Fine Particulate Matter and Mortality

IN ALLEGHENY COUNTY, PA

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AUTHOR

Iyad Kheirbek
Environmental Consultant

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Mr. Norman Anderson,
Environmental Public Health Consultant

Dr. Polly Hoppin,
University of Massachusetts Lowell

Dr. Evelyn O. Talbott,
University of Pittsburgh, Graduate School of Public Health

Mr. Jim Kelly,
Allegheny County Health Department

Mr. Chris Guignon,
EvolveEA

Mr. Court Gould,
Sustainable Pittsburgh

Mr. Matt Mehalik,
Sustainable Pittsburgh

CONTENTS

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

Despite improving air quality, current levels of fine particulate matter ($PM_{2.5}$) in ambient air remain harmful to public health in Allegheny County and throughout the US. To evaluate the public health risks of $PM_{2.5}$ in the Allegheny County region, this report applies methods widely used by the US Environmental Protection Agency (EPA), City and State health and environmental agencies, and researchers to calculate the number of deaths associated with exposures to recent levels of fine particulate matter ($PM_{2.5}$). Studies have consistently shown increased risks of disease and death associated with $PM_{2.5}$ exposures at levels commonly seen in urban regions and documented the public health improvements associated with reduced exposures.

This report finds that large numbers of premature deaths (up to 12% of total deaths, or, 770-1640 deaths per year estimated in 2012-2014) are attributed to current $PM_{2.5}$ levels in Allegheny County. Impacts vary by population characteristics including age, income and race. The majority of the mortality associated with $PM_{2.5}$ exposures occurred at air quality levels below–or in attainment with–National Ambient Air Quality Standards (NAAQS). Improvements in air quality in the region could provide a large and immediate public health benefit. Interventions in many US urban areas have already demonstrated significant air quality improvement from civic efforts to reduce levels of poor air quality to beyond current federal standards for clean air. For example, if the Pittsburgh area's air quality had been as clean as Boston, New York or San Francisco, several hundred deaths could have been avoided each year. Much like other health risk factors, such as smoking or poor diet, air pollution is rarely recorded as the cause of a hospitalization or death in official hospital or vital statistic records. However, the number of deaths associated with air pollution can be calculated using methods that combine estimates of the amount of air pollution that people breathe, the baseline health status of those populations, and information from peer-reviewed studies that report increases in risk resulting from people being exposed to pollutants at these levels. In this report, we use EPA's Benefits Mapping and Analysis Program (BenMAP-CE) to integrate exposure estimates derived from air quality monitoring and modeling, risk estimates from epidemiological studies, and local death rates to estimate the number of deaths in Allegheny County associated with $PM_{2.5}$ and the distribution of $PM_{2.5}$-attributable deaths in the region by geographic area and area poverty status and race.

This report estimates that from 2009-2011, exposures to $PM_{2.5}$ levels from anthropogenic sources (air pollution generated by man- made activities) of air pollution were associated with 900 (95% CIi: 660-1,140) to 1,920 (95% CI: 1,160-2,680) deaths each year in Allegheny County among adults over 30 years of age, or 7% to 14% of all deaths in the county in this age group, depending on the choice of risk estimate. Applying more recent air monitoring data and assuming underlying death rates and patterns have remained the same, in 2012-2014, this report estimates that $PM_{2.5}$ levels were still associated with 770 (95% CI: 560-970) to 1,640 (95% CI: 970-2,300) premature deaths, (depending on choice of risk function), or 6% to 12% of deaths in Allegheny County each year.

The report also finds that from 2009-2011 in the larger seven county Pittsburgh metropolitan statistical area (MSA) (Allegheny, Armstrong, Beaver, Butler, Fayette, Washington, and Westmoreland Counties), an estimated 1,700 (95% CI: 1,200-2,100)-3,700 (95% CI: 2,200-5,000) adult deaths can be attributed to PM2.5 each year, depending on the choice of risk function.

Most of the $PM_{2.5}$-attributable deaths in Allegheny County occurred in older populations, with 80% of the burden falling on adults over 65 years of age, reflecting the patterns in deaths by age group (78% of all deaths in the county occur among those over 65 years of age). Additionally, higher $PM_{2.5}$-attributable mortality burdens were observed in the highest poverty areas of Allegheny County, with high poverty townships (>20% of residents living below the federal poverty level) experiencing 33% higher $PM_{2.5}$-attributable mortality burden than low poverty townships. This inequity was due mainly to higher baseline mortality rates in low income areas, reflecting poorer underlying health status, including higher rates of underlying respiratory and cardiovascular disease. Despite fewer $PM_{2.5}$- attributable deaths in more affluent communities, levels in 2009-2011 still contributed to 100 (95% CI: 70-120)-210 (95% CI: 130-310) $PM_{2.5}$-attributable deaths per 100,000 residents above 30 years of age in these neighborhoods. These findings show that all communities have a stake in improving air quality in Allegheny County, as air pollution burdens everyone who lives in the region.

This report also finds that townships with high percentages of minorities (>30% of the population identifying as Black, Hispanic, Asian American, or American Indian and Alaskan Native in the 2010 US Census) had 18% higher rates of $PM_{2.5}$-attributable deaths than those with low percentages of minorities (<10% minority population). The pattern reflects that of low income populations, where townships with relatively higher percentages of minorities also experienced higher baseline mortality rates, reflecting poorer underlying health status.

i CI: Confidence interval

This report also compares levels in the 7-county Pittsburgh MSA to those observed in other US cities, and estimates the difference in the number of $PM_{2.5}$- attributable deaths that would have occurred had levels of had levels of $PM_{2.5}$ in Pittsburgh matched those of the other cities. Had Pittsburgh's air been as clean as the air in the majority of other US cities during 2009-2011, there would have been fewer deaths in the Pittsburgh MSA. Many $PM_{2.5}$-attributable deaths could have been avoided had levels met those of other major metropolitan areas such as Boston (490-1090 fewer deaths), Dallas (20-50 fewer deaths), New York City (230-510 fewer deaths), San Francisco (300-680 fewer deaths), Seattle (630-1390 fewer deaths), and up to 1,000-2,400 fewer deaths had the Pittsburgh MSA met levels seen in the cleanest MSA.

Conclusions/Recommendations

1. Actions to reduce emissions, especially from dominant sources, will lead to public health benefits by reducing chronic disease and premature mortality.

a. Because air pollution causes a substantial percentage of deaths in Allegheny County, priority measures should be taken to reduce exposure, especially targeting the largest sources of pollution.

b. Recent estimates of local emissions suggest that over half of primary $PM_{2.5}$ emissions in Allegheny County are generated from local industrial sources (including metals processing and industrial fuel combustion), while 20% are generated from on-road and non-road mobile sources[ii].

c. Improving levels to those seen in other US cities of similar size could produce significant public health benefits. Even marginal improvements in $PM_{2.5}$ could provide a large public health benefit - a 10% improvement in $PM_{2.5}$ levels (equivalent to moving Pittsburgh from the bottom 15th percentile of cities to the bottom 40th percentile of cities) could have avoided 100-220 deaths each year.

d. Actions to reduce emissions will lead to public health benefits across all communities and populations, including infants and children by reducing incidences of respiratory and cardiovascular diseases and extending life expectancy.

2. Significant detrimental public health impacts from $PM_{2.5}$ occur at levels below the National Ambient Air Quality Standards.

a. Currently, Allegheny County is the only county in the US that is non-attainment of federal standards for each of three pollutants. $PM_{2.5}$ ozone and sulfur dioxide[iii.]

b. The majority of the mortality associated with $PM_{2.5}$ exposures occurs at levels below the National Ambient Air Quality Standards (NAAQS) indicating that significant health benefits can be realized from efforts to improve air quality beyond the current federal standards for clean air. There is a lack of evidence for a threshold to the negative effects of $PM_{2.5}$. Therefore, the region should not consider eventual attainment with $PM_{2.5}$ NAAQS as reaching a level of acceptable public health risk, especially for populations at increased risk such as children, pregnant women, the elderly and those with lung and heart disease.

3. Public use datasets on cause- specific hospitalizations and emergency department visits at the neighborhood-level are required for additional evaluations.

a. While the most important health outcome associated

ii Source: EPA 2011 National Emissions Inventory VII, Criteria Pollutants by 14 Major Tiers. Available at: http://www3.epa.gov/ttn/ chief/net/2011inventory. http://www3.epa.gov/ttn/ chief/net/2011inventory.html

iii Non-attainment of the 24-hr PM2.5 standard, 8-hr ozone standard, and 1-hr SO2 standard. Source: https://www.epa.gov/air-trends/air- quality-design-values with $PM_{2.5}$ is premature death, multiple other morbidity outcomes are also linked to $PM_{2.5}$ exposure. These include emergency department visits and hospitalizations for cardiopulmonary disease, impaired lung development in children, adverse birth outcomes and cancer.

b. There are relatively few local, publicly-available data that make possible quantification of these outcomes in Allegheny County. Public use datasets with de-identified data would be useful to researchers and analysts in conducting air pollution- attributable health analyses to quantify the burden on illness and related health-care costs.

4. Densely populated areas of low income and minority residents should be prioritized as areas requiring immediate pollution reductions.

a. Analyses showed a disproportionately higher $PM_{2.5}$-attributable mortality burden in low income and high minority areas as compared to higher income and low minority areas. This was due mainly to higher baseline mortality rates in these areas (reflecting poorer underlying health and higher rates of adverse health outcomes), and to a lesser extent higher PM2.5 exposures. This suggests that while exposures should be reduced throughout the region, particular attention should focus on densely populated areas of low income and minority residents to reduce pollutant-attributable health disparities.

b. Regional emissions reductions will provide benefits to all populations but will provide the greatest benefit to those with highest underlying risk and therefore will also reduce health disparities.

5. Air quality should be improved throughout the county because nearly all areas experience elevated exposures as compared to most US cities and all population demographics experience a large burden of $PM_{2.5}$-attributable premature deaths.

a. More affluent communities, despite being only somewhat less polluted than lower income areas, still showed a considerable $PM_{2.5}$-attributable mortality burden.

b. This underscores the need to improve air quality throughout the county, both to protect the most vulnerable citizens and improve health outcomes throughout the county.

6. Reducing emissions from sources in the region will have co-benefits not quantified in this report.

a. While this report estimates the deaths due to long-term PM2.5 exposures, air pollution emissions contribute to many other adverse environmental and health outcomes.

b. Interventions that reduce emissions of $PM_{2.5}$ and its precursors can provide important co-benefits such as reduction of emissions of greenhouse gases, carcinogenic air toxics, and ozone precursors. Economic benefits include decreased costs associated with health burdens such as lost productivity, hospitalizations and emergency department visits and talent attraction and retention.

INTRODUCTION

Photo: Annie O'Neill, The Documentary Works

INTRODUCTION

Fine particulate matter ($PM_{2.5}$) is a common air pollutant associated with multiple adverse health outcomes including increased hospitalizations, emergency department visits, and deaths due to respiratory and cardio-vascular disease[2]. Estimates based on exposure levels in 2005, suggest that each year in the United States approximately 130,000 deaths are attributed to ambient $PM_{2.5}$ exposures leading to over 1 million years of life lost[3]. The harmful effects of $PM_{2.5}$ have been documented in many peer- reviewed studies, expert panel reviews and regulatory scientific assessments. Epidemiological research, toxicological studies, and controlled human studies have demonstrated the negative health effects of fine particulate matter exposures that include cardiovascular and respiratory diseases and cancer[2].

$PM_{2.5}$ is small enough to be inhaled deep into lungs and has been shown to negatively affect multiple systems of the human body[4]. Effects of exposures to $PM^{2.5}$ include increased airway inflammation, decreased lung function, changes in blood flow, increased blood pressure and blood clot formation, changes in heart rhythm, and markers of inflammation[2]. Long- term (chronic) exposures to $PM^{2.5}$ have been shown to cause systemic oxidative stress and inflammation and is associated with atherosclerosis in humans[4]. Evidence from epidemiological studies of Pittsburgh's population have reported associations between particle pollution and increased risks of death, cardiopulmonary hospitalizations, emergency department visits for asthma and adverse birth outcomes, consistent with other studies conducted throughout the United States[5, 6]. Although air quality

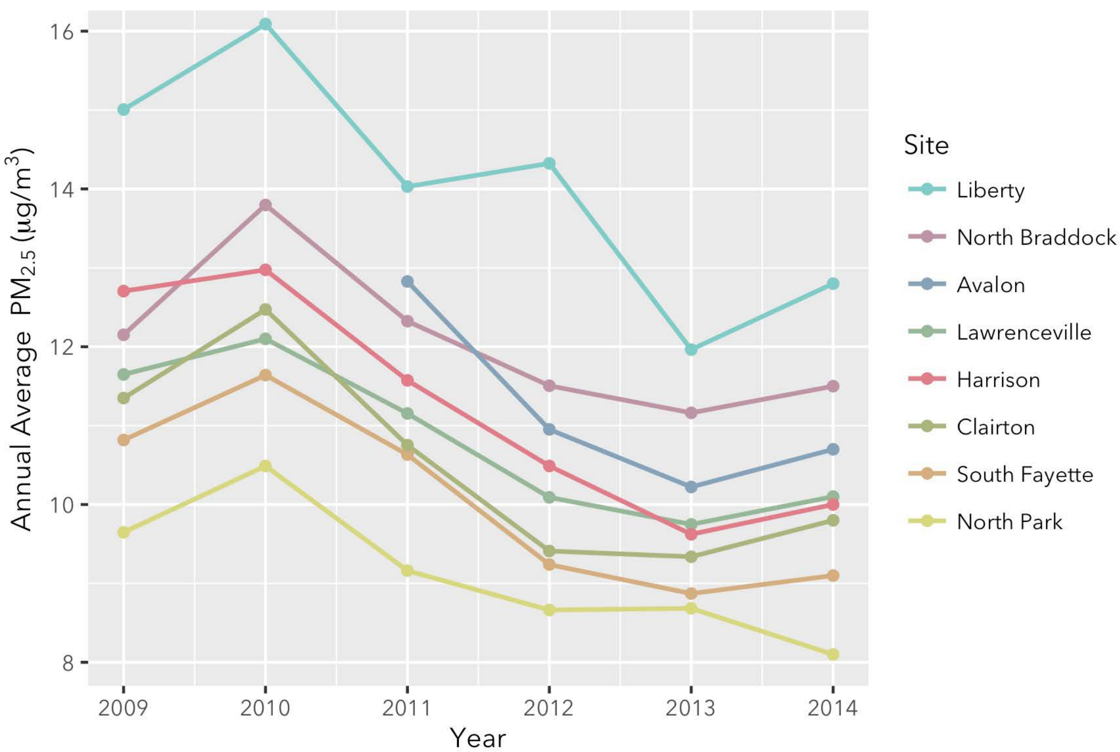


Figure 1: Trends in annual average PM2.5 concentrations at EPA Federal Reference Method Monitors in Allegheny County

has improved, epidemiologic studies show that statistically significant risks continue at and below levels that currently exist in Allegheny County[6]. The accumulation of evidence of the negative health effects of $PM_{2.5}$ led the US Environmental Protection Agency (EPA) to conclude that a causal relationship exists between long-term exposures to $PM_{2.5}$ and premature mortality[2].

There is also little evidence for a population-level threshold of $PM_{2.5}$ effects on short-term (acute) or long-term (chronic) health outcomes, indicating that benefits of air pollution reductions can be realized well below current levels and the National Ambient Air Quality Standards (NAAQS), particularly among vulnerable populations such as the very young, old, and those with preexisting medical conditions. For example, a prior analysis by the EPA showed that even if the 2007 PM2.5 NAAQS were met in Pittsburgh (annual: 15 µg/m^3, 24-hr: 35 µg/m^3) in 2005-2007, chronic $PM_{2.5}$ exposures would still be associated with 11.8% of deaths due to ischemic heart disease and acute exposures would still cause 1.1% of cardiovascular hospitalizations[7]. More recent analyses have demonstrated risks of mortality from $PM_{2.5}$ due to long- term and short-term exposures at levels well below those seen in Allegheny County[8].

While $PM_{2.5}$ exposures can affect everyone, those at most risk are the young, old, and those with preexisting medical conditions, including lung or heart conditions or diabetes. In 2013, 9.6% of adults in Pennsylvania had asthma, higher than the national average (9.0%) and ranking 17th among US states[9]. Moreover, Pennsylvania ranked 12th highest in rates of heart attack deaths in 2011 among US States[10]. Although not the primary driver of these health outcomes, particulate matter pollution can exacerbate these conditions and is important, preventable, risk factor. Unlike many other preventable disease risk factors, everyone is exposed to ambient air pollution. In recent years, despite declines in ambient $PM_{2.5}$ concentrations (Figure 1), levels in Allegheny County still exist at concentrations that can cause hospitalizations and deaths. On average, PM2.5 levels in the Pittsburgh Metropolitan Statistical Area (MSA) in 2012-2014 were higher than 85% of US cities[11].

While there is extensive evidence on the harmful effects of $PM_{2.5}$ on human health, it is often challenging to distill large amounts of evidence from complex research to communicate the health risks of air pollution and the avoided health events associated with reducing exposures. Air quality health impact assessment is one commonly used approach that combines data on air quality exposures, risks of morbidity and mortality associated with exposures, and population susceptibility to estimate the benefits of reducing air pollution levels or the contribution of current levels to overall public health burdens. These methods have been used extensively to produce quantitative estimates for informed air quality management and planning, research, and advocacy efforts to support emissions reduction strategies. Examples include risk analyses conducted by EPA in support of updated National Ambient Air Quality Standards[12] and recent analyses in New York City to support clean heating fuel policies[13]. These same methods have been used recently by public health agencies to assess public health burdens of $PM_{2.5}$ on premature mortality in New York City[14] and Minnesota[15] and are used by the Centers for Disease Control and Prevention (CDC)[16] to create indicators of premature mortality of benefits of improving $PM_{2.5}$ levels. Internationally, this analytic approach has been used to estimate the contribution of ambient air pollution to the global burden of disease[16].

In this report, we apply these air quality health impact methods to assess the number of deaths attributable to chronic exposures to recent levels of $PM_{2.5}$ in the Allegheny County region of southwestern Pennsylvania. We utilize data on current exposures to ambient $PM_{2.5}$ and baseline rates of death in the population then apply risk estimates derived from the published epidemiological literature to calculate the number of $PM_{2.5}$-attributable deaths in the local population. We then describe the geographic and socioeconomic variation in $PM_{2.5}$-attributable mortality in the region and explore the benefits that would be possible if air quality levels in the region were similar to those seen in other US cities.

METHODS

Members of GASP (Group Against Smog and Pollution), CAPS (Center for Atmospheric Particle Studies, and ACCAN (Allegheny County Clean Air Now) meet on the Neville Island Bridge to learn how to "read smoke" coming from nearby pollution sources.

Photo: Annie O'Neill, The Documentary Works

OVERALL METHOD

To assess the $PM_{2.5}$ associated mortality burden we applied methods adopted from those routinely used by the US EPA and state/local regulatory agencies to calculate the change in mortality that could occur if air pollutant levels were reduced to meet air quality benchmarks or regulatory goals[12, 14, 17, 18]. These methods use risk estimates from published studies that relate ambient air pollution concentrations to health outcomes in a health impact function. The health impact function includes the risk estimates, air pollution levels, baseline mortality rates, and exposed populations to estimate changes in deaths attributed to changes in air pollution. In a log-linear model of this relationship, the pollutant- attributable mortality is calculated as:

$$\Delta I=(1-e^{\beta\Delta X})\times P\times I_0$$

Where ΔI is the change in deaths associated with ΔX, the change in air pollution concentration being evaluated, β is the effect estimate derived from the epidemiological study being used to estimate pollutant risk, P is the exposed population and I_o is the population's baseline rate of mortality.

We conducted the health impact calculations using EPA's Benefits Mapping and Analysis Program Version 1.08 Community Edition (BenMAP-CE)[19]. BenMAP-CE has been used extensively for analyses of regulatory programs and the National Ambient Air Quality Standards (NAAQS)[12, 17, 18] and State air quality management planning. We supplemented BenMAP-CE's databases with locally relevant mortality data. Figure 2 describes the overall approach, with each data input described in detail in the following sections.

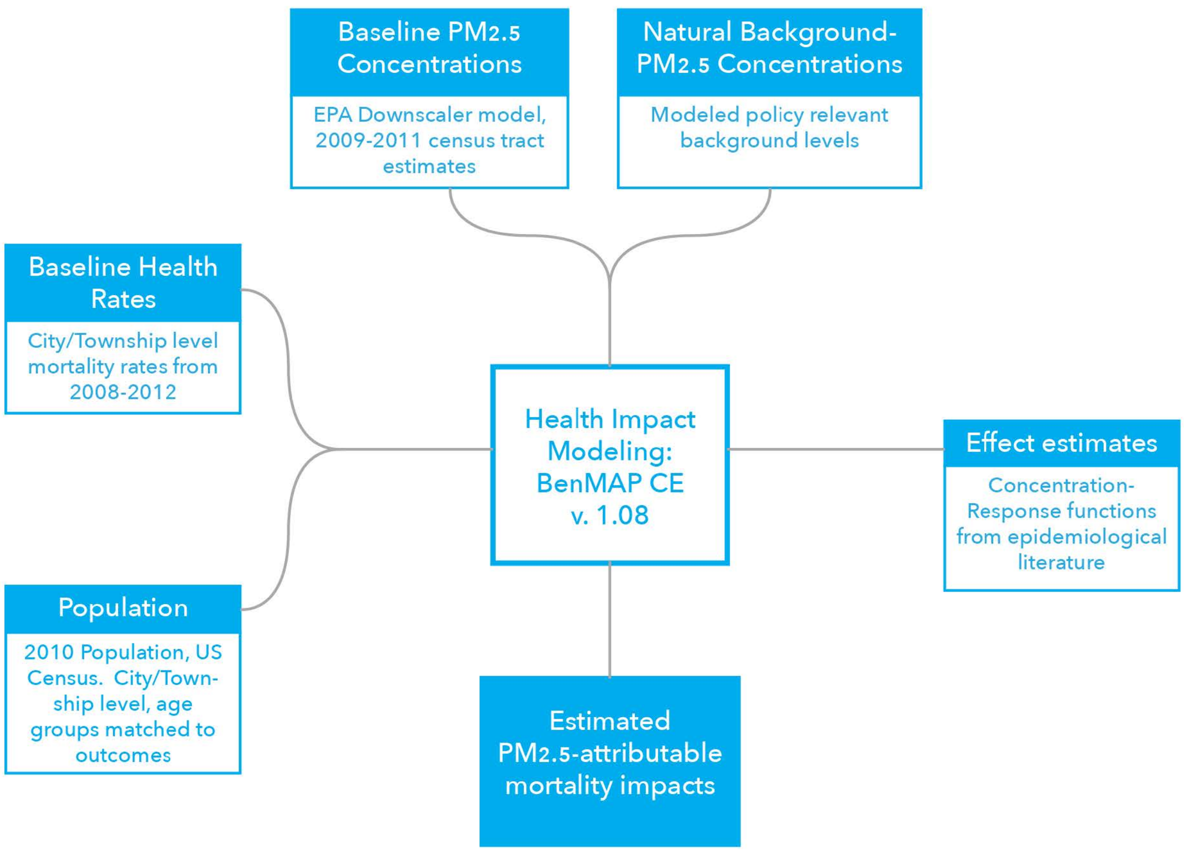


Figure 2: Overall approach to estimating premature deaths associated with $PM_{2.5}$

Air Quality Data
Annual Average PM2.5 Exposures, 2009-2011

We obtained census tract air quality data from the Center for Disease Control and Prevention's National Center for Environmental Health that collaborates with EPA to produce ambient $PM_{2.5}$ and ozone exposure estimates through the EPA/CDC Downscaler model[20]. These surfaces, developed for use in health studies of associations between daily air quality levels and health outcomes and for creating air quality indicators as part of national environmental health tracking, are produced using a Bayesian space-time downscaler model to "fuse" 24-hour average monitoring data from the National Air Monitoring Stations/State and Local Air monitoring stations (NAMS/SLAMS) with modeled air quality predictions generated through Community Multiscale Air Quality Model (CMAQ). The downscaler model was used to produce daily PM2.5 concentration estimates for the years 2009-2011 at every US census tract centroid by using CMAQ model output to fill in spatial and temporal gaps in the $PM_{2.5}$ monitoring network where only limited census tracts contain monitors that often operate on a one in every third and sixth day schedule. This air quality surface is subject to air quality modeling and monitor interpolation and its limitations, validation, and usage has been described elsewhere[21].

We average daily $PM_{2.5}$ levels across three years (2009-2011) to develop baseline exposure estimate for further health impact modeling (Figure 3). We elected to use 3 years of data to reduce the influence of unique meteorogical or emissions patterns that may occur in a single year.

Policy Relevant Background

To estimate the total burden of PM2.5 we computed the health benefits associated with a rollback of baseline levels to a policy relevant background concentration of (PRB). PRB is an estimate of $PM_{2.5}$ concentrations that would exist without anthropogenic (human made) emissions of $PM_{2.5}$ and its precursors the United States[2], estimated at 0.86 µg/m3 in the Allegheny County region. This estimate was derived for the region by EPA using air quality models that simulated $PM_{2.5}$ concentrations after all man-made emissions were removed from the model. The health burden of $PM_{2.5}$ in this report, therefore, provides an estimate of the public health impacts of all anthropogenic sources of $PM_{2.5}$.

Using the non-anthropogenic background as a counterfactual has been applied previously to estimate the national man-made PM burden[3], as well as in local studies conducted in New York City, Minneapolis, and in the Bay Are of California[14, 15, 22] and is justified as there is limited evidence for a threshold to the association of $PM_{2.5}$ and mortality[2,23]. However, it should be noted that PRB is a very low level not measured in most epidemiologic studies that characterize the health risks of $PM_{2.5}$. Despite this, studies have shown associations between $PM_{2.5}$ and mortality that persist to very low concentrations[8]. Additionally, an analysis of the mortality risk from long-term $PM_{2.5}$ exposures among a cohort in Canada described positive associations between $PM_{2.5}$ and death down to very low levels reaching the PRB [24].

Baseline Mortality Data

We obtained baseline mortality rates for 2008-2012 from the Pennsylvania Department of Public Health (PADOH). PADOH provides downloadable files detailing total deaths over a 5-year period for each city/borough/township in the state for 12 age categories. (Ages 0-4, 5-9, 10-14, 15-19, 20-24, 25-34, 35-44,45-54, 55-64, 65-74, and 75 and above)[iv]. We created tables for all-cause mortality (all deaths, regardless of cause) for each Pennsylvania township and age group and averaged over five years to provide counts of all-cause deaths per year per age group in each township.

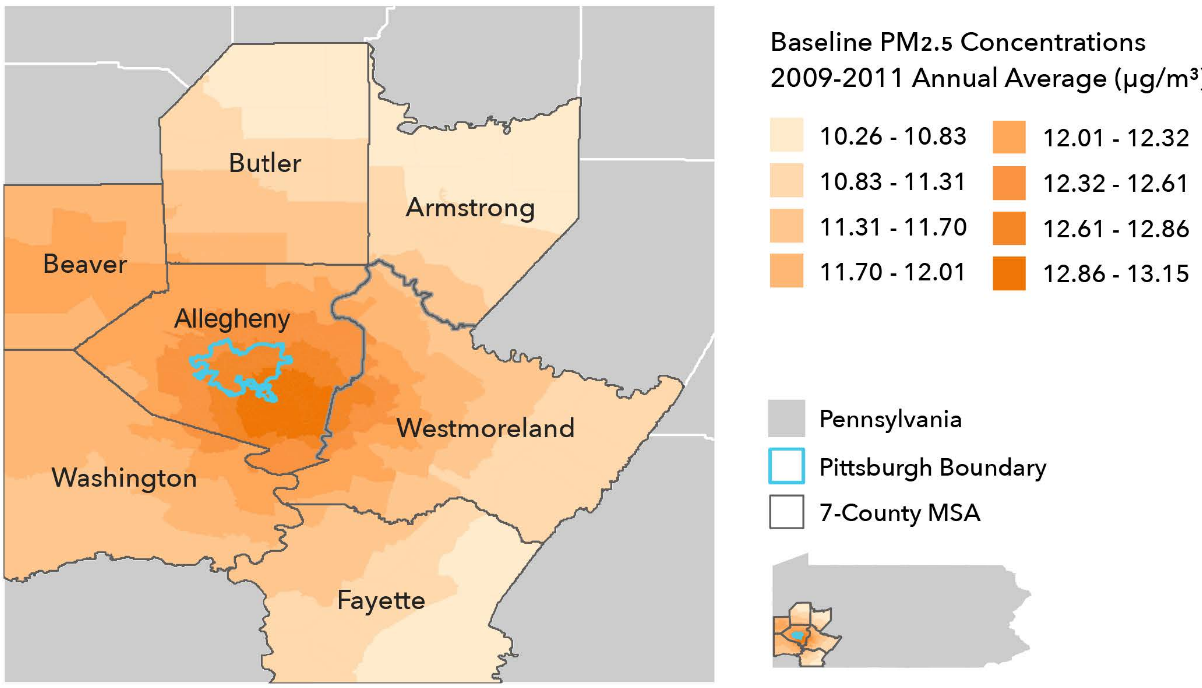


Figure 3: 2009-2011 annual average $PM_{2.5}$ concentration in census tracts in the Allegheny County region.

We then created population estimates for each township/age group from 2010 block-level US Census data using EPA's PopGrid program[19]. This program aggregates block-level population estimates to the user's choice of higher-level geography. The township-level population estimates were then aggregated to the age groupings of the mortality data and used as the denominator in estimating the town-ship/age- group specific baseline mortality rate.

Concentration Response Functions

Table 1 describes the two epidemiological studies used in this analysis to estimate the relationship between chronic exposures to $PM_{2.5}$ and mortality risk. The Krewski et al (2009) study of the American Cancer Society Cohort (ACS) followed 500,000 people in 116 cities, estimating that all-cause mortality rates in adults increased by 6% with a 10 μg/m³ increase in PM2.5 (95% CI: 3.5%-7.8%)[25]. The Lepuele et all (2012) study of the Harvard Six Cities (H6C) cohort suggested a stronger PM2.5 mortality risk, estimating that all-cause mortality rates in adults increased by 14% with c 10 μg/m3 increase in PM2.5 (95% CI: 7%-22%)[26].

iv http://www.portal.state.pa.us/portal/server.pt?open=514&objID=596038&-mode=2 These data were provided by the Bureau of Health Statistics and Research, Pennsylvania Department of Health. The Department specifically disclaims responsibility for any analyses, interpretations or conclusions.

Health Effect	Age Group	Effect Estimate	Study Location	Source of Estimate
Mortality	30 and above	6% increase in all-cause mortality associated with 10 μg/m^3 increase in $PM_{2.5}$	116 US Cities, American Cancer Society Cohort	Krewski et all 2009
Mortality	25 and above	14% Increase in all-cause mortality associated with 10 μg/m^3 increase in $PM_{2.5}$	Harvard Six Cities Cohort: Cities in MA, TN, MO, OH, WI, KS	Lepuele et al 2012

in PM2.5 (95% CI: 3.5%-7.8%) . The Lepuele et al (2012) study of the Harvard Six Cities (H6C) cohort suggested a stronger PM2.5- mortality risk, estimating that all-cause mortality rates in adults increased by 14% with a 10 μg/m3 increase in PM2.5 (95% CI: 7%-22%)26.

We selected the risk estimates from these two landmark cohort studies of US populations to represent a range in the potential long-term mortality risk from $PM_{2.5}$. Due to the difference in risk of $PM_{2.5}$ from these studies, we reported the $PM_{2.5}$ effects separately, and estimate $PM_{2.5}$-attributable mortality in Allegheny County as a range of results predicted from these two risk estimates. The ACS study includes the largest cohort among chronic PM2.5 studies in the US. The H6C study, despite a much smaller population size, includes a more diverse population and estimates mortality risk in eastern US cities with $PM_{2.5}$ composition potentially more similar to Allegheny County (higher sulfate levels). Other studies have reported risks of similar magnitudes. A meta-analysis of recent studies of mortality risk from long term exposures to PM2.5 reported a pooled effect estimate of 6% increase in all-cause mortality associated with a 10 μg/m3 exposure[27]– an estimate within the range of the effect estimates used in this study. A separate review suggested that the evidence from cohort studies to date indicates an average of 10% increase in all-cause mortality per 10 μg/m increase in all-cause mortality risk from all-cause mortality risk from long term exposures to $PM_{2.5}$ suggested a similar central estimate of approximately 1% increase per 1 μg/m3 $PM_{2.5}$ [28]– also within the range of the ACS and H6C estimates. Based on these comprehensive reviews and expert elicitations and the wide usage of the ACS and H6C studies in US risk assessments, we believe the two studies selected for this analysis provide a reasonable range of risk for use in calculation PM2.5 attributable deaths in Allegheny County.

Population and Area Socioeconomic Status

We created population estimates from the 2010 block level US Census tables, aggregated to borough/township/city-level shapefile[29] using EPA's PopGrid program to match the geography of the baseline mortality rates.

To assess the disparity of $PM_{2.5}$ attributable mortality impacts by area poverty, we accessed data from the US Census American Community Survey[30]. From these data, we extracted two fields for all census tracts within the analysis region: B17001e1 and B17001e2, corresponding to counts of "Total Population for whom poverty status is determined," and "Income in the past 12 months below poverty level: Population for whom poverty status is determined," respectively. The ratio of these fields was taken to estimate, at each census tracts, the township-level percent-in-poverty was calculated using the total population and total number below the poverty level by summing census tracts within the township. In the cases where multiple townships fell within one census tract, the townships were given the percent-in-poverty estimated for the tract they fell within. To evaluate disparity across areas of differing poverty, we categorized townships based on percent living below the federal poverty level: :0%-10%, 10%-20%, and over 20%[v]. For each category, we calculate the population weighted average $PM_{2.5}$ exposure, the baseline mortality rate, the $PM_{2.5}$-attributable burden rate.

We also evaluated disparity in $PM_{2.5}$-attributable morality impacts by percent minority populations in Allegheny County. Percent minority population was calculated as the percentage of individuals identified as Black, Hispanic, Asian American, or American Indian and Alaskan Native in the 2010 US Census, based on the definition of minority populations from the Southwestern Pennsylvania Commission's Report on Environmental Justice[31]. Townships were placed into one of four categories based on percent minority population: 0%-10%, 10%-30%, and above 30%[vi]. For each category, we calculate the population weighted average $PM_{2.5}$ exposure, the baseline mortality rate, and the $PM_{2.5}$ -attributable burden rate.

v Pennsylvania Department of Environmental Protection defines environmental justice areas as census tracts where 20% or more individuals live in poverty. Source: http://www.dep.pa.gov/PublicParticipation/OfficeofEnvironmentalJustice/Pages/PA-Environmental-Justice-Areas.aspx

vi Pennsylvania Department of Environmental Protection defines environmental justice areas as census tracts where 30% or more of the population is minority. Source: http://www.dep.pa.gov/PublicParticipation/OfficeofEnvironmentalJustice/Pages/PA-Environmental-Justice-Areas.aspx

RESULTS

Photo: Scott Goldsmith, The Documentary Works

RESULTS

Below we describe the findings by first presenting the results for Allegheny County, overall and by age group. We then map the rates of $PM_{2.5}$-attributable deaths across townships in the 7-County MSA and describe disparity in exposures and $PM_{2.5}$-attributable deaths in Allegheny County by area poverty status and percent minority populations. We report confidence intervals (95% CI) around the estimates based only on the reported confidence intervals from the risk estimates published in the epidemiologic study.

Using the risk function from Krewski et al (2009), we estimate that on average, 900 (95% CI: 660-1,140) deaths each year in 2009-2011, or 6.7% (95% CI: 4.9%-8.4%) of all deaths in adults over 30 years of age in Allegheny County were attributable to $PM_{2.5}$ (Table 2). Using the risk estimate from Lepuele et al (2012) study, we estimate that on average, $PM_{2.5}$ levels in Allegheny County were associated with 1,920 (95% CI: 1,160-2,680) deaths each year in 2009-2011, or 14.4% (95% CI: 8.6%-19.8%) of all deaths in adults over 30 years of age. We estimate that a 10% reduction in $PM_{2.5}$ levels (reducing each census tract by 10%) could avoid 100 (95% CI: 70-120) to 220 (95% CI: 130-310) deaths per year in Allegheny County, depending on the choice of risk function. In the 7-county Pittsburgh MSA (Allegheny, Armstrong, Beaver, Butler, Fayette, Washington, and Westmoreland Counties), an estimated 1,700 (95% CI: 1,200-2,100)-3,700 (95% CI: 2,200-5,000) deaths are attributed to PM2.5 in adults each year, depending on the choice of risk function. Allegheny County accounts for 51% of the population of adults over 30 years of age in the 7-County MSA.

Table 2: Health impacts of $PM_{2.5}$ on chronic, all-cause mortality in Allegheny County and the benefits of a 10% reduction in concentrations, annual average, 2009-2011

Outcome	Age Group	Source of Effect Estimate	Annual Deaths Attributable to $PM_{2.5}$ (relative to policy-relevant background)			Annual Deaths Avoided from a 10% Reduction in $PM_{2.5}$ Concentrations		
			Number of Events (95% CI)	Rate Per 100,000 Residents (95% CI)	Percent of Events (95% CI)	Number of Events (95% CI)	Rate Per 100,000 Residents (95% CI)	Percent of Events (95% CI)
All-Cause Mortality	30 and above	Krewski et al 2009	900 (660-1,140)	118 (86-148)	6.7% (4.9%-8.4%)	100 (70-120)	12.9 (9.5-16.3)	0.7% (0.5%-0.9%)
	30 and above	Lepuele et al 2012	1,920 (1,160-2,680)	253 (151-348)	14.4% (8.6%-19.8%)	220 (130, 310)	28.8 (17.2, 39.6)	1.6% (0.9% – 2.0%

The distribution of $PM_{2.5}$ attributable deaths by age group in Allegheny County follows the same pattern as the underlying rates of all-cause deaths. The largest $PM_{2.5}$ attributable mortality burden occus in older populations (ages 65 and above), accounting for 80% of deaths due to $PM_{2.5}$ in Allegheny County each year (Table 3), due to the higher baseline rates of death in this age group.

Table 3: Distribution of $PM_{2.5}$-attributable deaths in Allegheny County by age group annually, 2009-2011

Age Group	Annual Deaths Attributable to $PM_{2.5}$ (relative to policy-relevant background)	
	Number of Events (95% CI)	Rate Per 100,000 Residents (95% CI)
Krewski et al 2009 Estimate		
30-44	20 (17, 30)	11 (9, 17)
45-64	150 (110,210)	44 (32, 62)
65 and Above	720 (530,990)	360 (265, 495)
Lepuele et al 2012 Estimate		
30-44	50 (30,80)	23 (14, 37)
45-64	330 (220, 500)	95 (63, 140)
65 and Above	1,550 (1000, 2400)	770 (500,1190)

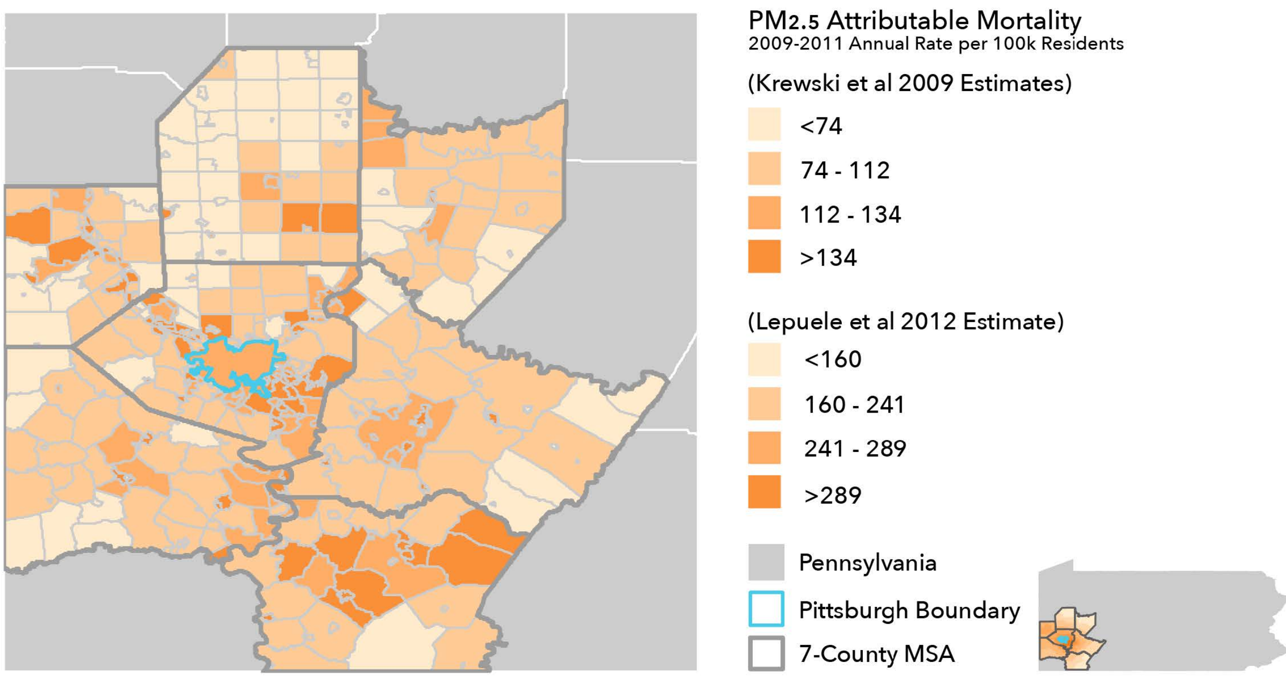
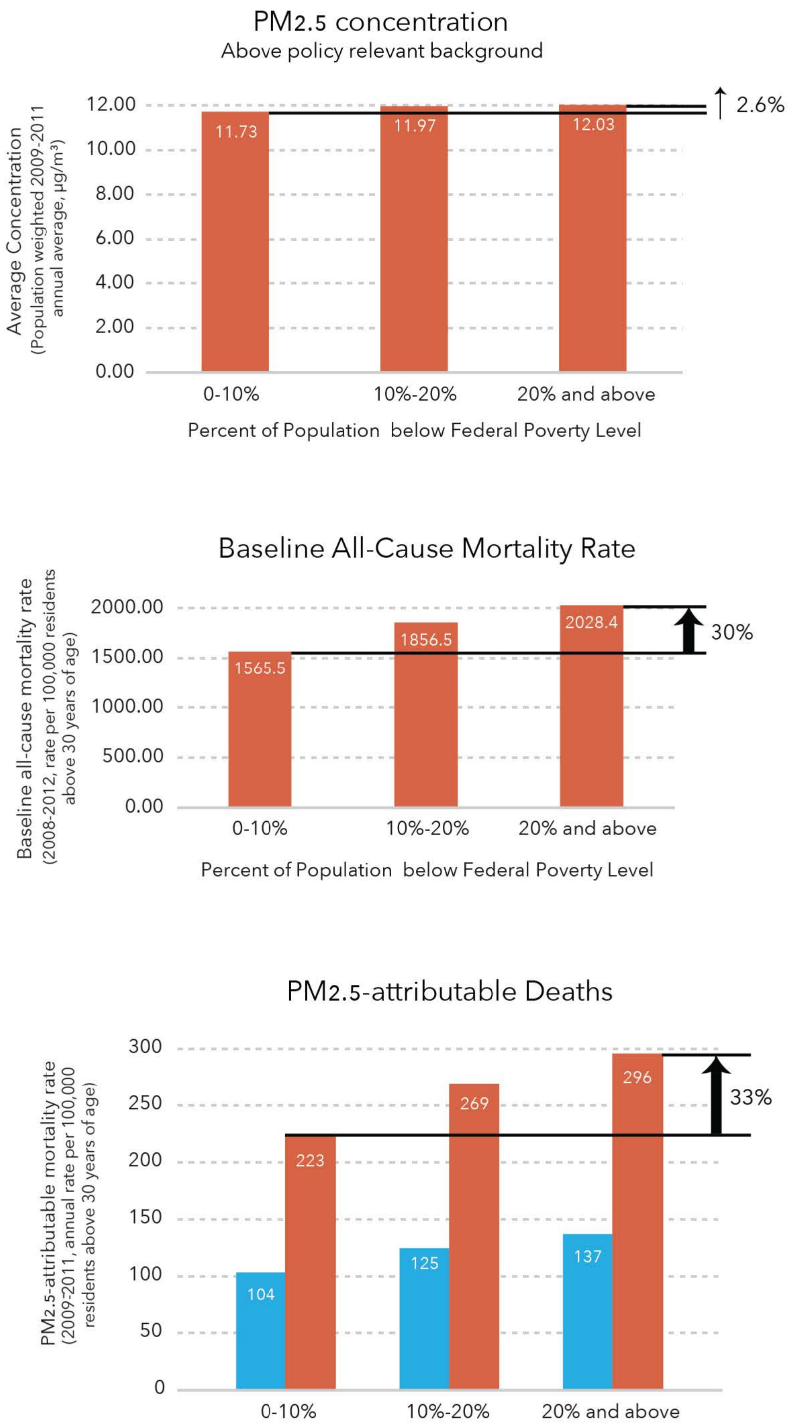


Figure 4: Rates of PM2.5-attributable mortality across townships in Southwest PA study area

There was wide variation in $PM_{2.5}$-attributable deaths across the Southwestern PA study area (Figure 5). The highest $PM_{2.5}$-attributable mortality rates were observed in the Pittsburgh metro area. Within the City of Pittsburgh, we estimate 130 to 280 deaths per 100,000 residents are attributable to $PM_{2.5}$ among adults over 30 years of age, depending on the choice of risk function. The relatively larger impacts in Allegheny County are likely due to shared patterns of high $PM_{2.5}$ concentrations, population density, and relatively higher baseline mortality rates.



When classifying townships in Allegheny County by area poverty status, we observed the highest $PM_{2.5}$-attributable mortality rates in townships in the highest poverty category (Figure 5), with 33% higher rates in the highest poverty townships (>20% of residents living below the federal poverty level) as compared to the lowest poverty townships (<10% of residents living below the federal poverty level). Comparing the factors that determine $PM_{2.5}$-attributable death rates shows that there are both higher $PM_{2.5}$ concentrations and baseline mortality rates in the higher poverty townships of Allegheny County, as compared to more affluent townships (Figure 5). In comparing the relative importance of each, we find smaller gradients in $PM_{2.5}$ exposures (2.6% higher PM2.5 levels in high, as compared to low poverty townships) and much larger gradients in baseline mortality (30% higher baseline mortality rates in high, as compared to low poverty townships), indicating that the primary driver of disparity in $PM_{2.5}$-attributable mortality are the baseline mortality rates. These higher baseline rates likely reflect worse underlying health status in these townships that contribute to lower life expectancy.

Figure 5: Comparison of PM2.5 concentrations, baseline mortality rates, and PM2.5-attributable deaths across Allegheny County townships of varying poverty status

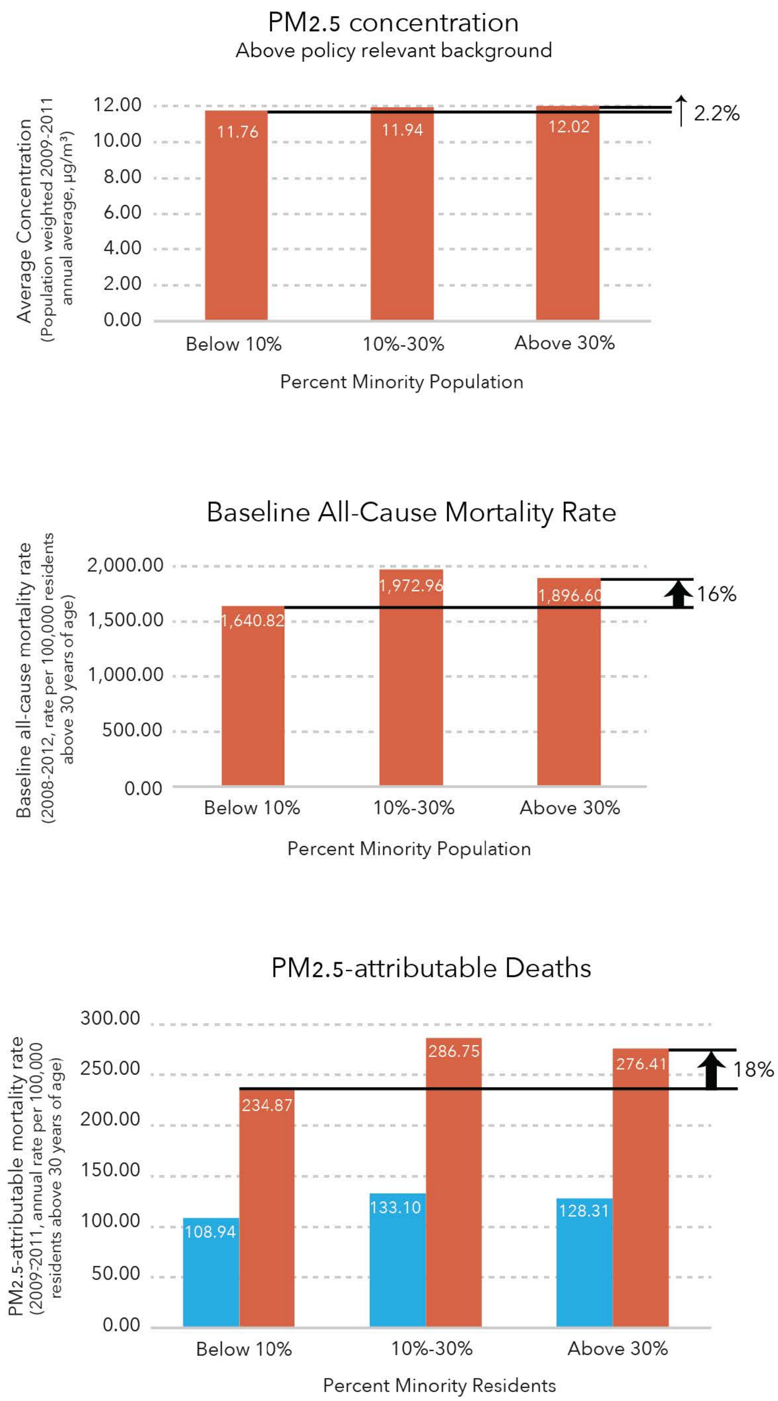


Figure 6: Comparison of PM2.5 concentrations, baseline mortality rates, and PM2.5-attributable deaths across Allegheny County townships of varying percent minority population

When classifying townships by percent minority populations, we observed gradients similar, though not as steep to those seen when townships are compared by poverty. In Allegheny County, township-level percent below the federal poverty level and percent minority are correlated (pearson's r=0.74), indicating higher poverty townships tend to have higher percentages of minority populations. Townships with high percentages of minorities (>30%) had 18% higher rates of PM2.5-attributable deaths than those with low percentages of minorities (<10%)(Figure 6). This difference was due to gradients in the baseline mortality rate and to a lesser extent higher PM2.5 levels in the high minority townships.

As noted in Figure 1, $PM_{2.5}$ levels have declined in recent years, with average levels 14.5% lower in 2012-2014 relative to 2009-2011. Assuming the population and rates of mortality have remained constant since 2009-2011, the reduction in $PM_{2.5}$ levels would have produced lower $PM_{2.5}$- attributable mortality in more recent years. Applying these reductions in average $PM_{2.5}$ concentrations, we estimate in 2012-2014 between 770 (95% CI: 560-970) and 1,640 (95%CI: 970-2,300) premature deaths each year (depending on choice of risk function) are still attributable to $PM_{2.5}$, or up to 12% of deaths each year in Allegheny County, $PM_{2.5}$ indicating there still exists a substantial impact of $PM_{2.5}$ on mortality. The premature deaths that have occurred in more recent years may have also been due, in part, to exposures occurring in previous years, during times of higher $PM_{2.5}$ levels.

DISCUSSION

The Air Quality Index (AQI) provides a color coded system based on levels of air pollutants relative to EPA's National Ambient Air Quality Standards (NAAQS), ranging from green (good) to purple (hazardous). In Pittsburgh, there were 243 days that were yellow or worse in 2015.

Photo: Brian Cohen, The Documentary Works

DISCUSSION

In this study we quantified the impacts of ambient fine particulate matter on mortality in the Allegheny County region to convey the public health risks of particulate pollution and provide estimates for communicating this risk to the public and stakeholders. We estimated, on average, in 2009-2011 between 900 (95% CI: 660-1,140) and 1,920 (95% CI: 1,160-2,680) deaths in Allegheny county each year were attributable to $PM_{2.5}$, or 7% to 14% of all deaths. $PM_{2.5}$- attributable deaths were not evenly distributed throughout the region, with wide variation in their rates, and contributing to 1,700 (95% CI: 1,200-2,100)-3,700 (95% CI:2,200-5,000) deaths in the 7-county Pittsburgh MSA. Due to its high population density, the highest numbers of $PM_{2.5}$-attributable deaths among townships in the 7-county region were found in the City of Pittsburgh.

In the US, lower income areas often experience higher rates of respiratory and cardiovascular disease[32]. Low income residents of Allegheny County have consistently reported higher morbidity than more affluent residents for indicators of asthma, respiratory conditions such as chronic obstructive pulmonary disease and emphysema, and cardiovascular disease[33]. These disparities are evident in this evaluation of $PM_{2.5}$-attributable mortality. In comparing $PM_{2.5}$-attributable death rates across townships in Allegheny County, since we've utilized a single risk function across all townships and normalized the township burdens by population, differences in the burden were attributed to differences in (1) $PM_{2.5}$ exposures and (2) the baseline mortality rate. In comparing these burdens across townships of varying poverty status, we found slightly higher average $PM_{2.5}$ concentrations in high as compared to low poverty townships (2.6% higher) and much higher baseline mortality rates in the high as compared to low poverty townships (30% higher). As a result, we observed disproportionately higher $PM_{2.5}$ burden in lower income townships, with 33% higher $PM_{2.5}$-attributable rates of death among residents above 30 years of age in high poverty areas relative to low poverty areas. The higher death rates in low income townships are likely reflecting the worse underlying health status and higher rates of disease in these townships leading to larger numbers of $PM_{2.5}$-attributable premature deaths. We observed similar but weaker gradients when stratifying townships by percent minority population. Townships with high percentages of minorities (>30%) had 18% higher rates of $PM_{2.5}$-attributable deaths than those with low percentages of minorities (<10%), also due to higher baseline rates of death in these communities.

Due to the larger baseline mortality rate in older populations, we observed the largest share of the $PM_{2.5}$ mortality burden in older populations (over 65 years of age), accounting for 80% of $PM_{2.5}$- attributable deaths in Allegheny County. This reflects the patterns in deaths by age group - 78% of all deaths in the county occur among those over 65 years of age.

$PM_{2.5}$ levels have declined in Allegheny County in recent years, similar to declines seen throughout the country during a period of decreasing emissions. Assuming the population and rates of mortality have remained constant since 2009-2011, we estimate that in 2012-2014 between 770 and 1,640 deaths each year (depending on choice of risk function) are still attributable to $PM_{2.5}$ in Allegheny County, or up to 12% of deaths each year, indicating there still exists a substantial impact of $PM_{2.5}$ on mortality.

Actions to Reduce Emissions will Produce Public Health Benefits

The large public health toll of $PM_{2.5}$ on Allegheny County residents demonstrates the significant public health gains that could come from cleaner air. We found that even marginal improvements in $PM_{2.5}$ could provide a large public health benefit - a 10% improvement in $PM_{2.5}$ levels (moving Pittsburgh from the bottom 15th percentile of cities nationwide to the bottom 40th percentile of cities) could avoid 100 (95% CI: 70-120)-220 (95% CI: 130-310) deaths each year. Additionally, while we only quantified the deaths associated with PM2.5, many other adverse health outcomes are related to these exposures, which are described in detail later in this section.

These findings underscore the need to reduce levels of $PM_{2.5}$ to improve health outcomes throughout the region. Older populations, higher poverty townships, and townships with higher percentages of minorities include higher rates of residents with underlying health conditions that produce higher rates of $PM_{2.5}$-attributable deaths. However, despite fewer $PM_{2.5}$- attributable deaths in more affluent communities (<10% of residents below the poverty level), levels in 2009-2011 still contributed to 104-220 $PM_{2.5}$-attributable deaths per 100,000 residents in these townships. These findings show that all populations have a stake in improving air quality in Allegheny County.

With the recent improvements in Allegheny County's $PM_{2.5}$ levels, in 2012-2014 concentrations are nearing the annual average $PM_{2.5}$ NAAQS. This indicates the majority of the mortality associated with $PM_{2.5}$ exposures occurs at levels below the NAAQS. Prior work has shown the mortality and morbidity risks from $PM_{2.5}$ continue well below the NAAQS8, 34 with little evidence for a threshold to the association of PM2.5 and mortality[2, 23]. These findings further highlight the need to reduce levels – improvements beyond the NAAQS will provide significant public health benefits, particularly among low income areas and the region's vulnerable populations.

Interventions to reduce air pollutants have proven effective in many urban areas, and public health benefits have been associated with reduced levels in short periods of time. For example, improvements in $PM_{2.5}$ levels in the 1980s and 1990s in the US accounted for about 15% of the increase in life expectancy over that time period[35]. More recent work has shown that reductions in air pollutant levels in southern California due to implementation of control policies have been associated with improved lung function in children[36].

All people, regardless of their choices, are exposed to air pollution– while the relative risks can be lower than other risk factors, these risks influence health in the entire population as opposed to specific subpopulations. The most effective ways to reduce exposures are through interventions that reduce emissions; unlike other risk factors, changing personal behaviors can only provide limited reductions in exposures to air pollutants. Air pollution related deaths and disease are preventable. There are demonstrated technologies and programs to reduce emissions that have been successful in many regions of the US. The economic value of these interventions have also been documented; analyses of the programs in the 1990 Clean Air Act amendments showed that the benefits far outweighed their compliance costs- by a factor of 30 to 17. Interventions that reduce emissions of PM2.5 and its precursors can often also provide important co-benefits such as reduction of greenhouse gas emissions and reduced emissions of carcinogenic air toxics.

Findings in the Context of Prior Work

A prior nationwide analysis of $PM_{2.5}$-attributable health impacts found that in 2009, a 10% reduction in $PM_{2.5}$ concentrations in Allegheny County could prevent 96 deaths each year, assuming the Krewski et al (2009) risk function applied[10]. These findings are consistent with the estimates derived in this report, where utilization of the Krewski et al 2009 risk function produced an estimate of 100 deaths prevented with a 10% reduction in $PM_{2.5}$ levels. A separate analysis indicated that meeting the National Ambient Air Quality Standards in 2012 in the Pittsburgh MSA would avoid 89 deaths each year[37]. While this prior analysis used similar EPA methodology as applied here, this report extends upon this work by first reporting the overall mortality burden of ambient $PM_{2.5}$ exposures, useful for placing air pollution in a public health context, then providing estimates at a higher spatial resolution. A higher spatial resolution allowed for a more detailed analysis of disparity in burden among populations of differing socioeconomic status, demonstrating the disproportionate burden among the region's low- income and minority residents.

An analysis of US risk factors found that in 2010 ambient particulate matter pollution ranked 8th among all causes when ranked by percent of deaths attributed to major risk factors, behind dietary risks, smoking, high blood pressure, high body mass index, low physical activity and high fasting glucose[16]. This study estimated that in 2010 ambient $PM_{2.5}$ pollution was associated with 4% of deaths nationwide, ranking above other important risk factors such as drug abuse, alcohol use and occupational risks. These estimates however, while useful in providing context on important causes of death nationwide, may not be representative of the risk profile of southwestern Pennsylvania residents. Wide variation in environmental exposures and health

health behaviors exist across the US,and the local estimates produced in this report suggest a significantly higher contribution of $PM_{2.5}$ to mortality in Allegheny County than the US on average.

Limitations and Areas for Future Work

This work only quantifies the burden of $PM^{2.5}$ on premature deaths in adult populations. However, improving air quality will benefit younger populations as well. For example, multiple studies have reported associations between adverse respiratory outcomes and expose to $PM_{2.5}$ among children, including impairments in lung development and reductions in lung function[2, 38-40]. Other researchers have demonstrated associations between $PM_{2.5}$ and respiratory related infant mortality[41]. Research conducted among Pittsburgh children has suggested associations between $PM_{2.5}$ exposures and development of autism[42]. New findings have also linked $PM_{2.5}$ to adverse birth outcomes, including studies conducted among mothers in Pittsburgh[6, 43]. While many studies have demonstrated associations between $PM_{2.5}$ and excess emergency department visits and hospitalizations for asthma among children[34, 44-46], research has shown that air pollution exposures can also contribute to new cases of asthma which can affect health over a lifetime[47]. Children in lower income areas may also be more susceptible to the effects of air pollutants due to social stressors in their environment as well, which can lead to synergistic effects on morbidity[48, 49]. Studies have also shown associations between $PM_{2.5}$ levels and reduced ability to perform activities and missed days of work and school. A recent nationwide analysis of $PM_{2.5}$ burden estimated that for each $PM_{2.5}$ attributable death there are almost 400 lost work days and minor restricted activity days due to $PM_{2.5}$ exposures[3].

In this report we've quantified the metric of numbers of premature deaths due to $PM_{2.5}$ to describe a population-level effect of exposures that increase the risk of early death. Although this is a commonly used metric in regulatory impact assessments and burden analyses in the US and worldwide, its meaning should be interpreted with caution. Because everyone dies eventually, these deaths should be interpreted as early deaths and reductions in air pollution will lead to postponement of death and thus increased life expectancy[50]. Future work could quantify the years of life lost and reduced life expectancy attributable to current $PM_{2.5}$ exposures in order to provide additional perspective into the effects of $PM_{2.5}$.

As with any study with multiple data sources, analysis steps, and assumptions, the results described here include several limitations. In estimating air pollution exposures, we utilized census-tract-level $PM_{2.5}$ exposure estimates from 2009-2011 air quality modeling and monitoring (EPA Downscaler model). This exposure model has been used for estimating the public health burden of air pollution in Minnesota[15] and for creating indicators of the mortality benefit of reducing $PM_{2.5}$ levels in US counties for the National Environmental Public Health Tracking Network[10]. Despite this, the air quality modeling is subject to a variety of limitations related to emissions inventories that often use proxy data that can include significant uncertainty, meteorological data that can vary in uncertainty in different locations, and ability of the model to mimic air pollution dispersion and chemistry in complex scenarios. We've tried to improve the estimates by using the fused model/ monitor surfaces to leverage the available monitoring data; however monitoring includes additional limitations related to spatial and temporal gaps in data. In using this model, the most recent year of available data was 2011. A more detailed discussion of the validation of the downscaler model can be found elsewhere[20, 21].

The health impact assessment includes many limitations that are common in local-scale air quality health impact modeling, that are explored in detail by other authors[51], [52]. To provide more accurate estimates of baseline deaths in the region, we used all- cause mortality estimates provided to the public by PA DOH at the township level, which offered increased spatial accuracy than the county-level estimates available in BenMAP-CE.

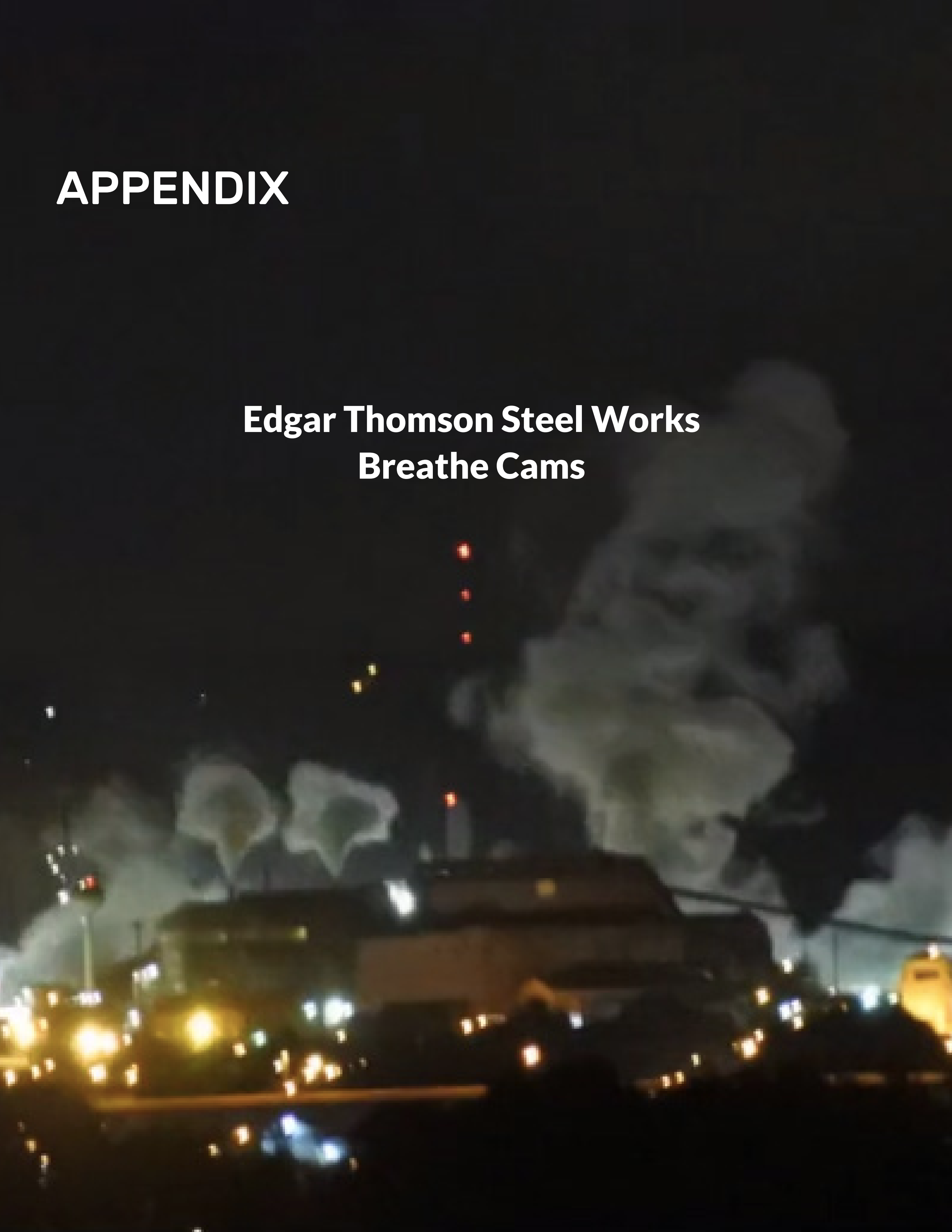
We characterized variation of $PM_{2.5}$-attributable deaths across townships and area poverty using only heterogeneity in baseline mortality rates and $PM_{2.5}$ exposures while assuming the $PM_{2.5}$ mortality risk is uniform across the region. This may underestimate the total number of $PM_{2.5}$-attributable deaths, particularly in high poverty areas of the region. In the Krewski et al (2009) analysis of the ACS cohort, while the city-wide $PM_{2.5}$ concentration was used as the exposure contrast, the authors did examine modification by education level, describing an increased risk with decreasing level of education. For this analysis we did not have access to education level in the death records and therefore were unable to use these risk estimates. Additional research has suggested increased short-term mortality risk from particulate matter exposures among populations of lower socioeconomic status[53]. The mixture of air pollutants may affect their associations with adverse outcomes while $PM_{2.5}$ composition might result in differing effects. For example, $PM_{2.5}$ with higher contents of some metals, such as nickel and arsenic, might make them more toxic[54, 55]. In 2014, annual average levels of nickel and arsenic in $PM_{2.5}$ at the two monitoring sites in Allegheny County were higher than 88% and 97% of sites nationwide[viii], respectively, suggesting disproportionately high exposures to these metals in the local population. Other studies have shown relatively stronger relationships between particulate matter and morbidity outcomes in the Northeast US where PM contains higher amounts of sulfate compared to other US regions[56, 57]. Similarly, analyses of the ACS cohort showed higher chronic mortality risk associated with $PM_{2.5}$ with higher sulfur content and from coal combustion sources[58, 59].

While the PA DOH provides township-level data on deaths, current community-level data on morbidity outcomes, namely emergency department visits and hospitalizations, are not readily available to the public. The databases available through EPA's BenMAP-CE approximate county- level emergency department rates using regional data. While these are potentially useful in nationwide, coarser level analyses, wide variation in rates of emergency department visits and hospitalizations often occur in urban areas. As a result, we elected not to compute its $PM_{2.5}$-attributable burden as there would be significant uncertainty in the estimates. Future work could benefit from making de-identified, cause-specific morbidity outcome data available for researchers and analysts to estimate the health impacts of air pollution. One possibility is through the National Environmental Health Tracking Program, which provides state-specific data portals for environmentally relevant data.

viii Based on 2014 annual summary monitoring data downloaded from EPA at: http://aqsdr1.epa.gov/aqsweb/aqstmp/airdata/ download_files.html

APPENDIX

Edgar Thomson Steel Works
Breathe Cams



APPENDIX

To better communicate the benefits of reducing levels of $PM_{2.5}$ in the Pittsburgh metropolitan area, we estimated how many $PM_{2.5}$- attributable deaths could have been avoided in 2009-2011 had levels in the region met those seen in other US cities. To do this we accessed data previously used to compare US Cities as part of the Breathe Meter, which ranks US Cities (defined as Metropolitan Statistical Areas) using 2012-2014 annual average $PM_{2.5}$ concentrations measured as part of EPA regulatory monitoring. To estimate the change in the $PM_{2.5}$-attributable mortality burden associated with changing levels to meet those seen in other US cities we:

1. Set the baseline $PM_{2.5}$ concentration as the average of 2009-2011 annual average PM2.5 concentrations for the 7 counties in the Pittsburgh MSA (Allegheny, Armstrong, Beaver, Butler, Fayette, Washington, and Westmoreland). These were calculated by averaging census tract data from the 2009- 2011 EPA Downscaler model.

2. Created "control" air quality levels by first calculating the percent difference between the Pittsburgh MSA and every other MSA in 2012-2014 using the monitored $PM_{2.5}$ concentrations in the Breathe Meter list. This percent difference was then applied to the baseline concentration of the Pittsburgh MSA in the 2009- 2011 baseline scenario to simulate the incremental change in $PM_{2.5}$ concentrations associated with meeting $PM_{2.5}$ levels of other cities.

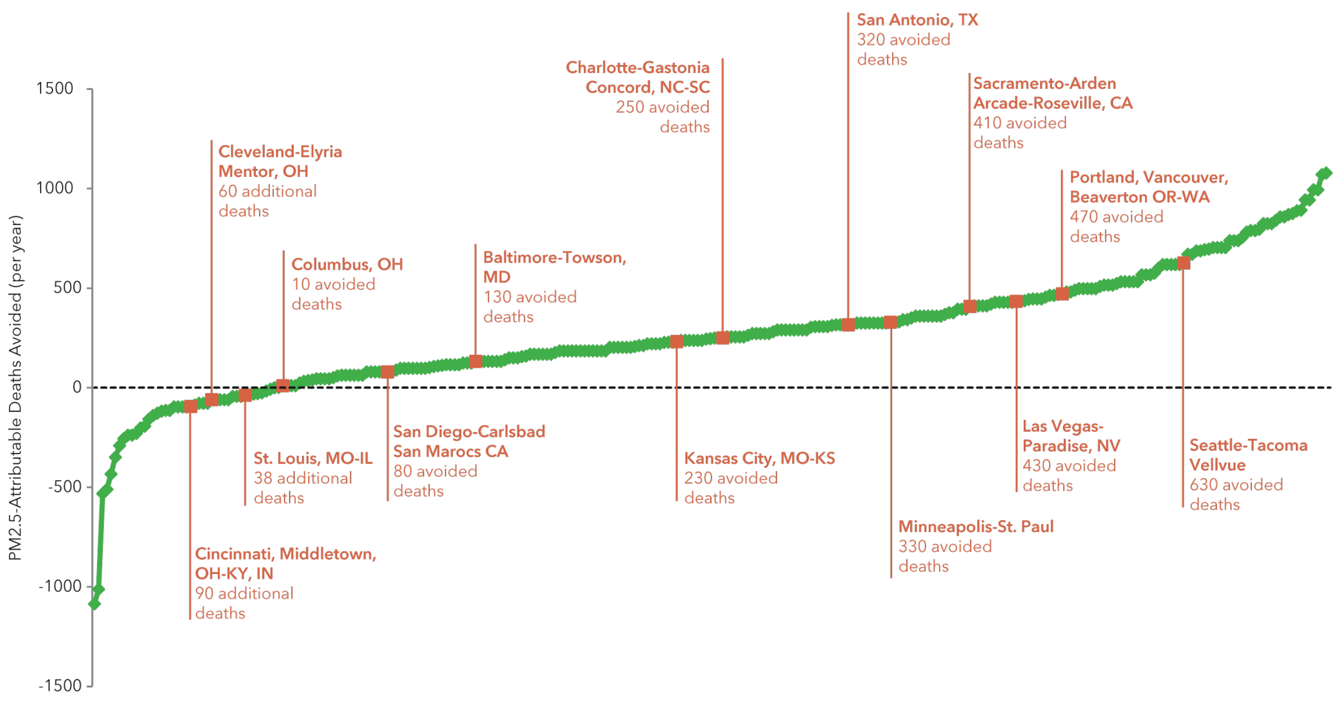
3. Used the age-specific population and mortality rates in the 7-county Pittsburgh MSA, the chronic mortality risk estimates from Krewski et al (2009) and Lepuele et all (2012) studies, and the incremental change in

i http://breatheproject.org/learn/breather-me- ter/

$PM_{2.5}$ concentrations associated with meeting levels of other cities in a health impact calculation to estimate how many deaths in populations above 30 years of age would be avoided (or how many additional deaths would have occurred) each year on average in 2009-2011 had air quality levels in Pittsburgh MSA had met those in the other cities.

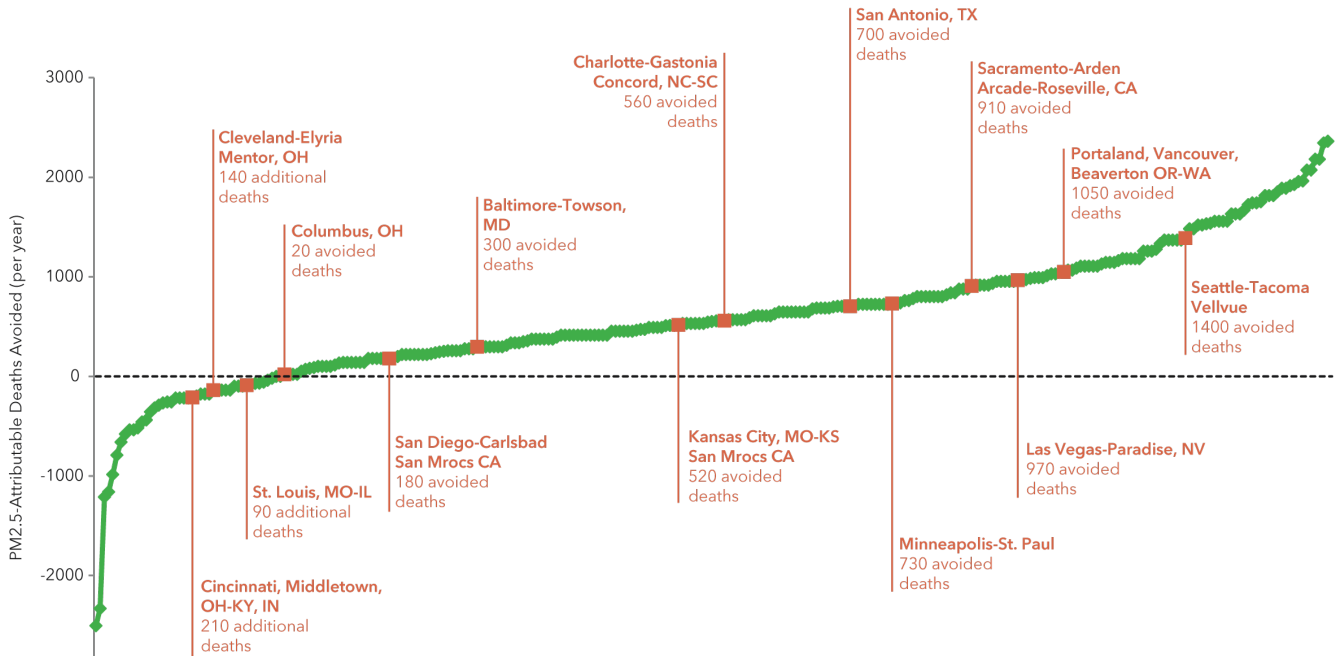
Due to worse levels of $PM_{2.5}$ in Pittsburgh as compared to most other cities (ranked in the bottom 15th percentile of cities), Pittsburgh would have seen fewer deaths in 2009-2011 if air quality had met those seen in the majority of US Cites. Comparing to cities of similar populations, the 7-county Pittsburgh MSA could have avoided to 230-520 deaths if levels met those seen in Kansas City, 320-710 deaths if levels met those seen in San Antonio, and 630-1390 deaths if levels met those of Seattle, corresponding to a 14%, 20%, and 38% reduction in the $PM_{2.5}$- attributable burden, respectively (Figures A1, A2, and Table A1).

Figure A1: Number of avoided mortalities in 7-County Pittsburgh MSA if $PM_{2.5}$ levels met those of other cities (Krewski et al 2009 estimate)*



*Estimates shown reflect annual mortality benefits in 2009-2011, on average, estimated using the Krewski et al 2009 risk estimate, among residents over 30 years of age of the 7-county Pittsburgh MSA. Positive values indicate a decrease in $PM_{2.5}$-attributable deaths; negative values indicate an increase in $PM_{2.5}$-attributable deaths. Green dots represent all CMSAs while select red dots are CMSAs with similar population size to Pittsburgh.

Figure A2: Number of avoided mortalities in 7-County Pittsburgh MSA if $PM_{2.5}$ levels met those of other cities (Lepuele et al 2012 estimate)**



** Estimates shown reflect annual mortality benefits in 2009-2011, on average, estimated using the Lepuele et al 2012 risk estimate, among residents over 30 years of age of the 7-county Pittsburgh MSA. Positive values indicate a decrease in $PM_{2.5}$-attributable deaths; negative values indicate an increase in $PM_{2.5}$-attributable deaths. Green dots represent all CMSAs while select red dots are CMSAs with similar population size to Pittsburgh.

Table A1: Number of avoided deaths in 7-County Pittsburgh MSA if $PM_{2.5}$ levels met those of other cities

CMSA	Number of avoided deaths in 7-County Pittsburgh MSA	
	Using Krewski et al 2009 Estimate	Using Lepuele et al 2012 Estimate
Aberdeen, SD	570	1260
Adrian, MI	290	650
Akron, OH	-20	-40
Albany-Schenectady-Troy, NY	580	1280
Albuquerque, NM	670	1480
Alexandria, LA	430	950
Allegan, MI	340	760
Allentown-Bethlehem-Easton, PA-NJ	160	360
Altoona, PA	-260	-580
Anchorage, AK	890	1960
Anderson, IN	80	180
Ann Arbor, MI	190	420
Appleton, WI	320	720
Asheville, NC	320	710
Athens, OH	360	800
Athens-Clarke County, GA	80	180
Atlanta-Sandy Springs-Marietta, GA	100	230
Atlantic City, NJ	420	940
Augusta-Richmond County, GA-SC	150	340
Augusta-Waterville, ME	530	1180
Austin-Round Rock, TX	290	650
Bakersfield, CA	-350	-790
Baltimore-Towson, MD	130	300
Bangor, ME	620	1370
Baraboo, WI	500	1110
Baton Rouge, LA	250	560
Bay City, MI	430	950
Beaver Dam, WI	320	720
Bennington, VT	690	1520

CMSA	Number of avoided deaths in 7-County Pittsburgh MSA	
	Using Krewski et al 2009 Estimate	Using Lepuele et al 2012 Estimate
Birmingham-Hoover, AL	-30	-70
Bishop, CA	480	1070
Bismarck, ND	790	1740
Bloomington, IN	90	200
Boone, NC	520	1140
Boston-Cambridge-Quincy, MA-NH	490	1090
Bridgeport-Stamford-Norwalk, CT	330	740
Brigham City, UT	450	990
Brookings, SD	360	800
Buffalo-Niagara Falls, NY	270	610
Burlington, NC	320	720
Burlington-South Burlington, VT	820	1820
Butte-Silver Bow, MT	60	140
Cadillac, MI	790	1740
Canton-Massillon, OH	-160	-360
Casper, WY	940	2070
Cedar Rapids, IA	130	300
Charleston, WV	110	240
Charleston-North Charleston, SC	390	880
Charlotte-Gastonia-Concord, NC-SC	250	560
Charlottesville, VA	460	1030
Chattanooga, TN-GA	120	260
Cheyenne, WY	1070	2350
Chicago-Naperville-Joliet, IL-IN-WI	-40	-80
Chico, CA	220	490
Cincinnati-Middletown, OH-KY-IN	-90	-210
Clarksburg, WV	200	450
Clarksville, TN-KY	60	140
Clearlake, CA	1080	2360
Cleveland-Elyria-Mentor, OH	-60	-140
Clinton, IA	40	80
Columbia, SC	160	350
Columbus, GA-AL	0	0
Columbus, OH	10	20

CMSA	Number of avoided deaths in 7-County Pittsburgh MSA	
	Using Krewski et al 2009 Estimate	Using Lepuele et al 2012 Estimate
Concord, NH	480	1070
Corning, NY	740	1630
Corpus Christi, TX	100	220
Dallas-Fort Worth-Arlington, TX	20	50
Daphne-Fairhope-Foley, AL	260	570
Davenport-Moline-Rock Island, IA-IL	50	110
Dayton, OH	120	280
Decatur, AL	240	530
Des Moines-West Des Moines, IA	250	550
Detroit-Warren-Livonia, MI	110	250
Dickinson, ND	990	2180
Dothan, AL	290	650
Dover, DE	370	820
Duluth, MN-WI	690	1530
Durham, NC	440	970
East Stroudsburg, PA	270	610
Eau Claire, WI	410	920
El Centro, CA	110	250
El Dorado, AR	80	180
El Paso, TX	120	280
Elkhart-Goshen, IN	-40	-100
Erie, PA	-200	-460
Eugene-Springfield, OR	510	1130
Evansville, IN-KY	-100	-220
Fairbanks, AK	-140	-320
Fairmont, WV	100	220
Fargo, ND-MN	670	1480
Farmington, NM	990	2180
Fayetteville, NC	240	530
Fayetteville-Springdale-Rogers, AR-MO	190	420
Flint, MI	380	840
Florence, SC	200	450
Florence-Muscle Shoals, AL	240	530
Fort Madison-Keokuk, IA-MO	-100	-220

CMSA	Number of avoided deaths in 7-County Pittsburgh MSA	
	Using Krewski et al 2009 Estimate	Using Lepuele et al 2012 Estimate
Fort Payne, AL	170	380
Fort Smith, AR-OK	100	220
Fort Wayne, IN	100	220
Fresno, CA	-510	-1160
Gadsden, AL	150	340
Gainesville, GA	240	530
Gettysburg, PA	50	100
Goldsboro, NC	260	570
Grand Island, NE	530	1180
Grand Rapids-Wyoming, MI	170	380
Grants Pass, OR	260	570
Green Bay, WI	310	690
Greensboro-High Point, NC	320	710
Greenville, NC	450	990
Greenville-Mauldin-Easley, SC	190	420
Grenada, MS	220	490
Gulfport-Biloxi, MS	210	470
Hagerstown-Martinsburg, MD-WV	50	100
Hammond, LA	390	880
Hanford-Corcoran, CA	-1090	-2500
Harrisburg-Carlisle, PA	-30	-60
Harrisonburg, VA	290	650
Hartford-West Hartford-East Hartford, CT	430	950
Hattiesburg, MS	-40	-100
Helena, MT	700	1560
Hickory-Lenoir-Morganton, NC	200	450
Hilo, HI	440	990
Hobbs, NM	430	950
Honolulu, HI	870	1920
Hot Springs, AR	100	220
Houma-Bayou Cane-Thibodaux, LA	500	1110
Houston-Sugar Land-Baytown, TX	-60	-140
Huntington-Ashland, WV-KY-OH	130	300
Huntsville, AL	220	490

CMSA	Number of avoided deaths in 7-County Pittsburgh MSA	
	Using Krewski et al 2009 Estimate	Using Lepuele et al 2012 Estimate
Indianapolis-Carmel, IN	-190	-440
Iowa City, IA	190	420
Jackson, MS	60	140
Jackson, WY-ID	880	1930
Jasper, IN	-110	-260
Johnstown, PA	-240	-540
Juneau, AK	620	1370
Kahului-Wailuku, HI	840	1850
Kalamazoo-Portage, MI	190	420
Kalispell, MT	360	800
Kansas City, MO-KS	230	520
Kapaa, HI	890	1960
Keene, NH	260	570
Kingsport-Bristol-Bristol, TN-VA	290	650
Klamath Falls, OR	10	20
La Crosse, WI-MN	360	800
Laconia, NH	820	1820
Lafayette, IN	50	100
Lafayette, LA	360	800
Lake Charles, LA	450	1010
Lancaster, PA	-240	-540
Lansing-East Lansing, MI	310	690
Laramie, WY	940	2070
Las Cruces, NM	700	1560
Las Vegas-Paradise, NV	430	970
Lebanon, NH-VT	700	1560
Lebanon, PA	-430	-980
Lewiston-Auburn, ME	520	1140
Lexington-Fayette, KY	130	300
Lincoln, NE	360	800
Little Rock-North Little Rock-Conway, AR	-80	-180
Logan, UT-ID	190	420
Los Angeles-Long Beach-Santa Ana, CA	-130	-290
Louisville/Jefferson County, KY-IN	-120	-270

CMSA	Number of avoided deaths in 7-County Pittsburgh MSA	
	Using Krewski et al 2009 Estimate	Using Lepuele et al 2012 Estimate
Lumberton, NC	320	720
Lynchburg, VA	460	1030
Macon, GA	80	180
Madera, CA	-1010	-2330
Madison, WI	210	470
Manchester-Nashua, NH	690	1520
Marshall, MN	600	1330
Marshall, TX	130	300
McAlester, OK	100	220
Medford, OR	-100	-220
Memphis, TN-MS-AR	100	220
Merced, CA	-230	-520
Michigan City-La Porte, IN	120	260
Middlesborough, KY	150	340
Milwaukee-Waukesha-West Allis, WI	140	310
Minneapolis-St. Paul-Bloomington, MN-WI	330	730
Missoula, MT	120	280
Mobile, AL	270	610
Modesto, CA	-530	-1210
Monroe, LA	340	760
Montgomery, AL	60	140
Morgantown, WV	260	570
Muncie, IN	50	100
Muscatine, IA	-40	-100
New Castle, IN	130	300
New Haven-Milford, CT	320	710
New Orleans-Metairie-Kenner, LA	310	700
New York-Northern New Jersey-Long Island, NY-NJ-PA	230	510
Niles-Benton Harbor, MI	320	720
Nogales, AZ	170	380
Ogden-Clearfield, UT	260	590
Oklahoma City, OK	180	400
Omaha-Council Bluffs, NE-IA	210	460
Owensboro, KY	-80	-180

CMSA	Number of avoided deaths in 7-County Pittsburgh MSA	
	Using Krewski et al 2009 Estimate	Using Lepuele et al 2012 Estimate
Oxnard-Thousand Oaks-Ventura, CA	240	530
Parkersburg-Marietta-Vienna, WV-OH	80	180
Pascagoula, MS	190	420
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	60	140
Phoenix-Mesa-Scottsdale, AZ	330	730
Pittsburgh, PA	0	0
Pittsfield, MA	520	1140
Platteville, WI	270	610
Pocatello, ID	410	920
Portland-South Portland-Biddeford, ME	390	880
Portland-Vancouver-Beaverton, OR-WA	470	1050
Portsmouth, OH	220	490
Poughkeepsie-Newburgh-Middletown, NY	500	1110
Prineville, OR	60	140
Providence-New Bedford-Fall River, RI-MA	620	1370
Provo-Orem, UT	290	650
Raleigh-Cary, NC	230	510
Rapid City, SD	700	1540
Reading, PA	-60	-140
Redding, CA	740	1630
Reno-Sparks, NV	230	510
Richmond, VA	380	840
Richmond-Berea, KY	310	690
Riverside-San Bernardino-Ontario, CA	-30	-70
Riverton, WY	500	1110
Roanoke, VA	290	650
Rochester, MN	530	1180
Rochester, NY	450	990
Rock Springs, WY	820	1820
Rome, GA	-10	-20
Rutland, VT	290	650
Sacramento--Arden-Arcade--Roseville, CA	410	910
Salinas, CA	800	1760
Salisbury, NC	200	450

CMSA	Number of avoided deaths in 7-County Pittsburgh MSA	
	Using Krewski et al 2009 Estimate	Using Lepuele et al 2012 Estimate
Salt Lake City, UT	430	970
San Antonio, TX	320	710
San Diego-Carlsbad-San Marcos, CA	80	180
San Francisco-Oakland-Fremont, CA	300	680
San Jose-Sunnyvale-Santa Clara, CA	470	1040
San Luis Obispo-Paso Robles, CA	320	720
Santa Barbara-Santa Maria-Goleta, CA	350	780
Santa Cruz-Watsonville, CA	760	1670
Sault Ste. Marie, MI	700	1560
Savannah, GA	170	380
Scottsbluff, NE	860	1890
Seaford, DE	320	720
Seattle-Tacoma-Bellevue, WA	630	1390
Sheridan, WY	530	1180
Shreveport-Bossier City, LA	-110	-260
Sierra Vista-Douglas, AZ	570	1260
Sioux City, IA-NE-SD	200	450
Sioux Falls, SD	410	920
Somerset, KY	190	420
South Bend-Mishawaka, IN-MI	60	140
Spartanburg, SC	170	380
Spokane, WA	410	920
Springfield, MA	530	1180
Springfield, MO	190	420
Springfield, OH	10	20
St. Cloud, MN	570	1260
St. Joseph, MO-KS	-100	-220
St. Louis, MO-IL	-40	-90
State College, PA	200	450
Stockton, CA	-290	-660
Syracuse, NY	620	1370
Talladega-Sylacauga, AL	120	260
Terre Haute, IN	-60	-140
Texarkana, TX-Texarkana, AR	10	20

CMSA	Number of avoided deaths in 7-County Pittsburgh MSA	
	Using Krewski et al 2009 Estimate	Using Lepuele et al 2012 Estimate
Thomasville-Lexington, NC	80	180
Toledo, OH	40	90
Topeka, KS	310	690
Torrington, CT	860	1890
Trenton-Ewing, NJ	320	710
Truckee-Grass Valley, CA	740	1630
Tucson, AZ	780	1720
Tulsa, OK	170	380
Tuscaloosa, AL	190	420
Valdosta, GA	270	610
Vallejo-Fairfield, CA	120	260
Virginia Beach-Norfolk-Newport News, VA-NC	430	950
Visalia-Porterville, CA	-1250	-2900
Warner Robins, GA	190	420
Washington-Arlington-Alexandria, DC-VA-MD-WV	240	550
Waterloo-Cedar Falls, IA	130	300
Watertown, SD	320	720
Weirton-Steubenville, WV-OH	-60	-140
Wheeling, WV-OH	-90	-200
Wichita, KS	250	560
Wilmington, NC	620	1370
Winchester, VA-WV	190	420
Winston-Salem, NC	280	630
Worcester, MA	520	1160
Yakima, WA	240	530
York-Hanover, PA	-80	-180
Youngstown-Warren-Boardman, OH-PA	30	70
Yuba City, CA	360	800
Yuma, AZ	500	1110

*Estimates shown reflect annual mortality benefits in 2009-2011, on average, estimated using the Krewski et al 2009 and Lepuele et al 2012 risk estimates, among residents over 35 years of age of the 7-county Pittsburgh MSA. Positive values indicate a decrease in $PM_{2.5}$-attributable deaths; negative values indicate an increase in $PM_{2.5}$-attributable deaths.

APPENDIX II

EPA 2011 National Emissions Inventory Estimates of PM2.5 for Allegheny County[ix]

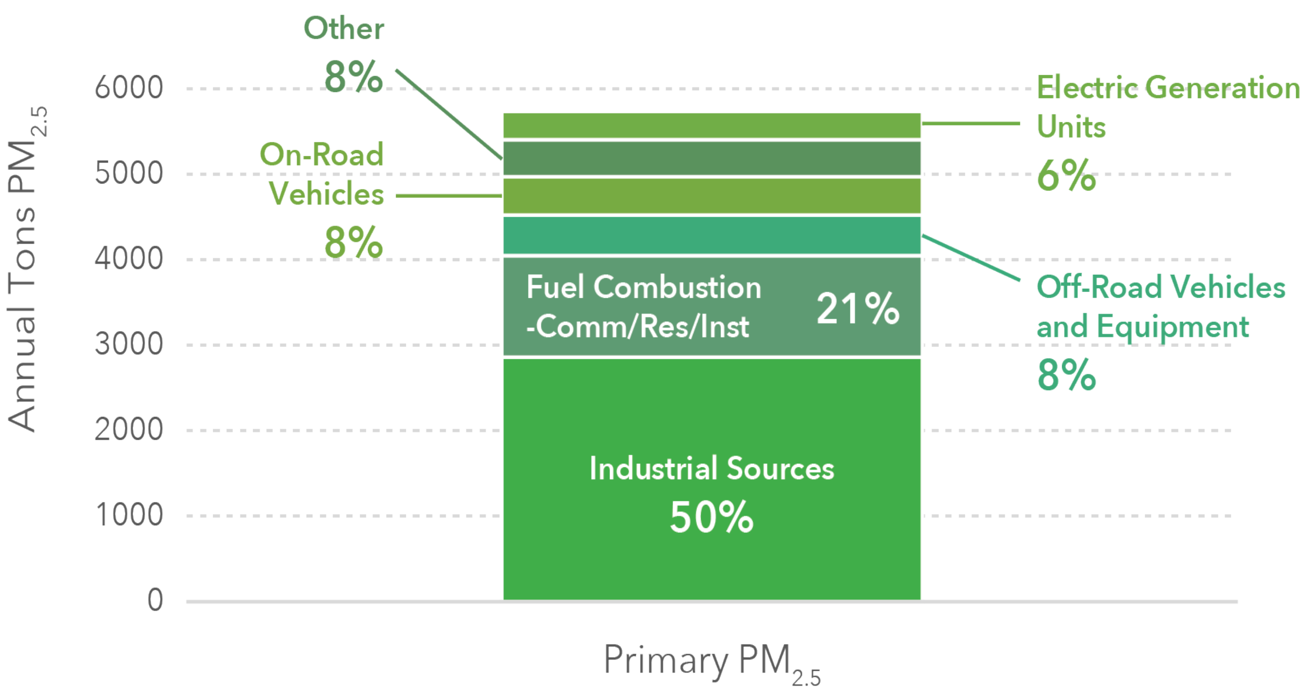


Figure AII-1: Major source contributions to primary $PM_{2.5}$ emissions in Allegheny County

ix Source: EPA 2011 National Emissions Inventory VII, Criteria Pollutants by 14 Major Tiers. Available at: http://www3.epa.gov/ttn/chief/net/2011inventory.html

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