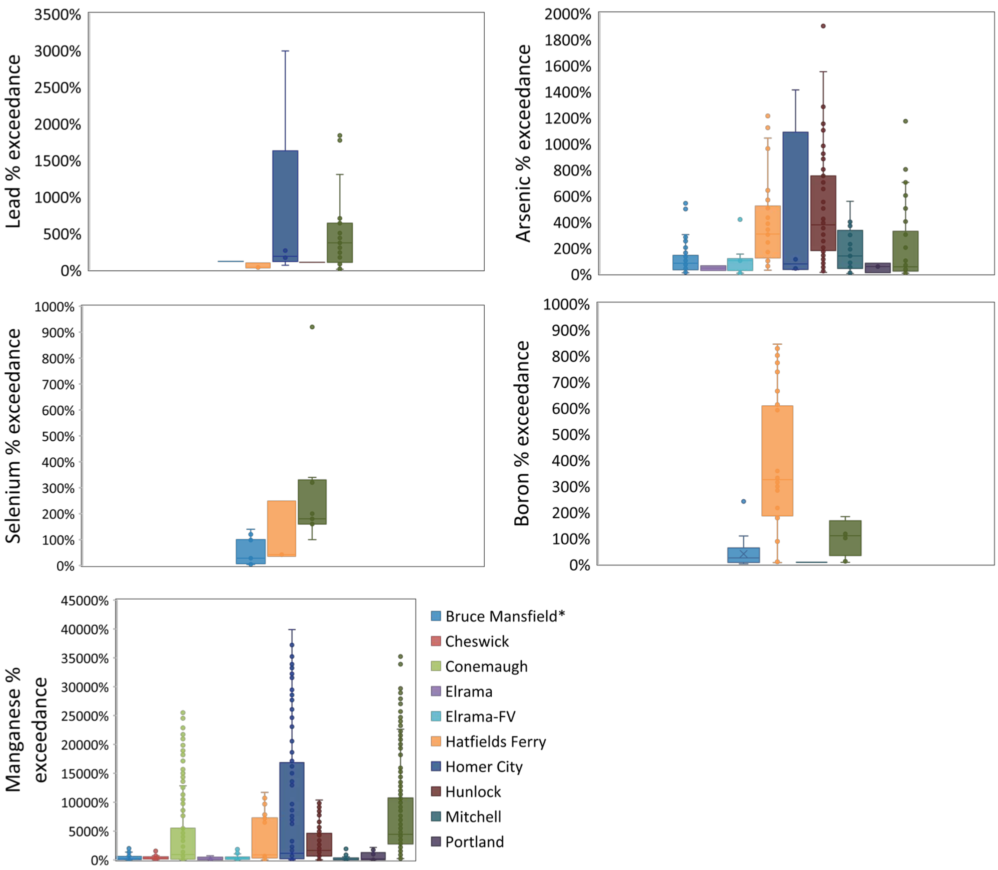

Figure 4.3: Box plot of percent exceedances for contaminants above health standard levels for plants with available data, 2010-2014. Lead, arsenic and selenium use the MCL. Boron uses the CHA standard. Manganese uses the LHA standard. Dots represent individual exceedance measurements. Solid line indicates mean for all data. Retired plants include: Hatfields Ferry, Mitchell, Elrama, and Elrama-Fern Valley. Hunlock has converted to NGCC and other plants are coal. Boron's highest outlier at Mitchell (6,733%) not shown. *Bruce Mansfield had no data within the three-mile radius of the plant.

Exceedances for lead MCL standards occurred at five plants, with the highest percent increase for a single sample shown for Homer City at 2,987% above the MCL for a sample date in 2014. The Hatfields Ferry, Hunlock, and Bruce Mansfield plants all had average exceedances below 200%. The broadest ranges of exceedance percentages were associated with Homer City and Seward plants. Three coal plant sites (including retired plant Hatfields Ferry) exceeded the MCL for selenium. Bruce Mansfield exceeded the advisory standard the least, with a maximum exceedance of 4%. Seward had the highest single exceedance at 920%, for total and dissolved concentrations, for a sample taken in 2010.

The LHA for manganese was exceeded by all 11 plants with available data. The highest single exceedances for manganese were at Homer City (37,200% above the LHA) and Seward (35,200% above the LHA), although there was a broad range of exceedance levels at measured sites.

Boron CHA levels were exceeded by the Hatfields Ferry, Bruce Mansfield, Mitchell, and Seward plants. Of these four plants, only two are still in operation. Seward had the highest single exceedance, near 6,733%, for a sample taken in 2014. Any exceedance can contribute to or cause adverse health impacts in exposed populations, especially for children.

As noted previously, retired plants can contribute to exceedances above health-based advisory and regulatory safe levels. Six of the eleven plants assessed in our analysis are located within three miles of an Environmental Justice Area, and all six (Cheswick, Elrama, Hatfields Ferry, Hunlock, Bruce Mansfield and Mitchell) recorded exceedances for manganese. These measurements reflect an environmental health hazard in vulnerable communities, 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 exceedances of groundwater contaminants near these industrial power facilities. Sampling was not comprehensive at these eleven 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 Pennsylvania, 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 [86]. 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 [35]. 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 [35]. 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 [87]. 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.

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

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: [52, 88, 89]) 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) [11]. 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.

We included the following categorical information from the TRI database in our assessment:

- **Classification:** chemicals fall into three standard categories: 1) persistent bioaccumulative toxic chemicals (PBTs); 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 Clean Power Plan subject plants in 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.

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. This scale allows a relative comparison between the three plant classes, with coal releasing the most cumulative TRI chemicals, and NGCC second. While NGCC plants in Pennsylvania do not release the same cumulative mass of chemicals as coal, they do release several hundred thousand pounds each year.

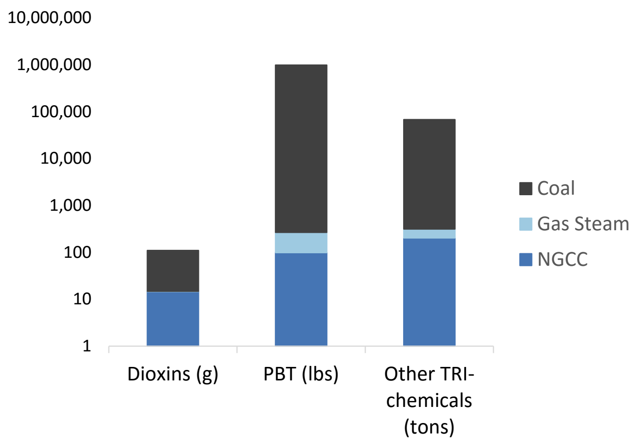

Figure 4.4: Logarithmic bar chart for total on-site toxic releases from Pennsylvania's CPP subject power plants. Dioxins, PBTs, and other TRI chemicals not covered by the previous two categories are shown.

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 and coal refuse plants emit the highest rate of toxic releases. Coal plants emit CO_2 at relatively similar rates, but toxic releases at a wide range of rates, while NGCC and coal refuse plants have a wider range of CO_2 rates. This figure shows that a reduction in carbon emissions at one plant may have a much greater concomitant reduction in toxic releases than at another plant, even for plants of the same fuel type. A similar comparison of CO_2 emission rates per MWh to criteria pollutant emissions and health burdens will be shown in Section 5.

Table 4.2 presents the total mass of on-site releases of dioxins, PBTs, and other chemical releases and identifies the percentage of these releases near Environmental Justice Areas. Only reportable TRI data are depicted in this table. Dioxins are a relatively small fraction

Table 4.2: Total on-site toxic releases from power plants, and percentage of releases within or near Environmental Justice Areas, 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.

	Dioxins (grams)	*% Near EJ Area*	**PBTs (lbs)**	*% Near EJ Area*	**Other chemicals (tons)**	*% Near EJ Area*
Coal	95	*53%*	991,000	*44%*	67,900	*24%*
NGCC	15	*100%*	99	*100%*	203	*61%*
Gas steam	<1	*38%*	168	*100%*	112	*100%*

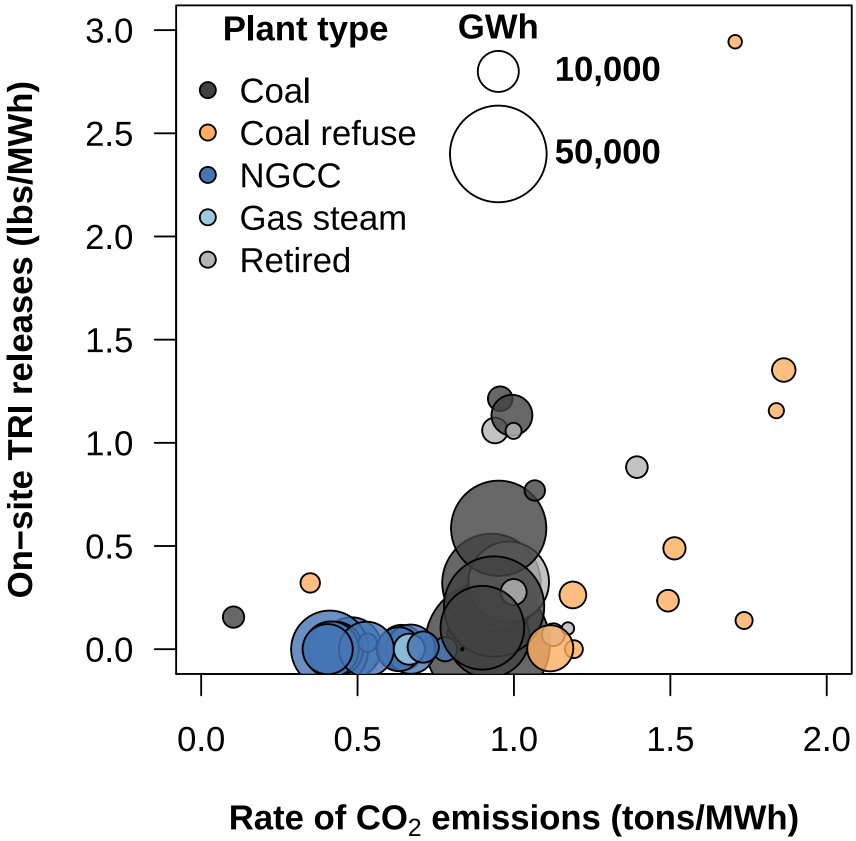

Figure 4.5: Rate of on-site toxic releases per MWh compared to rate of CO_2 emissions per MWh, 2010-2014.

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**, both coal and NGCC emit dioxins. PBTs and other TRI chemicals are also released from both NGCC and coal, but in much higher quantities than dioxins. NGCC plants within a three-mile radius of an Environmental Justice Area released over 98 lbs of PBTs and 203 tons of other TRI chemicals on-site between 2010-2014 (61% of releases were near these communities). Coal power plants released even more on-site: 990,535 lbs of PBTs and 67,863 tons of other TRI chemicals, with 44% and 24% being released within a three-mile radius of an Environmental Justice Area, respectively.

Of total releases, which are comprised of on-site, off-site and POTW releases combined, NGCC plants, which are disproportionately situated within a three-mile radius to urban and low income communities (see Section 3), kept nearly all of their releases on-site at the facility. Unlike NGCC, coal plants sent some of their TRI releases off-site for disposal including approximately 53.4% of PBTs and 99.8% of other TRI chemicals; off-site releases for dioxins were insignificant compared to on-site releases. Whether TRI chemicals remain on-site, as is the case with NGCC plants, or if they are transferred off-site, it is important to recognize that those communities surrounding disposal sites are in many cases low income and/or communities of color [89].

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. While each statute, and subsequent regulations thereafter, defines the hierarchy of noncompliance, how it is to be handled, and how notifications and penalties are to be assigned and assessed, it is clear that a noncompliant 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 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 [90]. 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 each facility's historic and current status [90]. 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 three-year facility compliance status designations are as follows [90]:

- **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); no plants in this report had a facility-level U status in the three-year timeframe studied.

We exclude retired facilities from our calculations to avoid overestimating the number of violations and inspections compared to the other current parameters (total plants by class, GWh produced, etc.).[3] 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.

4.4.3 Results: compliance and violations

Figure 4.6 shows the total number of inspections and violations at Pennsylvania power plants, subdivided by statute and whether the violation was formal or informal. According to data in **Figure 4.6**, Grays Ferry received ten informal and nine formal CAA violations, 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 hazards associated with these plants due to inconsistent numbers of inspections.

Figures 4.7a and **4.7b** show violation and inspection data in relation to potentially vulnerable communities. Facilities with no inspections or violations were not graphed. We include retired facilities to provide a historic and current picture of what types of plants do and do not have violations. We compare two different measures of vulnerability:

- EPA Demographic Index, which combines the population fraction of minority and low income individuals (see Equation 3.2);
- PA DEP Environmental Justice Areas, defined as census blocks where 20% or more of the population lives in poverty and/or 30% or more is a racial minority.

The 15 power plants located in communities that fell below the 50th percentile on the EPA Demographic Index had 23 violations and 98 inspections over the past five years, whereas the remaining 35 power plants at or above the 50th percentile had 106 violations and 242 inspections—twice the number of violations per plant but similar inspection rates for both percentile groups. Using the PA DEP Environmental Justice metric corroborates these findings. For the 25 plants within three miles of an Environmental Justice Area, there were

[3] Shawville, which is projected to switch to NGCC in 2016, and Portland, which is classified as coal by the EPA but burns mostly oil, are kept in the coal category and included in calculations.

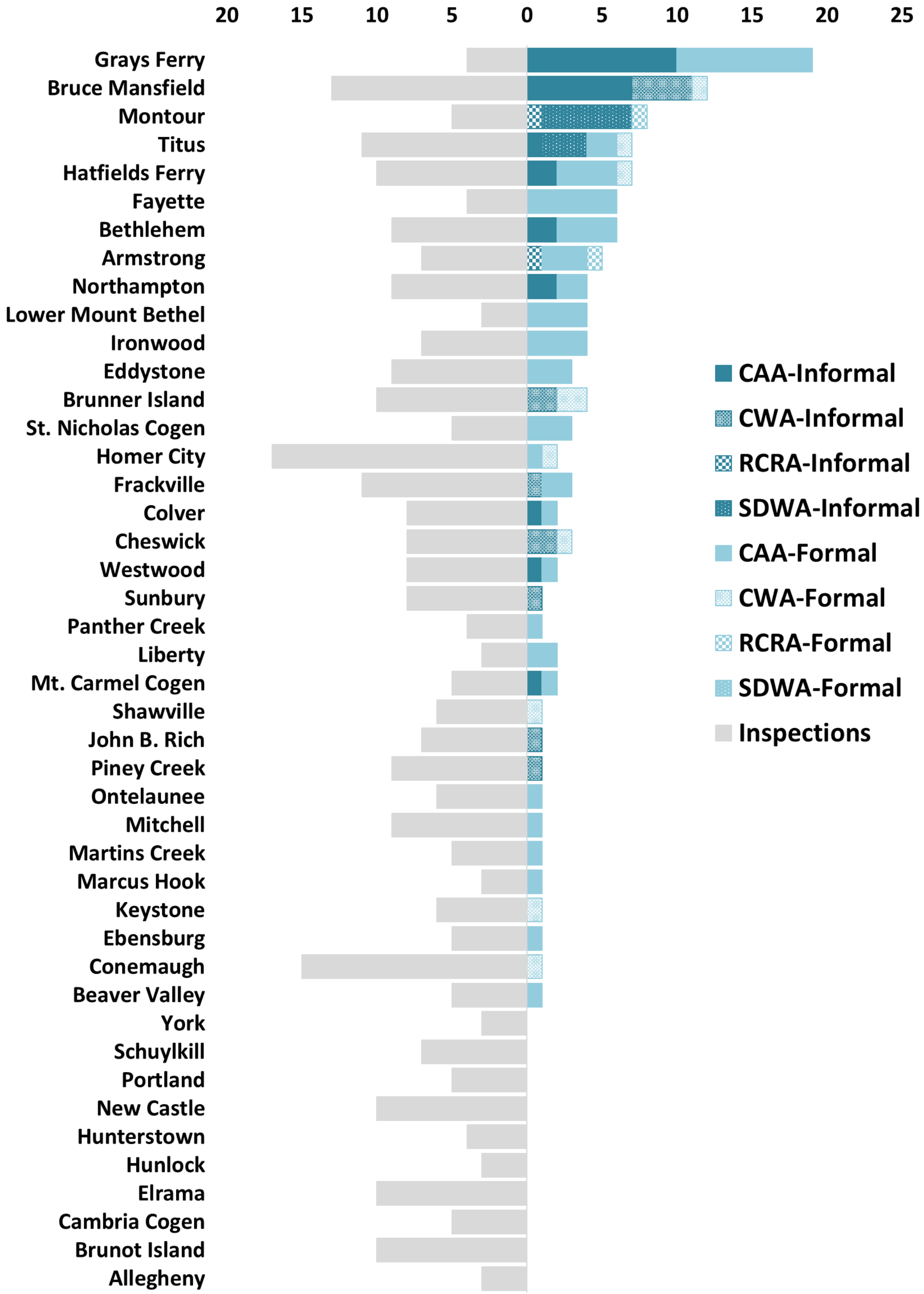

Figure 4.6: Chart of total plant inspections (left bars) and violations (right bars) between 2011-2015 and first quarter of 2016. Panda Patriot and Panda Liberty are not yet operational; Fairless had no inspections or violations.

85 violations and 178 inspections, compared to 44 violations and 162 inspections at the other 25 plants without a nearby Environmental Justice Area. Both the EPA Demographic Index and the PA DEP Environmental Justice metric use different methods and thresholds to quantify areas that are vulnerable, but the outcome from both approaches show that plants in vulnerable communities receive more violations, which may pose additional environmental health hazards in these areas.

We next compare these metrics to the Cumulative Vulnerability Index introduced in Section 3.3.4. Grays Ferry (NGCC, 19 violations), Bruce Mansfield (coal, 12 violations) and Titus (retired coal, 7 violations) are among the top five plants with violations between 2011-2015, and are also among the ten highest-ranked plants for cumulative demographic, environmental and health burdens in nearby communities, as shown in **Figure 3.8**.

Figure 4.7c shows the state percentile for low income and minority populations of communities living near power 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.

Table 4.3 compares the total and average number of inspections and violations for each power plant class. Of the three plant classes, coal had the highest average number of inspections held over the five-year period, both within and outside of Environmental Justice Areas and overall combined. While the largest total number of violations and total and average number of inspections received between 2011-2015 were for coal plants, the average number of violations per plant is highest for NGCC plants over the last five years. NGCC plants also lead in violations per GWh, on average. Without giving consideration to the severity of a violation, coal is more heavily assessed per violation than NGCC and gas steam combined. These results suggest that coal plants are still responsible for the largest number of violations, but NGCC plants have a larger rate of violations received per facility and per unit generation (GWh). Of the NGCC plants that received violations during a noncompliance status period, at least one third of those violations was contaminant-related. For

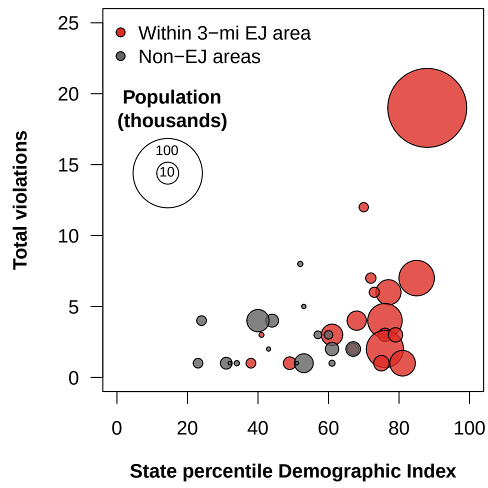

Figure 4.7a. Number of plant violations and state Demographic Index for nearby communities. Circle area reflects population size. Red indicates proximity to an Environmental Justice Area.

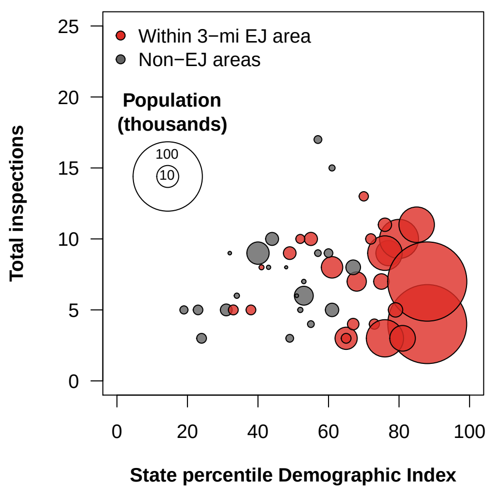

Figure 4.7b. Number of plant inspections and state Demographic Index for nearby communities.

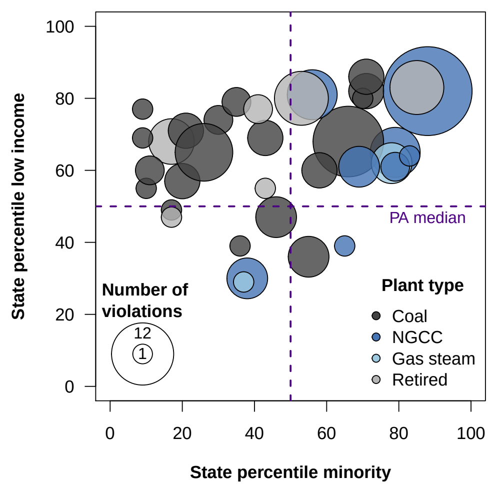

Figure 4.7.c. Comparison of plant violations and state percentiles for minority and low-income population fractions. Circle size denotes violations (2011-2015) for all plants, including currently retired.

Figure 4.7

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 Environmental Justice 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 per EJ Area plant	Average number per non-EJ Area plant
VIOLATIONS						
Coal	58	2.42	0.143	$25,590	2.80	2.14
NGCC	43	2.69	0.204	$4,576	4.22	0.71
Gas steam	5	2.50	0.472	$10,216	4.00	1.00
INSPECTIONS						
Coal	193	8.04	0.474	—	7.60	8.36
NGCC	62	3.88	0.295	—	5.11	2.29
Gas steam	14	7.00	1.32	—	9.00	5.00

coal facilities, at least 44% 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.

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.

There were only two gas steam plants evaluated, with both having a noncompliance status (one with a significant noncompliance) in the last 12 quarters (**Figure 4.9**). Three NGCC plants (out of 14 total) had one or more non-compliance status, of which two plants had the most severe designation of significant noncompliance. Nearly 65% of all coal plants had one or more quarters in a noncompliance status within the last 12 calendar quarters, with eight of those plants having a significant noncompliance. As shown in **Figure 4.9**, while coal did have a higher percentage of plants with a noncompliance status, all three plant classes had plants with the most severe noncompliance designation: significant noncompliance. 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 (at the facility-level, no facilities had the unknown compliance status). Hatfields Ferry, Armstrong and Mitchell had the highest number (ten) of calendar quarters in the most severe noncompliance status (S).

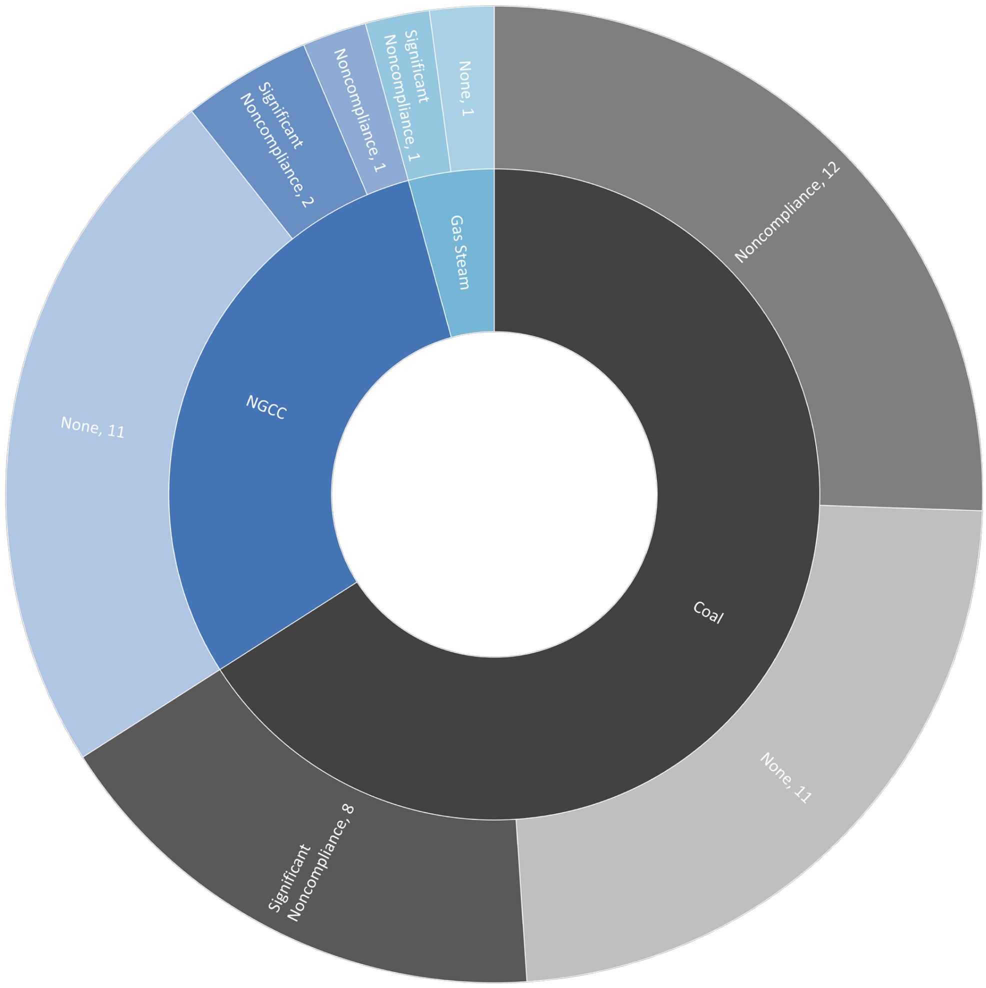

Figure 4.8: Most severe plant compliance status within the last 12 calendar quarters by plant class. Data are for all plants operational during timeframe. Circles segments are proportional to the total number of plants within that category. The inner circle shows the plant class. The outer circle is divided into three sections for each plant class: S (significant noncompliance), V (noncompliance), and None (no reportable violations).

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 Northampton which was given S status for only one quarter. 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. An increase in NGCC generation at existing power plants under the Clean Power Plan may therefore run the risk of increasing demand on plants with a historic record of environmental violations and therefore increase the burden on populations living near those plants.

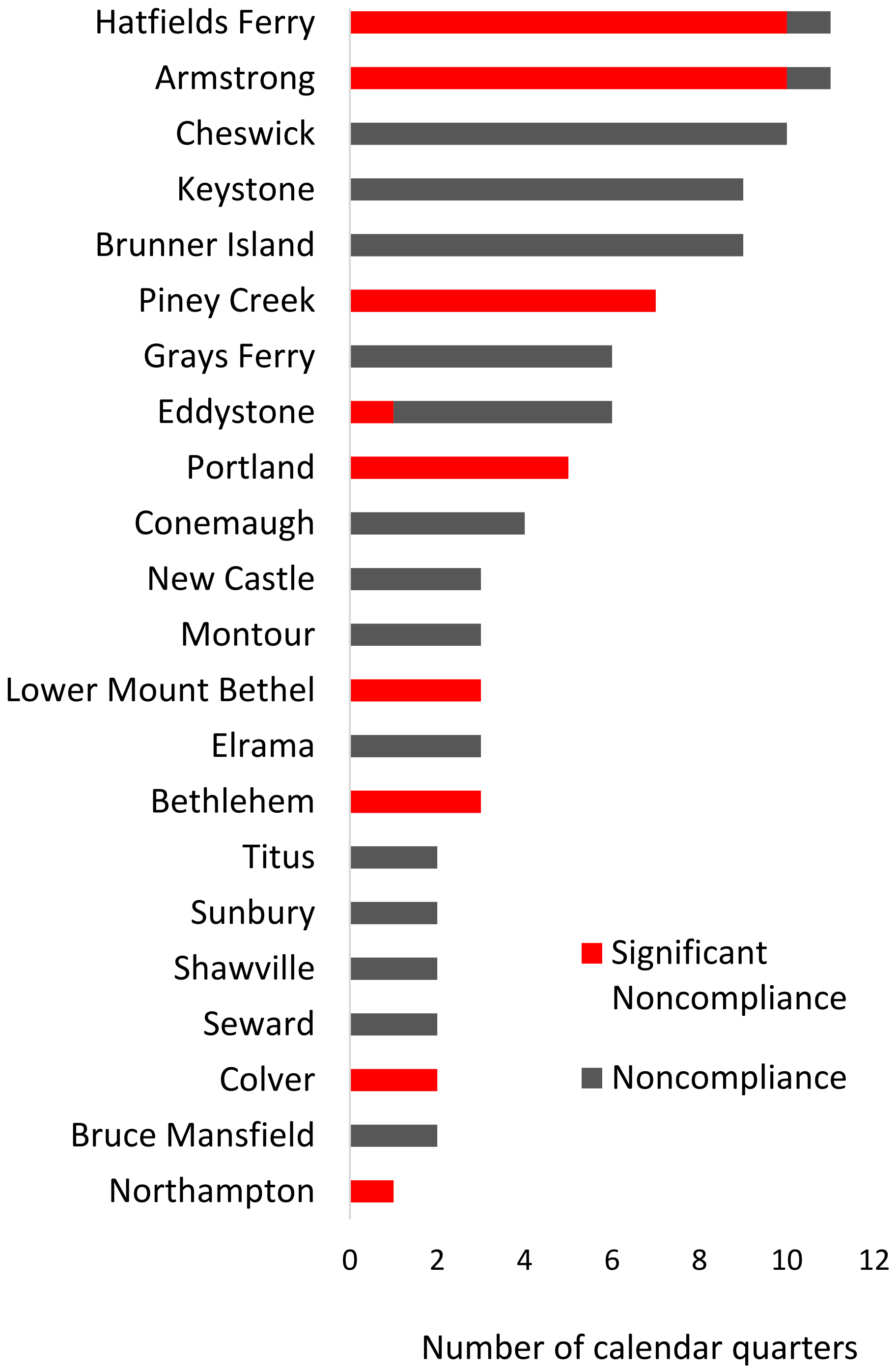

Figure 4.9: Facility compliance status for the last twelve calendar quarters. Facilities with no compliance status to report were not included; unknown status for a facility is included.

5. Air pollution from power plants: regional health impacts

In this section, we analyze the historic criteria air pollutant emissions from power plants in Pennsylvania 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 [91, 92]. 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 [93, 94]. 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 CO_2 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 [95] 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 of 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: 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 [32, 33], adverse birth outcomes [96], cardiovascular and respiratory disease [31], and mortality [34].

Power plants represent the greatest source of SO_2 emissions in the United States [97] 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 [98]. Low level chronic exposures to SO_2 may also contribute to morbidity and mortality such as chronic obstructive pulmonary disease [99]. In other contexts, epidemiological studies have found an association between SO_2 exposure with circulatory system deaths [100], exacerbation of asthma [101], and symptomatic bronchoconstriction [102]. 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 adverse respiratory health outcomes, such as increased hospitalizations [103], increased frequency of respiratory symptoms [104], and increased mortality [105] 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 [106], emergency department visits [107], cardiorespiratory morbidity [108], and mortality [109].

Preliminary epidemiology can help develop and test hypotheses about what adverse 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 [110]. 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 [81] and incorporates US EPA and ATSDR information on health effects linked to pollutant exposure [35, 80, 98].

** 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 [3], hospitalization for asthma and acute respiratory infections [4], and birth defects [5]. 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 [5]. 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 [6]. Other evidence suggests an association between some respiratory symptoms and estimates of coal-fired power plant NO_x emissions [111]. 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 [7].

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 Pennsylvania, 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 Pennsylvania. 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 Pennsylvania 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 [29]; 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 [112] 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 and nuclear resources [30]. We also differentiate between coal and coal refuse plants according to initial designations by the EPA and subsequent information from individual power plant websites. However, we note that many plants of all classes burn multiple fuels (e.g. petroleum at gas steam plants). We focus our results on power plants under the Clean Power Plan's jurisdiction that generated power in 2015.

5.2.2 Emissions analysis

A number of power plants in Pennsylvania rank among the highest emitters of total mass (tons) or rate (tons/MWh) of criteria pollutants in the United States. Homer City Generating Station, a coal plant located in Indiana County, emitted more SO_2 than any other power plant in the United States in 2015, and Keystone Generating Station in Armstrong County ranked 15th. Homer City, Keystone, and Bruce Mansfield Generating Station in Beaver County all ranked among the top 15 plants for total NO_x emissions in 2015.

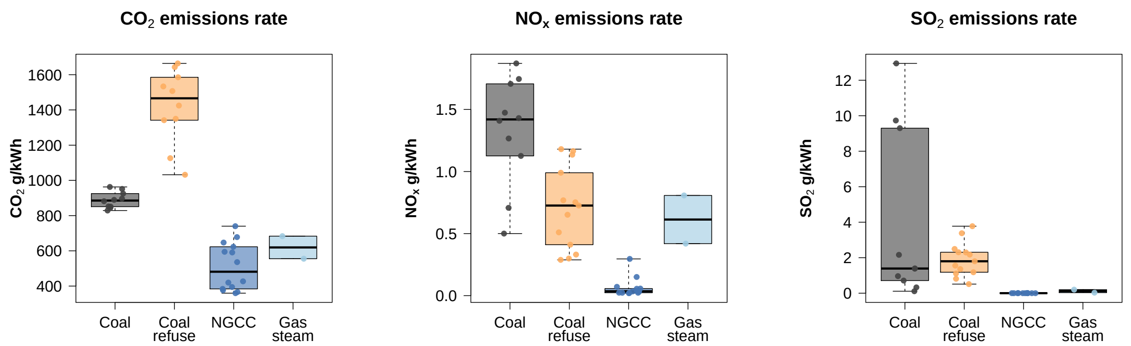

Figure 5.1: Box plot of 2015 power plant emission rates by plant class for CO_2, NO_x and SO_2.

Box plots of CO_2, NO_x and SO_2 emission rates from each power plant class are given in **Figure 5.1**. The *rate* of emissions—mass per kWh or 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. A number of the coal refuse plants produce steam used at nearby facilities for heating and other purposes, but this additional useful heat is not reflected in the emission rates reported here, which may therefore overestimate the emissions per unit of useful work from these plants.

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. Homer City has much higher SO_2 emissions than any other plant in the state, but only ranks 3rd for rate of these emissions per MWh. The second-highest emitter—Keystone—has the 9th highest emission rate. NGCC plants have a much lower rate of criteria pollutant emissions than coal plants, but the rate of NO_x emissions is not negligible and can still negatively impact air quality, as we will see in the next section. From a CO_2 standpoint, the plants classified as coal refuse plants tend to have a high emission rate per MWh, but as noted earlier these data do not reflect the value of any useful steam produced at these plants.

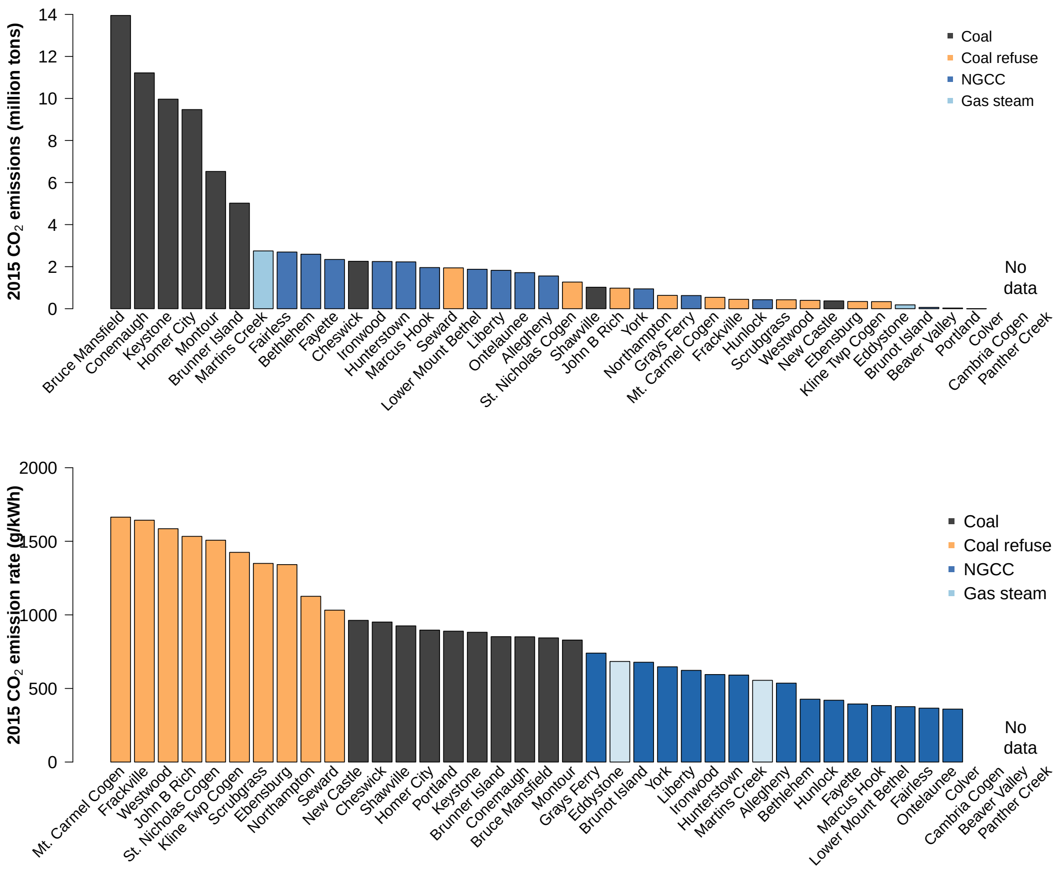

Figure 5.2: Bar chart of total mass (tons) and rate (g/kWh) of 2015 power plant CO_2 emissions.

Homer City had the third-highest rate of SO_2 emissions (g/kWh) in the country, ranking it very high for both mass and rate of SO_2 emissions. However, Homer City ranked much lower for carbon dioxide—47th for total CO_2 emissions nationwide and 85th for rate of CO_2 emissions—so a Clean Power Plan compliance approach that focused solely on CO_2 may not yield the greatest health benefits unless all of these measures are considered.

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.

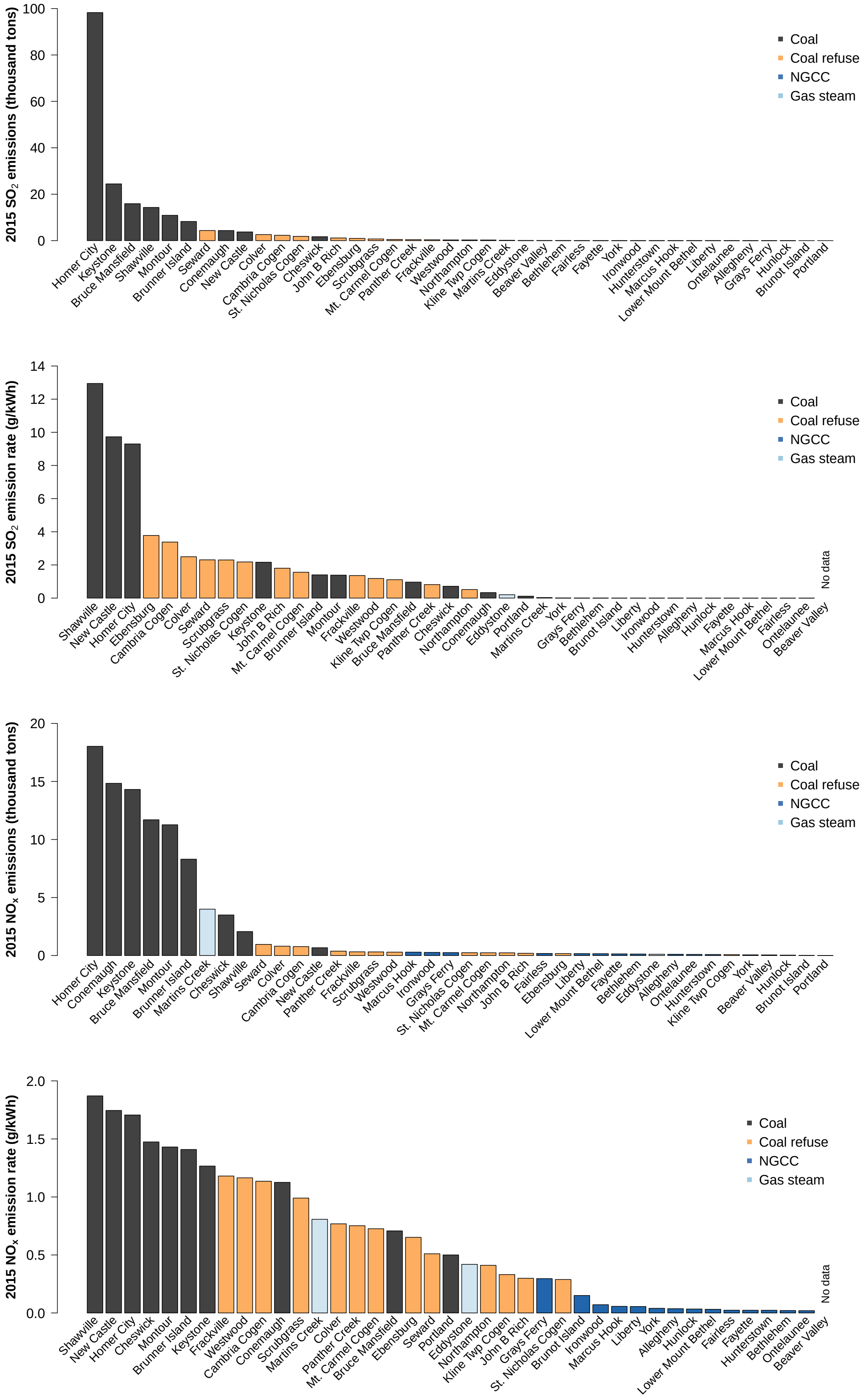

Figure 5.3: Bar chart of total mass (tons) and rate (g/kWh) of 2015 power plant SO_2 and NO_x emissions.

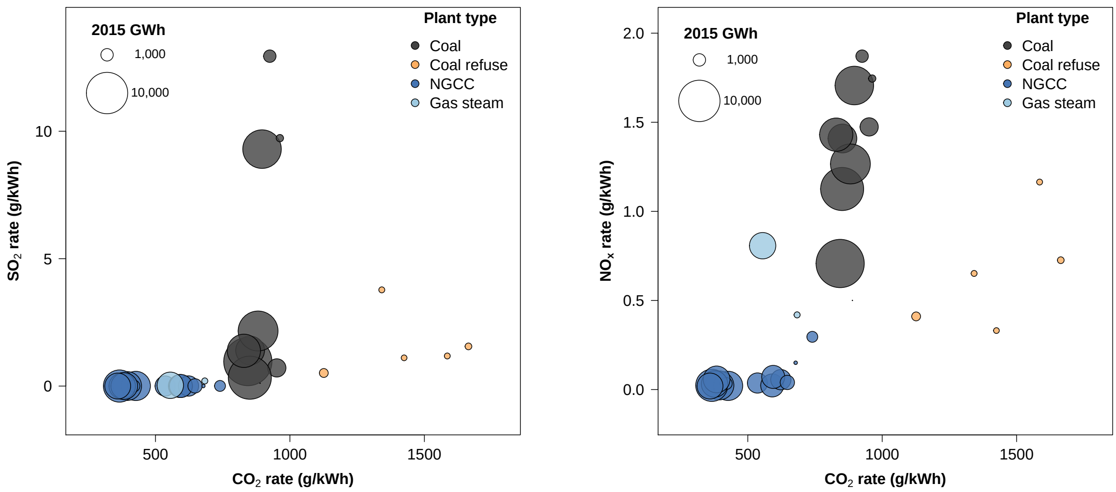

Figure 5.4: Bubble charts comparing 2015 plant CO_2 emission rates to SO_2 and NO_x emission rates. Circle size reflects GWh of generation in 2015.

We next consider these emissions in the context of background air quality. To do so, we analyze emissions of NO_x, a precursor for both ozone and $PM_{2.5}$ formation, along with three different measures of background air quality: 1) average pollutant concentrations modeled for the three-mile radius around each plant; 2) number of days with elevated pollutant concentrations within each plant's Air Quality Management District; and 3) NAAQS designations at the plant location.

Average 8-hour summer ozone and 24-hour $PM_{2.5}$ concentrations are reported in the EPA's EJSCREEN analysis for the year 2011 [2]. NAAQS non-attainment areas are designated by the EPA for 8-hour ozone and 24-hour $PM_{2.5}$ concentrations [38]. However, the NAAQS standards do not reflect the EPA's recent update to the ozone standard from 75 ppb to 70 ppb; they also do not reflect any information on areas with a lower number of poor air quality days than the non-attainment threshold. We therefore also provide a count of "exceedance days" from 2013-2015, defined as days when pollutant concentrations exceeded 8-hour ozone standards (70 ppb) or 24-hour $PM_{2.5}$ standards (35 $\mu g/m^3$); data and methods are described in Section 3.2.3.

In **Figure 5.5** (left), we plot each plant by the average nearby summer 8-hour ozone concentration from EJSCREEN and the number of ozone exceedance days in the last three years. The red color indicates plants located in NAAQS non-attainment areas for the 2008 ozone standard. The circle size indicates total NO_x emissions. The righthand plot shows similar data for 24-hour $PM_{2.5}$ concentrations and NAAQS non-attainment areas. We note that a number of plants in particular have large NO_x emissions in non-attainment areas with high average ozone concentrations and high counts of elevated ozone days. The $PM_{2.5}$ plot shows that certain plants have high emissions of NO_x in areas of both high average and high counts of days with elevated $PM_{2.5}$ concentrations, even if these areas are not out of attainment. The Clean Power Plan may offer opportunities to reduce ozone and $PM_{2.5}$ precursor emissions in some of these areas with high background levels of poor air quality.[1]

[1]The pollutant concentrations in these regions may be attributable in part to the power plants but also to numerous other emissions sources; this plot is not meant to attribute pollution to any one source.

Air quality benefits may be estimated by modeling changes in atmospheric concentrations based on emission reductions at these sources. These results here suggest the need to look carefully at not just at background levels of criteria pollutants but also the potential to reduce the numbers of days with high short-term concentrations of criteria pollutants.

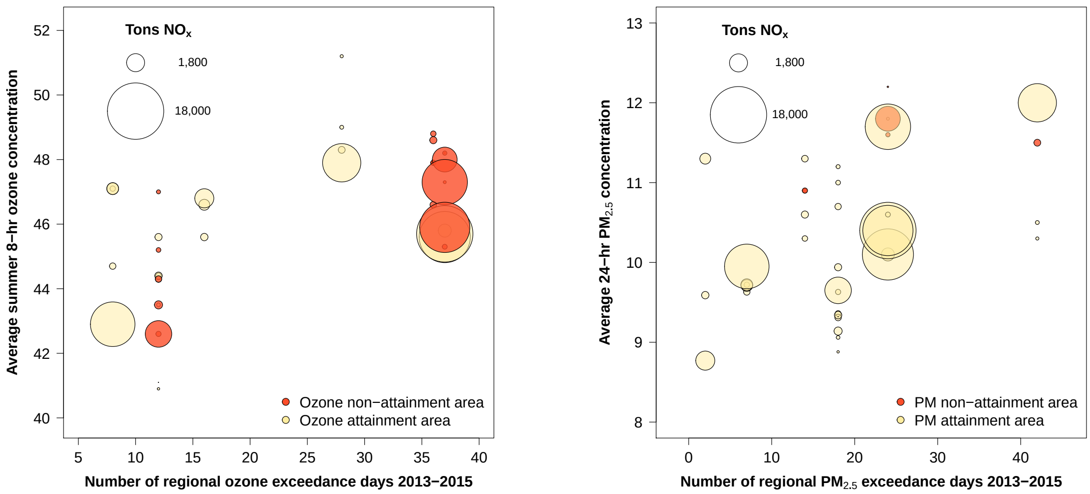

Figure 5.5: NO_x emissions and background air quality. Power plants plotted by number of pollutant exceedance days (2013-2015) in each plant's Air Management District and average pollutant concentrations for ozone (left) and $PM_{2.5}$ (right). Circle size reflects total NO_x emissions. Red indicates the plant in located in a non-attainment area for ozone (left) or $PM_{2.5}$ (right).

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 Pennsylvania, 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 72 different power plants operating in Pennsylvania, 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 [113], and 2) the Air Pollution Emission Experiments and Policy analysis model (AP2, formerly APEEP), which is described in Muller *et al.* [114] and was used in the National Research Council's *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* [115].

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* [116]. 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 [1, 19]. Due to computational limitations, reduced order modeling is preferred when evaluating the impacts of many individual power 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 [117, 118] as a function of plant class and US state. The Mercury and Air Toxics Standards (MATS) puts limits on power plant emissions of primary $PM_{2.5}$ [112], thus, to account for controls that may have been recently added to comply with MATS, the literature-based emission rates of primary $PM_{2.5}$ were adjusted down (when needed) to the MATS compliance level of 0.30 lb/MWh [86].

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 [119] 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.* [120], while the high estimate is based on epidemiological studies presented in Lepeule *et al.* [121]. Both sets of research are considered to have different strengths and weaknesses, and EPA states that is does not favor one result over the other [1].

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 [113]).

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 Pennsylvania is $8.9 billion in the low estimate and $20 billion in the high estimate (2010$). The AP2 model estimates the cost of health impacts as $5.9 billion. The non-CPP Plants have a health impact of $23.8 million (COBRA low estimate) and $53.9 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 Pennsylvania plants subject to the Clean Power Plan are 1,036 (low estimate) and 2,346 (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 Pennsylvania, we can assume that the ozone impacts from NO_x would contribute to additional health burdens 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.

Table 5.2: Estimated $PM_{2.5}$ health burden from Pennsylvania 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)	8,865	20,044
Adult mortality	1,036	2,346
Non-fatal heart attacks	127	1,280
Infant mortality	2	
Respiratory hospital admissions	287	
Cardiovascular hospital admissions	373	
Acute bronchitis	1,403	
Upper respiratory symptoms	25,570	
Lower respiratory symptoms	17,892	
Asthma ER visits	604	
Minor restricted activity days	757,752	
Work loss days	126,658	
Asthma exacerbations	27,177	

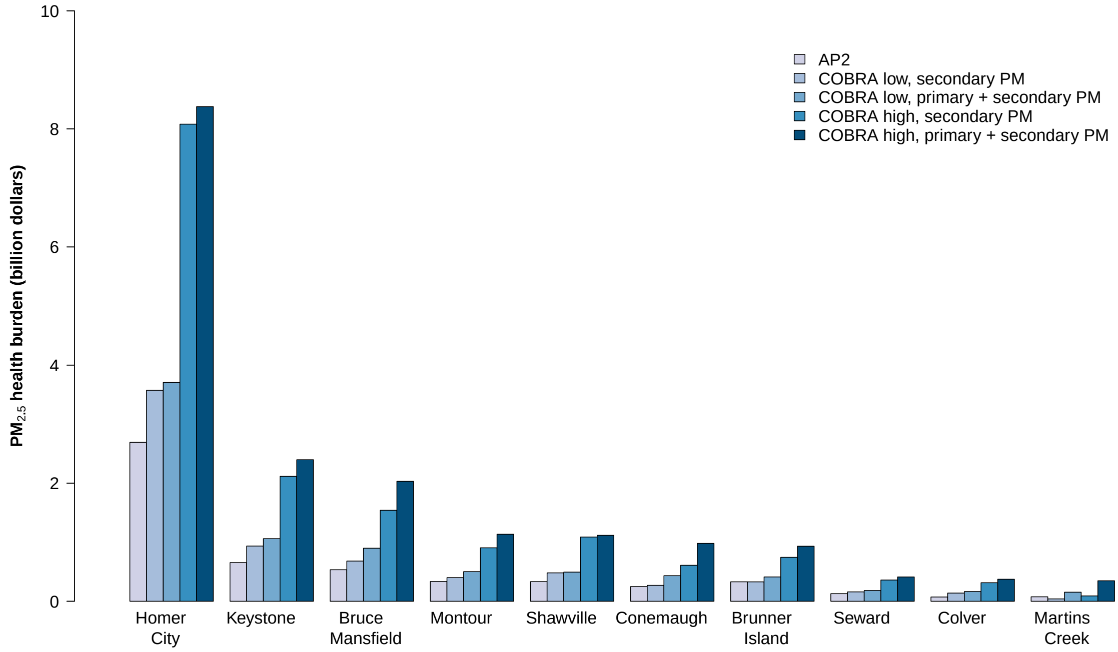

Figure 5.6: Bar chart of estimated cost of health burden for ten highest impact plants, by model. Estimates are from the models AP2 and COBRA, including high and low estimates from COBRA as well as results inclusive and exclusive of primary $PM_{2.5}$ emissions.

The 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 5.6**. 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 14% 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.

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.

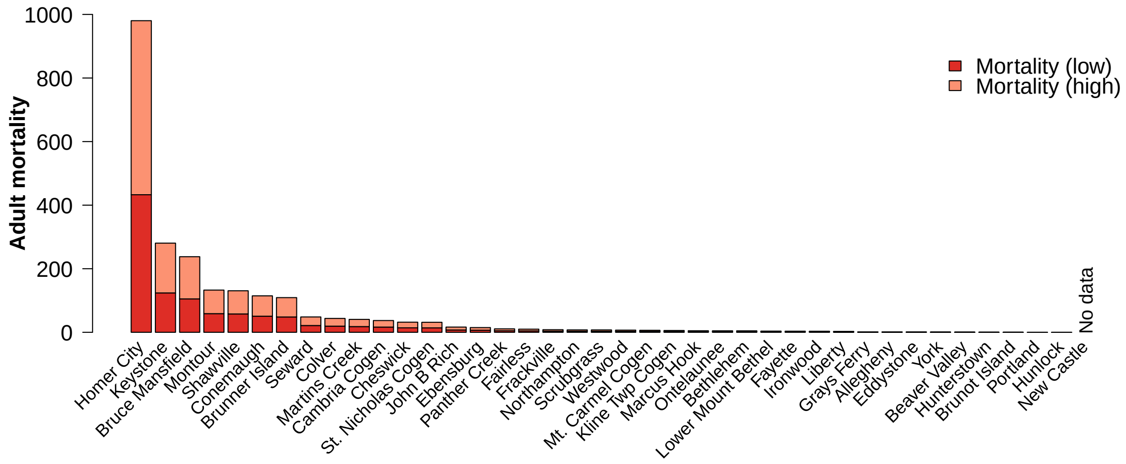

Figure 5.7: Bar chart of low and high mortality estimates for each power plant.

Figure 5.7 shows COBRA low and high estimates for mortality from each plant. Homer City has the most associated $PM_{2.5}$-related mortalities, with a low estimate of 433 and a high estimate of 981 early deaths attributable to criteria air pollutants emitted from its stack.[2] 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 30% of the health impacts are contained within the state of Pennsylvania. Estimated mortality in Pennsylvania, by county, is mapped in **Figure 5.8**. 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 Pennsylvania, not just plants in that county. The blue

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

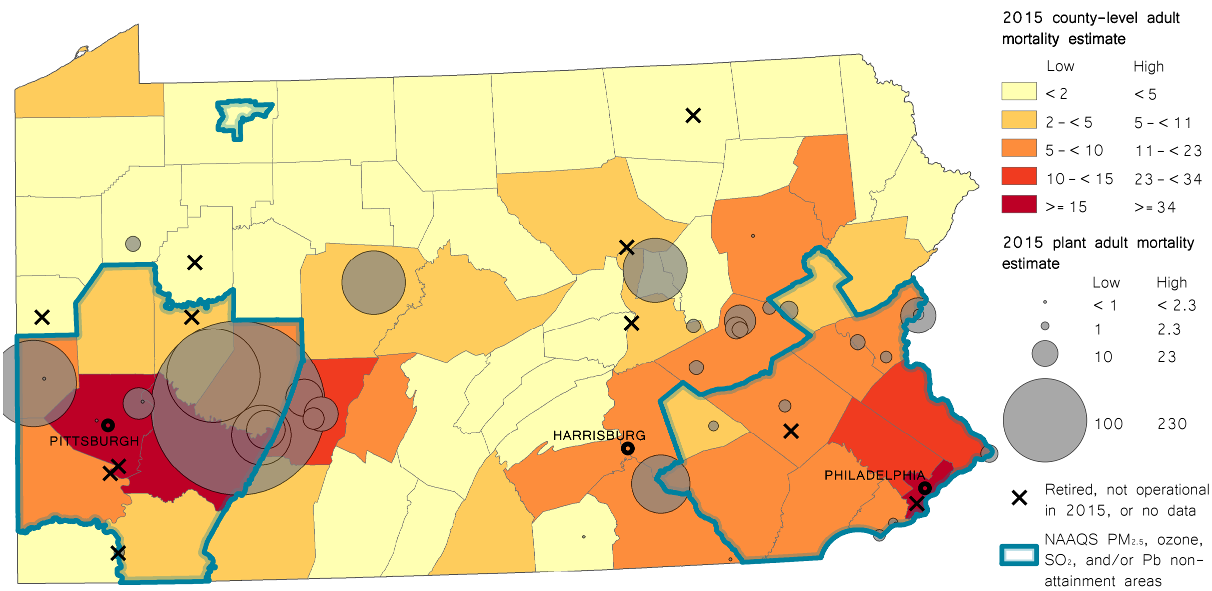

Figure 5.8: Estimated regional Pennsylvania power plant $PM_{2.5}$ mortality impacts by county. Color indicates total mortality burden for each county. Circle size represents total mortality impacts for a plant, which extend far beyond the county where each plant is sited. Blue line designates NAAQS non-attainment areas.

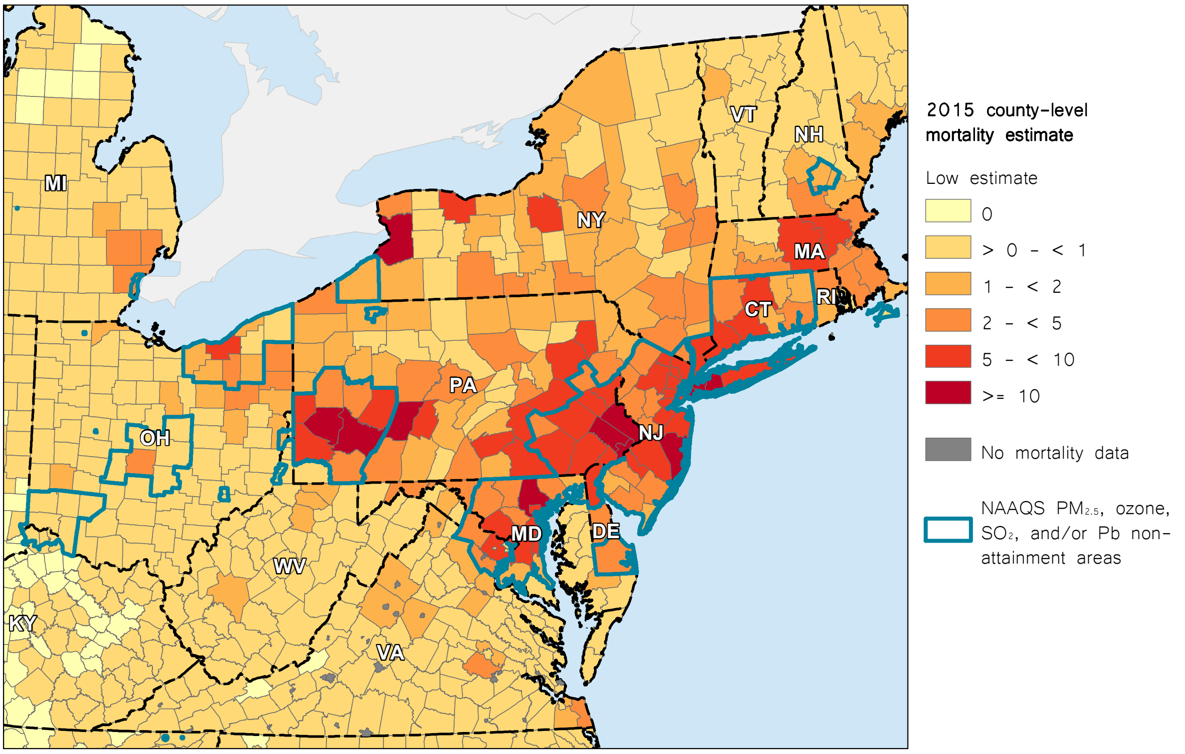

Figure 5.9: Estimated regional power plant $PM_{2.5}$ mortality impacts by county (low estimate). Color indicates health burden for each county. Blue line designates NAAQS non-attainment areas.

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.[3]

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 **Figure 2** in Appendix .1. Out-of-state mortality estimates are highest in New York (177 low, 400 high), New Jersey (106 low, 239 high), Maryland (67 low, 152 high), Ohio (58 low, 134 high) and Virginia (55 low, 126 high). Regional mortality estimates by county are mapped in **Figure 5.9**. An additional 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 5.10 provides a bar plot of estimated mortality by county for $PM_{2.5}$ impacts from 2015 power plant emissions. Allegheny, Westmoreland, Philadelphia, Montgomery, and Bucks 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.[4]

[3]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.

[4]Population data from EDDIE, 2014 estimates [47].

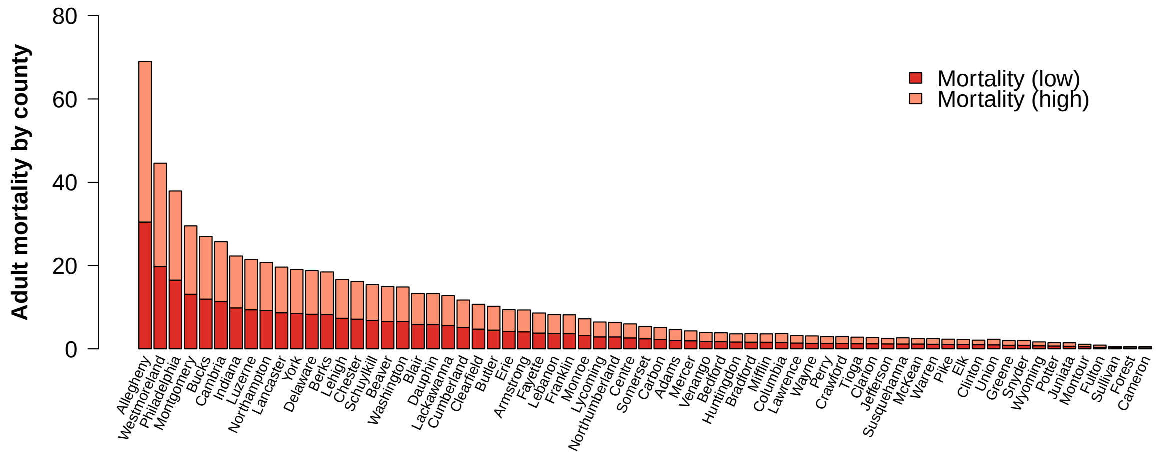

Figure 5.10: Bar chart of low and high estimates of mortality from primary and secondary $PM_{2.5}$ associated with all plants, by county.

The results give a range of costs of health burden per capita of approximately \$90-960 (low estimate) and \$210-2,200 (high estimate). The five counties with the highest per capita health burdens are Indiana, Cambria, Armstrong, Clearfield and Westmoreland, which are all clustered in the same area and are home to three of the five power plants with the highest cumulative $PM_{2.5}$ health impacts. These results are shown in the map in **Figure 5.11**. Areas designated as Environmental Justice Areas are outlined in blue. This map highlights where the health burden is higher per person, on average, than in other areas, as well as where this environmental health burden may fall on potentially vulnerable communities, highlighting potential areas that may experience disproportionate impacts from these plants.

Figure 5.12 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 show the highest burden of health impacts. The largest health burden from Homer City, for example, falls on Allegheny

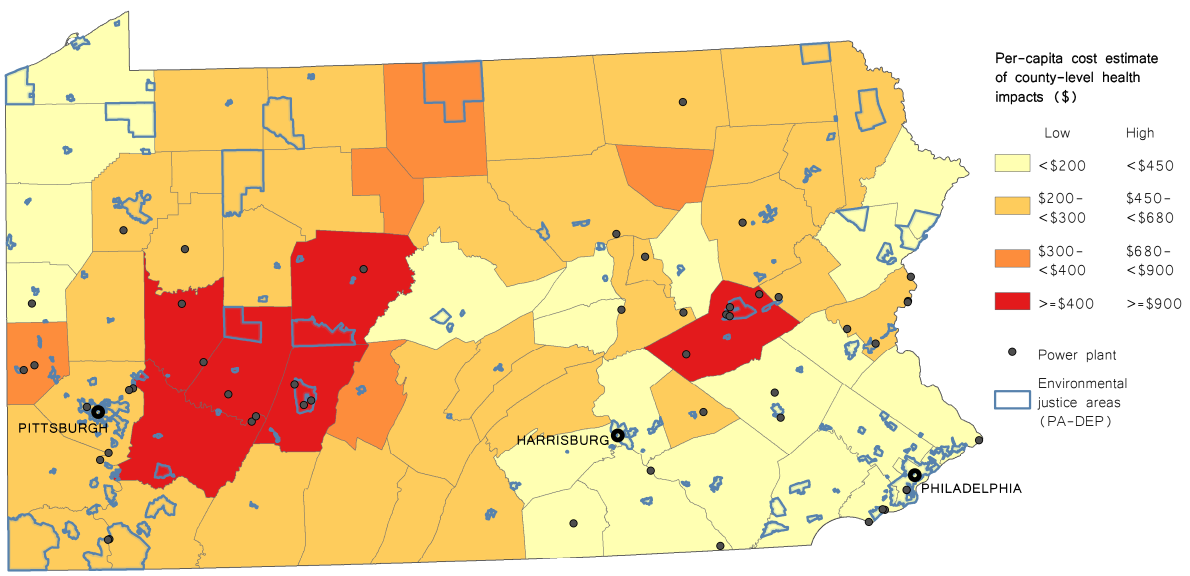

Figure 5.11: Map of estimated $PM_{2.5}$ health burden per capita by county, given in dollars (2010\$). PA DEP-designated Environmental Justice Areas are outlined in blue.

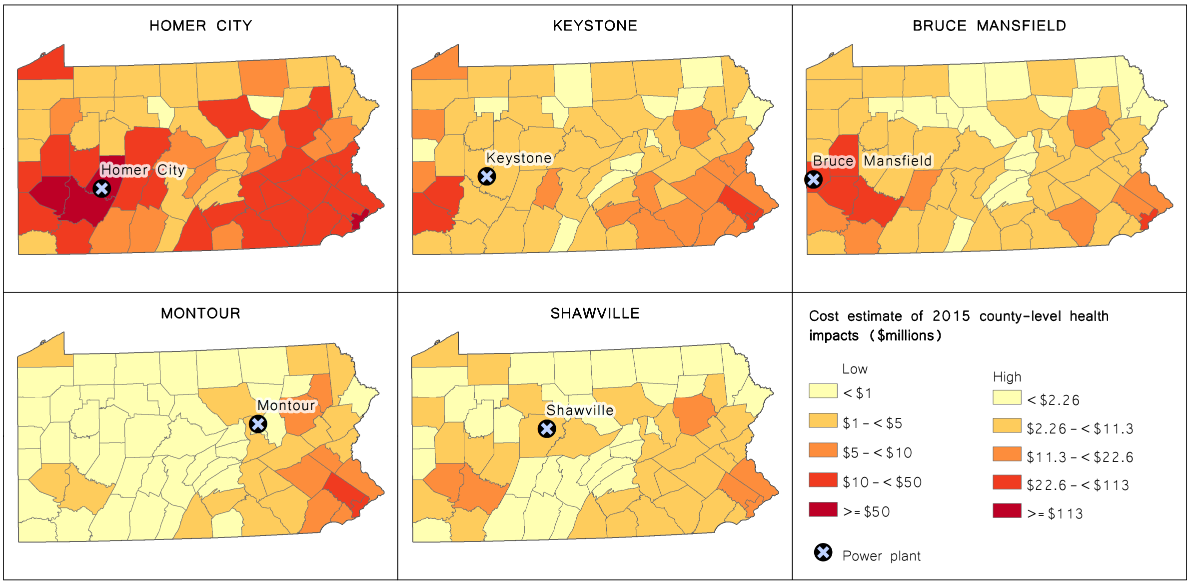

Figure 5.12: Estimated cost of health burden from the five plants with the highest 2015 impact. Shawville is expected to convert to NGCC in the coming years.

County, which is nearby but also has 14 times the population of Homer City's home county of Indiana; Bruce Mansfield similarly has the highest health impact on Allegheny County, while its home county of Beaver comes second; on the other side of the state Montour has the highest total impact in Philadelphia, even though it is further away, in part due to its population density as well as typical atmospheric conditions. We note Shawville is expected to undergo conversion to NGCC in the coming years. We show a separate visualization of these data on a single map in Appendix .1 **Figure** 4.

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 suscep-

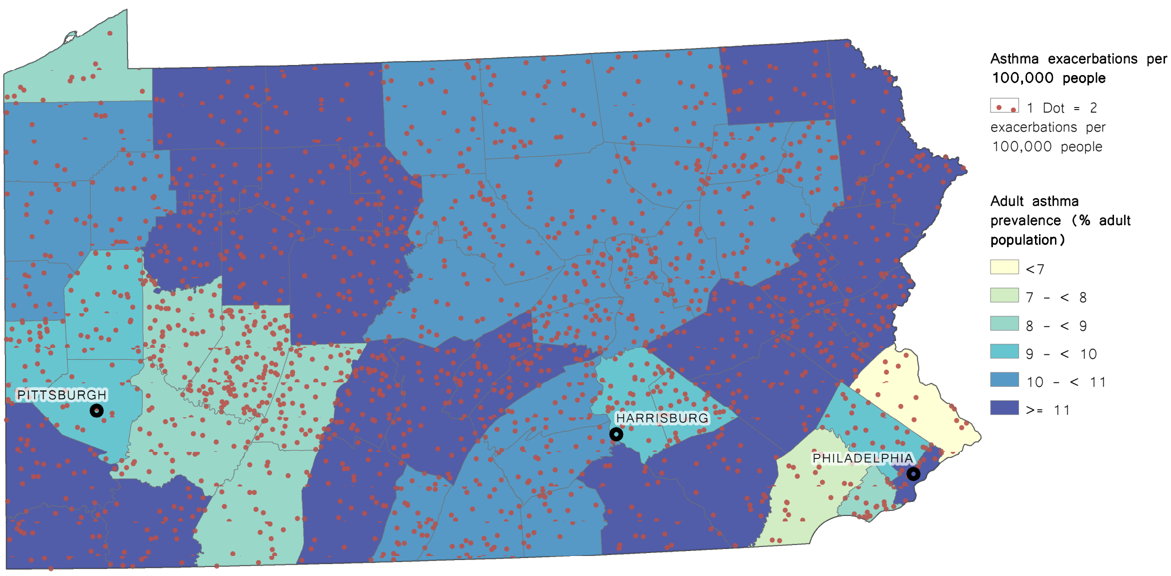

Figure 5.13: Asthma prevalence and asthma exacerbations per capita, by county.

tibility to adverse health outcomes from exposure to air pollutants like $PM_{2.5}$ [50]. Adult asthma prevalence data are accessed at the Pennsylvania EDDIE database and given for the years 2012-2014 [47]; data are available on the county or multi-county level. We note that asthma prevalence is self-reported, and therefore data contains a significant amount of inherent uncertainty. However, these numbers can still provide insight into some underlying trends. In **Figure 5.13**, we map the adult asthma prevalence along with the per capita asthma exacerbations per county. We use the per capita value to ensure that both prevalence and exacerbations are provided as a rate per unit population. We give the total asthma exacerbations per county in Appendix .1 **Figure 5**. Population-weighted results more heavily weight urban areas like Philadelphia and Pittsburgh.

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, 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 plants would require simultaneously considering the health burden per MWh from each plant. **Figure 5.14a** provides a comparison of both the total estimated cost of health burden and mass of CO_2 emissions from each plant. **Figure 5.14a** 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.

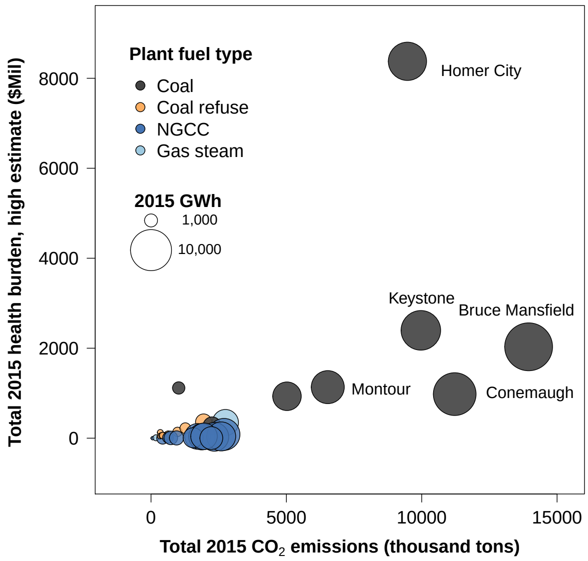

Figure 5.14a: 2015 cost of $PM_{2.5}$ health impacts from each power plant compared to total CO_2 emissions.

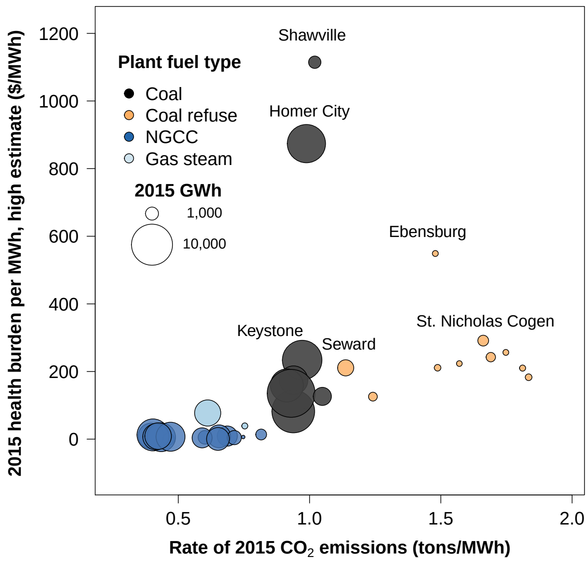

Figure 5.14b: Intensity of health impacts per MWh compared to intensity of CO2 emissions per MWh from each power plant in 2015.

Figure 5.14

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, which gives these plants up to four years to reduce emissions of mercury and other toxic air pollutants. These standards may lead to a reduction in SO_2 emissions from certain plants from 2015 levels following the installation of scrubbers and other technologies to reduce toxic air pollutant emissions. 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 Pennsylvania, we re-ran the COBRA models assuming a maximum SO_2 emission rate of 1.5 lbs/MWh. In 2015, only two coal-burning plants in Pennsylvania emitted SO_2 below this rate, according to EPA AMPD data [25]. Under these assumptions, the aggregate mortality count from the COBRA models for plants covered by the Clean Power Plan is reduced by 58% to 431 (low estimate) and 976 (high estimate). The impacts of some of the highest impact plants are reduced by a larger fraction, including by 85% at Homer City and 90% at Shawville.[5] Under this SO_2 limit, the five plants with the highest estimated mortality impacts are Bruce Mansfield (85 low, 192 high), Homer City (61 low, 139 high), Keystone (58 low, 131 high), Conemaugh (51 low, 115 high) and Montour (39 low, 89 high).

Pennsylvania also recently introduced additional "Reasonable Available Control Technology" standards for power plants to help the state comply with NAAQS ozone standards [123]. These standards set a NO_x emissions target of 0.12 lbs/MMBtu. These and other standards are projected by the state to also reduction SO_2 emissions to approximately 0.2 lbs/MMBtu [124]. While the actual emission rate per plant will vary, we capped historic plant emission rates of SO_2 and NO_x to these values to test the sensitivity of our results to these rules. We find that the SO_2-related $PM_{2.5}$ cost of health impacts drops by 61% and mortality estimates fall to 248 (low) and 562 (high) a year. The NO_x-related $PM_{2.5}$ cost of health impacts falls by 52%, and mortality estimates fall to 42 (low) and 95 (high). Taken together with primary $PM_{2.5}$, which we assume stays the same because we capped these emission estimates to reflect MATS standards, net mortality estimates under these standards would be 438 (low) and 991 (high).

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 14 operational NGCC plants in Pennsylvania in 2015 were 18 (low) and 41 (high), with corresponding health burden cost estimates of $154 and $349 million dollars. In addition, the two gas steam plants were estimated to have a mortality impact of 18 (low) and 42 (high) and associated health burden cost of $158 and $358 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.

[5]Shawville is currently expected to undergo conversion to natural gas, which would reduce emissions further [122].

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 Pennsylvania 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 Pennsylvania 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 Pennsylvania 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. In Section 3 we found that 75% of NGCC plants in Pennsylvania are located in communities with a higher fraction minority population than the state median; the summed populations living within three miles of NGCC plants in Pennsylvania are 44% minority, much higher than the state median of 9%, state average of 21%, and population living near coal plants of 11%. The most urban plants—those with the largest population densities in the surrounding area—are all NGCC plants. 75% of both coal and NGCC plants are located in communities with a larger low income population percentage than the state medians. Four of the five plants that rank highest on our Cumulative Vulnerability Index, reflecting aggregate health, environment and demographic burdens, are NGCC plants as well. 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. However, NGCC plants had the highest average number of violations in recent years, over 1.5 times higher than coal, and received less than half the number of inspections compared to coal plants. **These data suggest that a shift from coal to existing NGCC may reduce many burdens associated with coal generation but potentially increase the demand on plants in urban, low income and minority 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 1000 (low estimate) and 2,300 (high estimate) associated with primary and secondary $PM_{2.5}$ resulting from combustion at Pennsylvania 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 \$5.9 billion (AP2), \$8.9 billion (COBRA low), and \$20 billion (COBRA high) in our three models. These aggregated burdens fall heaviest on heavily populated areas in Allegheny, Westmoreland, Philadelphia, Montgomery and Bucks counties; the counties with the highest power plant $PM_{2.5}$ health burden per capita are Indiana, Cambria, Armstrong, Clearfield and Westmoreland. 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.

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 $50 to $500 for coal plants alone in the low 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, certain coal plants had the highest individual total emissions of CO_2, but the highest rate of CO_2 emissions per MWh were found at coal refuse plants, and the highest health impacts per MWh were found at a mix of coal and coal refuse plants.

We also found the highest aggregated health burden frequently fell on counties with larger populations, but the highest per capita health burdens were located in a set of southwest counties with a large concentration of coal plants in them or nearby. 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 vulnerabilities or existing environmental burdens that may make them more susceptible to adverse health outcomes. These data suggest the need to account for both disparities in health burdens as well as cumulative 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 Pennsylvania has focused primarily on coal, NGCC and fossil steam plants, given the current fuel mix of Pennsylvania 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 greenhouse gas emission reductions of switching from coal to natural gas [22, 125], 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 [126], and so this methane leakage greatly increases the climate impacts of using natural gas as a fuel.

The National Renewable Energy Laboratory estimates that Pennsylvania has the economically competitive potential to generate 3 TWh per year from wind and 102 TWh per year from utility-scale PV, which would provide nearly half of Pennsylvania's 2015 in-state generation of 216 TWh [30]; the total technical potential for renewable electricity generation is much higher, including 48 TWh [127] to 50 TWh [128] from rooftop solar; 35 TWh from wind [127]; 1,367 TWh from utility-scale solar [127]; and even 23.5 GWh from offshore wind in Lake Erie [129]. These numbers show significant potential for growth from 2015 generation levels of 3.35 TWh from wind and 300 GWh from all solar resources [30].

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 active and recently retired coal plants are under consideration for repowering with natural gas. 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 Pennsylvania, 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 [130]. 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 Pennsylvania 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 Pennsylvania 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 Pennsylvania.

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Appendix .1. Additional figures

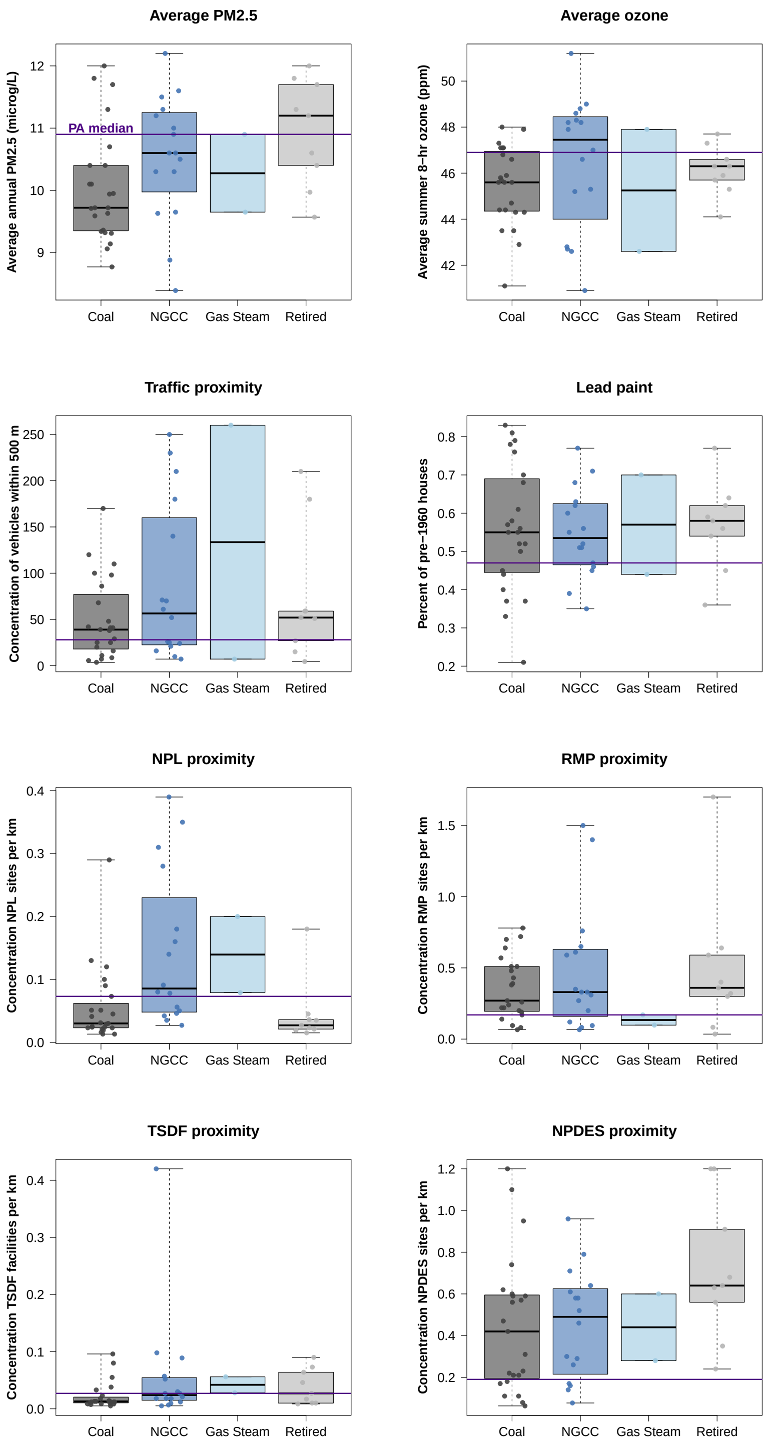

Figure 1: Box plot of environmental indicators (raw values) in regions near power plants. Purple line indicates state median.

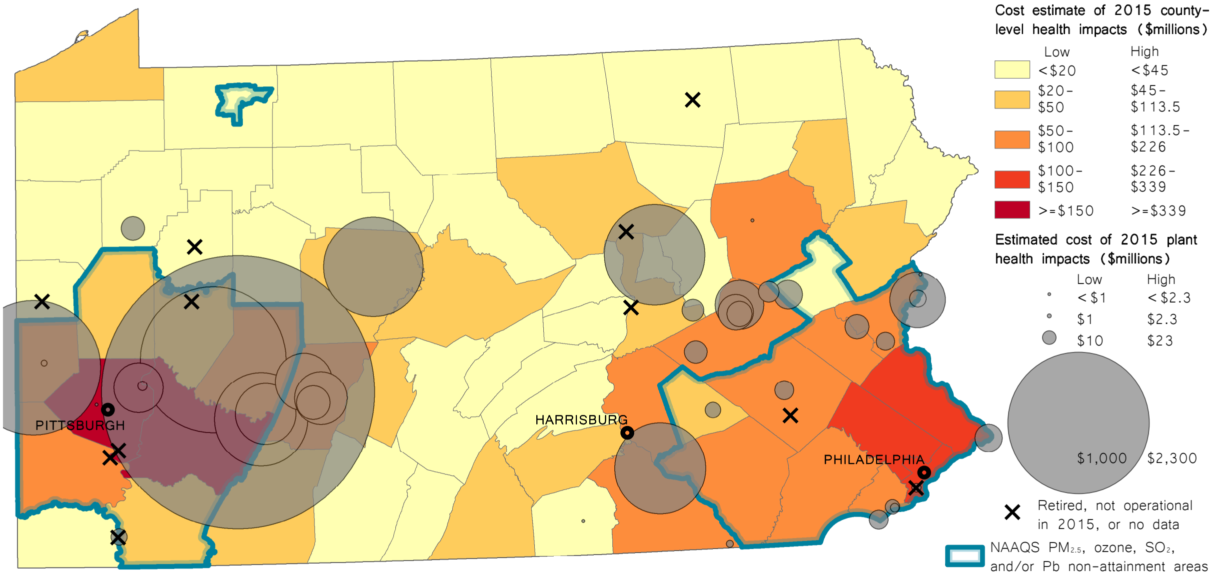

Figure 2: Estimated cost of health impacts from $PM_{2.5}$ associated with Pennsylvania power plants, by county.

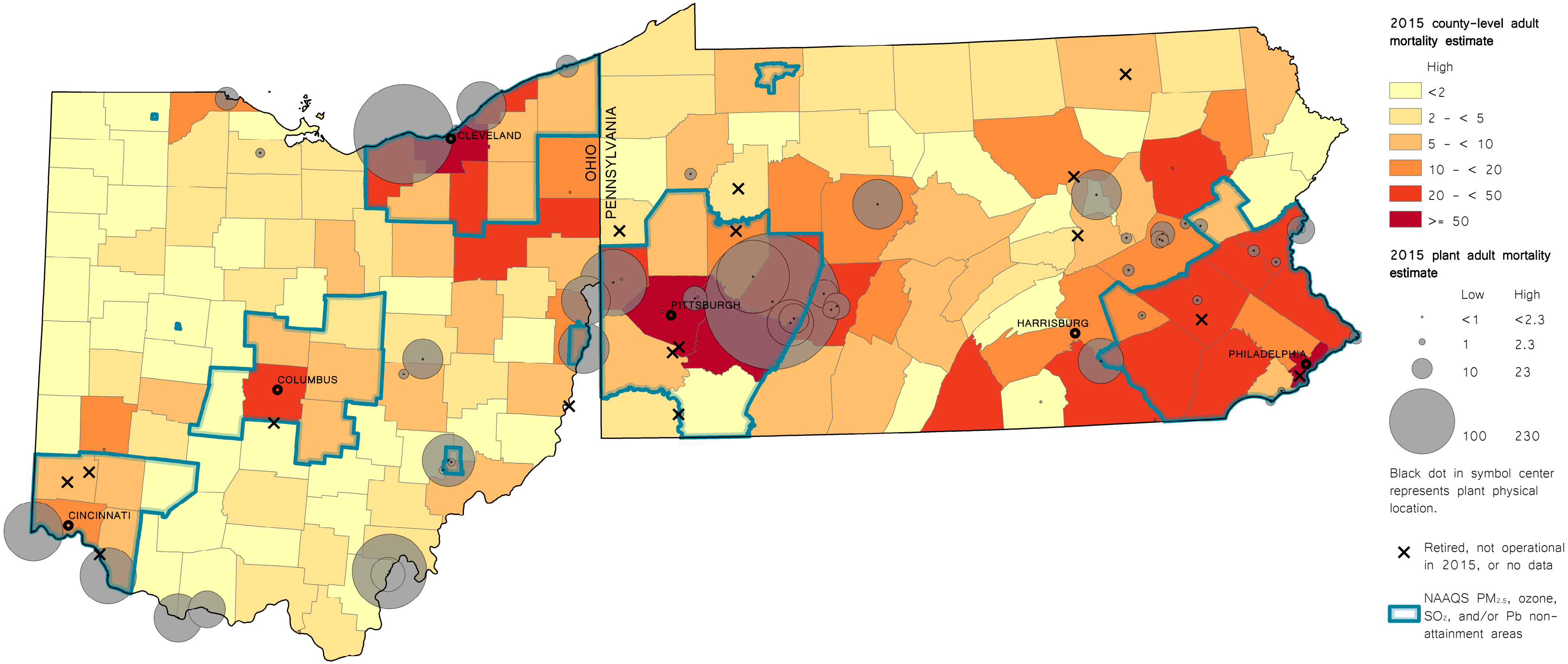

Figure 3: $PM_{2.5}$ mortality impact estimates, by county, associated with combined Ohio and Pennsylvania power plant emissions in 2015. Circle size represents nationwide mortality impacts from each plant. Blue outlines indicate regions where air quality is designated as non-attainment under NAAQS.

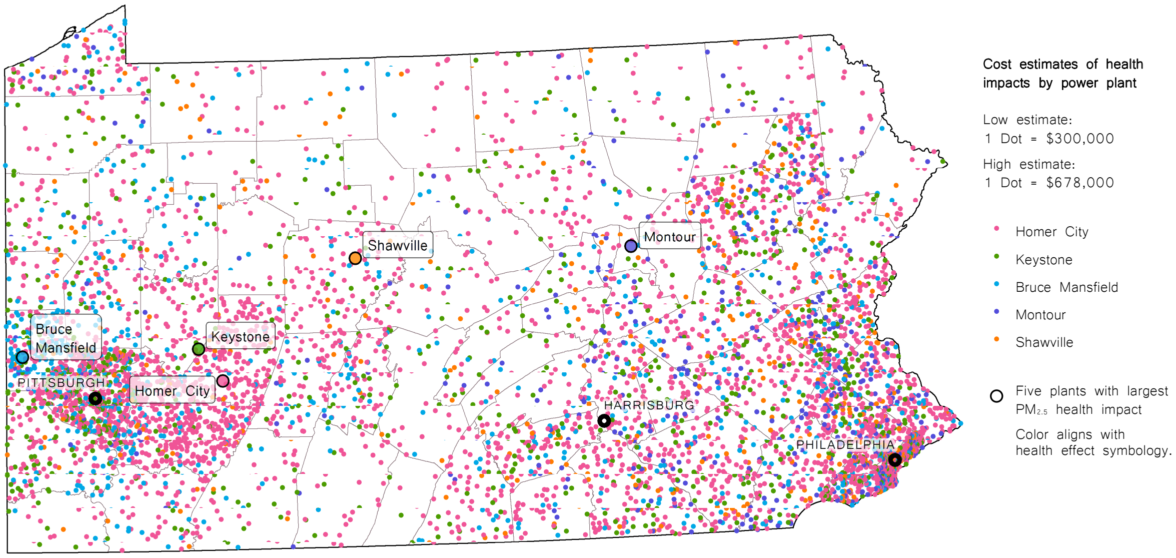

Figure 4: Dot map of estimated $PM_{2.5}$ health burden costs for five high impact plants, by county. Dots represent intensity of health impacts, not individual incidents.

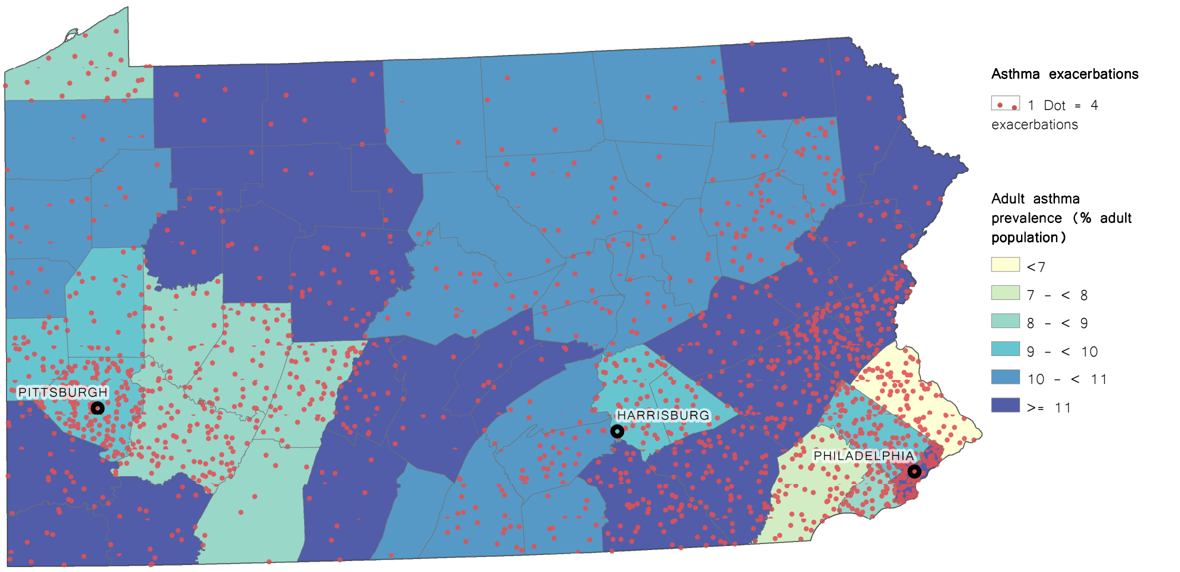

Figure 5: Asthma prevalence and total asthma exacerbations, by county.

Appendix .2. Reference tables

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

ORISPL ID	Report name	Clean Power Plan name	Additional names
55710	Allegheny	Allegheny Energy Units 3 4 & 5	
3178	Armstrong	FirstEnergy Armstrong Power Station	
10676	Beaver Valley	AES Beaver Valley Partners Beaver Valley	
55690	Bethlehem	Bethlehem Power Plant	
6094	Bruce Mansfield	FirstEnergy Bruce Mansfield	
3140	Brunner Island	PPL Brunner Island	
3096	Brunot Island	Brunot Island	
10641	Cambria Cogen	Cambria Cogen	
8226	Cheswick	Cheswick Power Plant	
10143	Colver	Colver Power Project	
3118	Conemaugh	Conemaugh	
10603	Ebensburg	Ebensburg Power	
3161	Eddystone	Eddystone Generating Station	
3098	Elrama	Elrama Power Plant	
55298	Fairless	Fairless Energy Center	
55516	Fayette	Fayette Energy Facility	Dynegy Fayette II
50879	Frackville	Wheelabrator Frackville Energy	
54785	Grays Ferry	Grays Ferry Cogeneration	
3179	Hatfields Ferry	Hatfields Ferry Power Station	
3122	Homer City	Homer City Station	
3176	Hunlock	Hunlock Power Station	
55976	Hunterstown	Hunterstown	
55337	Ironwood	PPL Ironwood LLC	Talen Ironwood
10113	John B Rich	John B Rich Memorial Power Station	Gilberton Power Company
3136	Keystone	Keystone	
50039	Kline Twp Cogen	Kline Township Cogen Facility	Northeastern Power Cogen
55231	Liberty	Liberty Electric Power Plant	
55667	Lower Mount Bethel	Lower Mount Bethel Energy	
55801	Marcus Hook	FPL Energy Marcus Hook LP	NextEra Energy Marcus Hook
3148	Martins Creek	PPL Martins Creek	
3181	Mitchell	FirstEnergy Mitchell Power Station	
3149	Montour	PPL Montour	
10343	Mt. Carmel Cogen	Foster Wheeler Mt Carmel Cogen	
3138	New Castle	New Castle Plant	
50888	Northampton	Northampton Generating Company LP	
55193	Ontelaunee	Ontelaunee Energy Center	
58420	Panda Liberty	Moxie Liberty Generation Plant	
58426	Panda Patriot	Moxie Patriot Generation Plant	
50776	Panther Creek	Panther Creek Energy Facility	
54144	Piney Creek	Piney Creek Project	
3113	Portland	Portland	
3169	Schuylkill	Schuylkill Generating Station	
50974	Scrubgrass	Scrubgrass Generating Company LP	
3130	Seward	Seward	
3131	Shawville	Shawville	
54634	St. Nicholas Cogen	St Nicholas Cogen Project	
3152	Sunbury	Sunbury Generation LP	
3115	Titus	Titus	
50611	Westwood	Westwood Generation LLC	
55524	York	York Energy Center	

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
PA EJ Area	Demographic	Designated if 20% of population or more live in poverty or 30% or more are minority	PA DEP	Unknown
Low birthweight	Health	Percent of babies born below 2500 g	ACS, EDDIE	2008-2012
Disability	Health	Percent of population with one or more of six difficulties: hearing, vision, cognitive, ambulatory, self-care, or independent living	ACS, EDDIE	2008-2012
Cancer prevalence	Health	Percent of population with a cancer diagnosis of any kind	ACS, EDDIE	2012
Children's uninsurance	Health	Percent of children under age six without health insurance	ACS, EDDIE	2008-2012
Asthma	Health	Percent of adults reporting they currently have asthma	EDDIE	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 Pennsylvania power plants, 2015 (COBRA model unless otherwise indicated).

Health impact	Homer City	Keystone	Bruce Mansfield	Montour	Shawville	Conemaugh	Brunner Island	Seward	Colver	Martins Creek
$Millions health burden (high)	8,377	2,397	2,031	1,135	1,117	980	932	412	373	347
$Millions health burden (low)	3,704	1,060	898	501	493	433	412	182	165	154
$Millions health burden (AP2)	2,691	654	534	334	332	249	330	129	72	76
Adult mortality (high)	980	281	238	133	131	115	109	48	44	41
Adult mortality (low)	433	124	105	59	58	51	48	21	19	18
Non-fatal heart attacks (high)	496	140	118	66	77	58	54	24	23	20
Non-fatal heart attacks (low)	53	15	13	7	7	6	6	3	2	2
Respiratory hosp. admissions	121	35	29	16	16	14	13	6	5	5
Cardiovascular hosp. admissions	157	45	37	21	21	18	17	8	7	7
Acute bronchitis	589	170	138	81	80	68	67	29	24	25
Upper respiratory symptoms	10,737	3,092	2,506	1,471	1,454	1,238	1,227	526	431	464
Lower respiratory symptoms	7,513	2,164	1,754	1,030	1,017	866	858	368	302	325
Asthma ER visits	251	72	58	36	35	29	30	12	10	12
Minor restricted activity days	317,906	91,440	74,110	43,719	43,115	36,742	36,314	15,595	12,913	13,859
Work loss days	53,147	15,291	12,377	7,310	7,209	6,140	6,074	2,607	2,154	2,316
Asthma exacerbations	11,409	3,287	2,665	1,565	1,545	1,316	1,303	491	459	495