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Strategies for Boosting United States GDP by Reducing PM2.5 Air Pollution

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Strategies for Boosting United States GDP by Reducing $PM_{2.5}$ Air Pollution

by

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Table Of Contents

Table Of Contents (Continued)

Dedication

This paper is dedicated to Dr. Brinda Mahalingam at the University of Alabama in Huntsville, who was gracious with her time throughout the writing process, helped me find relevant resources, and gave me valuable feedback.

Abstract

This paper looks at strategies that can be implemented to maximize the economic benefits of reducing fine particulate matter ($PM_{2.5}$) air pollution control measures in the United States. Some examples of these strategies include focusing efforts on regions that have high-population areas with the highest $PM_{2.5}$ air pollution levels, targeting industries that cause a disproportionate amount of air pollution, and focusing on increasing life expectancy, including improving maternal health in high-risk mothers. Historically, it has been shown that improvements in $PM_{2.5}$ air pollution levels have resulted in a boost to gross domestic product (GDP). There is room for improvement in this area, and by using a strategic approach, the US can use its resources more efficiently to improve $PM_{2.5}$ and its deleterious effects, which will boost the economy.

Chapter 1: Introduction

Air Pollution and Premature Death

Air pollution comes from a variety of sources, including gases emitted from industrial processes, vehicular emissions, and particulate matter generated by vehicles and farming, among other sources. This study outlines the types of air pollution and then focuses on fine particulate matter ($PM_{2.5}$) because it is associated with the most significant health consequences. It looks at the sources of the different types of air pollution and describes how air pollution can be detrimental to health, even causing premature death. For example, air pollution causes respiratory and cardiovascular problems and increases the risk of infections and cancer in the population ("Health Consequences of Air Pollution on Populations"). Then, it explores how deadly air pollution is. This feature is important because premature deaths account for over 70% of the reduction in gross domestic product (GDP) from air pollution (Muller 8) because of the resultant decrease in the workforce.

Air Pollution and its Effect on GDP

Next, this study looks at the effect of air pollution on the GDP in the United States (US). Air pollution affects health and sometimes even causes death. This leads to a fall in labor hours, and, therefore, less production of goods and services, which affects GDP. Specifically, it looks at metrics used to quantify the impact of air pollution, such as gross annual damages (GAD), gross external damages (GED)., and environmentally adjusted value added (EVA). Then, it explores the global effects of air pollution. It looks at mega-cities that have populations over 10 million, high pollution levels, and a disproportionate number of deaths due to air pollution. The concept of population-weighted $PM_{2.5}$ is introduced, which accounts for population density and pollution levels. Next, it looks at deaths from air pollution worldwide, which are disproportionately located in developing countries. Finally, the study looks at strategies for reducing $PM_{2.5}$ air pollution and boosting GDP in the United States.

Chapter 2: Types and Sources of Air Pollution

Types of Air Pollution

Air pollution can be separated into two components: gases and particulate matter. Gases contributing to air pollution include carbon dioxide and monoxide, nitrogen and sulfur oxides, ozone, volatile organic compounds (VOCs), and methane ("Air Pollution and Your Health").

Particulate Matter (PM) is comprised of sulfates, nitrates, carbon, or mineral dust. PM is classified by the size of its particles. Fine particles are called $PM_{2.5}$ because their particle size is 2.5 microns or smaller. Coarse particles are called PM_{10} because they contain particles from 2.5-10 microns in size ("Particulate Matter Pollution Fact Sheet" 1).

The Environmental Protection Agency (EPA) sets National Ambient Air Quality Standards for six air pollutants. This standard includes the two pollutants that pose the most extensive peril to health: ground-level ozone and particulate matter ("Criteria Air Pollutants").

Sources of Air Pollution

"Noxious gases, which include carbon dioxide, carbon monoxide, nitrogen oxides (NOx), and sulfur oxides (SOx), are components of motor vehicle emissions and byproducts of industrial processes" ("Air Pollution and Your Health"). Ground-level ozone is not directly emitted; instead, it is formed via photochemical reactions between nitrogen oxides (NOx) and VOCs under the influence of sunlight ("Ground-Level Ozone Basics"). The emissions from motor vehicles and industrial activities include noxious gases such as carbon dioxide, carbon monoxide, nitrogen oxides (NOx), and sulfur oxides (SOx) ("Air Pollution and Your Health"). Gasoline and natural gas used in vehicles are significant sources of VOCs; however, they are emitted by a variety of sources, including paint, glue, cleaning materials, and pesticides. VOCs rapidly evaporate at ordinary temperatures, and they are called organic because they contain covalent carbon bonds.

Fine particles ($PM_{2.5}$) are also primarily from sources like automobiles and industrial facilities ("Particulate Matter Pollution Fact Sheet" 2). Organic gas, nitrogen and sulfur oxides, and ammonia discharge react in the air, creating minute particles. These fragments can be suspended in the air and move over a large area. Coarse particles are discharged more directly by soil disrupted by vehicles, mining, farming, building projects, and wind.

Chapter 3: How Air Pollution Affects Health

In human cells, exposure to air pollution, in general, is linked to oxidative stress and inflammation, which increase the risk of chronic illnesses and cancer (“Air Pollution and Your Health”). However, there are some unique effects of certain pollutants, which will also be outlined.

How Different Types of Pollutants Cause Disease

Gases cause adverse health effects in a variety of ways. Carbon monoxide (CO) binds to red blood cells more strongly than oxygen, reducing the capacity of blood to circulate oxygen throughout the body (“Types of Pollutants”). Sulfur dioxide also causes respiratory issues, especially in those with underlying conditions such as asthma. Nitrogen compounds worsen breathing issues such as asthma when it is converted to ozone. Ozone is a strong oxidant and can induce injury to the lungs, resulting in swelling and irritation, leading to various symptoms, including coughing, chest tightness, and exacerbation of asthma symptoms (“What Kinds of Harmful Health Effects Can Ozone Cause?”). Inhalation of ozone triggers swelling in the respiratory tract lining, precipitating and intensifying a range of symptoms. Exposure to ozone can impede the volume of air that the lungs inhale, causing breathlessness. It also heightens lung cells’ penetrability, rendering them more susceptible to infection and toxic agents.

Particulate Matter: The adverse effects of particulate matter intensify as the size of the particles decreases (“Health and Environmental Effects of Particulate Matter (PM)”). This effect is because of the greater ability of smaller particles to penetrate deeper into the respiratory system, potentially allowing them to enter the bloodstream. Exposure to such particulates can negatively impact both pulmonary and cardiovascular health. Scientific research has established a correlation between exposure to particle pollution and a range of health issues, including premature mortality among individuals with preexisting cardiac or pulmonary conditions, nonfatal cardiac events, irregular cardiac rhythm, exacerbated asthma symptoms, impaired lung function, and heightened respiratory symptoms such as airway irritation, coughing, or difficulty breathing. Vulnerable populations, such as individuals with cardiovascular or respiratory diseases, children, and elderly individuals, are particularly susceptible to the effects of particle pollution exposure.

How Different Types of Pollutants Cause Premature Death

While some gases, such as sulfur dioxide, directly cause irritation to the respiratory tract and worsening inflammation in those with underlying conditions, carbon monoxide works differently by displacing oxygen and can cause death at high concentrations because of a lack of oxygen (“Types of Pollutants”).On the other hand, nitrogen compounds convert to ozone, which causes death by decreasing respiratory function and increasing the risk of infections such as pneumonia.

Coarse particulate matter (PM_{10}) is less likely to cause death because the irritation it causes is less widespread. In contrast, fine particulate matter ($PM_{2.5}$) can enter the bloodstream, which causes inflammation and increases the risk of stroke and blood-related issues throughout the body. This ability to cause widespread harm is one of the reasons that $PM_{2.5}$ is the most deadly air pollutant.

Chapter 4: How Deadly is Air Pollution?

According to *State of Global Air/2019,* "Air pollution is among the highest five risk factors for population health globally." Additionally, it is the ninth-largest risk factor for premature death in the United States (Murray et al.). Furthermore, "Out of Noise, Air, Water Light, and Soil it has been established that air pollution poses the greatest danger to human life" ("The Most Polluting Industries in 2022").

Air Pollution and Premature Death

Many studies have linked high air pollution with decreased life expectancy. In a well-designed prospective study, Dockery et al. aimed to assess the association between fine particulate air pollution and mortality rates while controlling for individual risk factors in adults. This study took place over a 14-16-year period and followed a group of 8,111 people from six cities in the United States with varying levels of air pollution. They found a statistically significant decrease in lifespan for participants who lived in the areas of the United States with higher $PM_{2.5}$ air pollution, even after adjusting for variables such as smoking and other health factors. The increased mortality was due to lung cancer and heart and lung disease.

In a different study, Eftin et al. used Medicare data to examine the chronic effect of $PM_{2.5}$ air pollution on the United States senior population. They found that Medicare data gave comparable results to earlier studies, so it could be used to estimate the damaging effects of chronic air pollution. This study also found a significant association between chronic $PM_{2.5}$ air pollution exposure and premature death.

Pope et al., in "Mortality risk and fine particulate air pollution in a large, representative cohort of US adults," looked at $PM_{2.5}$ air pollution exposure and premature death in a group that represented the entire United States population, using National Health Interview Surveys from

1986-2014. They found increased mortality due to heart and lung disease and lung cancer in this population, including younger people and seniors.

Chapter 5: Effect of Air Pollution on GDP in the United States

Metrics Used to Quantify the Effect of Air Pollution

Others have looked at ways to measure the effect of air pollution on GDP in the United States. In "Measuring the Damages of Air Pollution in the United States," Muller and Mendelsohn looked at the effect of various levels of specific air pollutants on the US economy. They used a metric called gross annual damages (GAD) to quantify the monetary impact of air pollution on the economy. They looked at each pollutant separately and then at the combined effect of the pollutants as they interacted to determine the most economically efficient way to curb the detrimental impact of air pollution. For example, it was determined that four pollutants, which only make up half of the emissions, account for 80% of the damage. These pollutants included fine particulate matter, ammonia, sulfur dioxide, and volatile organic compounds. They found that the decrease in GDP was a result of lower production due to premature death (71%), increased rate of illness (23%), and other factors like decreased crop and timber production (6%).

Another study by Muller, "Boosting GDP Growth by Accounting for the Environment," used a metric called gross external damages (GED) to quantify air pollution effects over several years in the US. Then they used GDP minus GED to find a figure called environmentally adjusted value added (EVA). This study showed decreased economic damage due to improved air pollution levels from 1999-2008, a result of fewer premature deaths and sick days, which boosted the number of hours worked and, therefore, overall production.

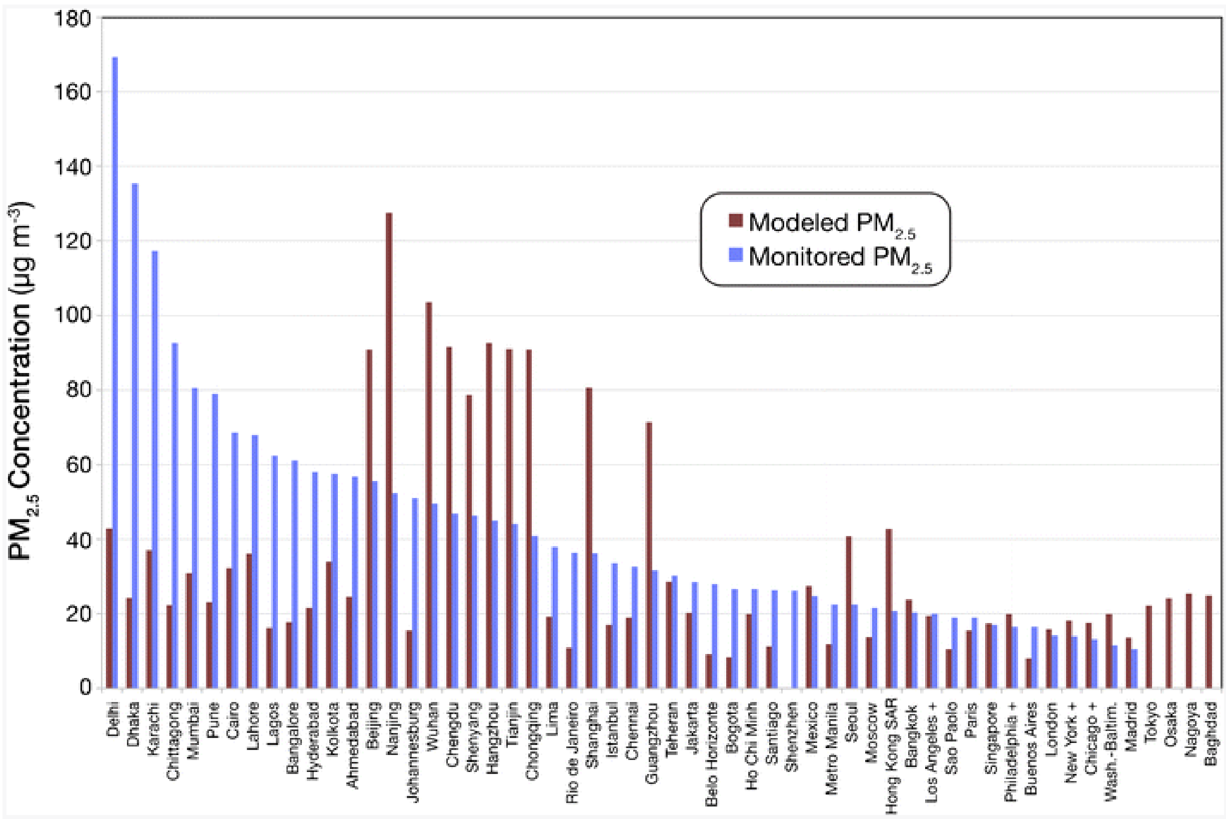
Chapter 6: Global Effects of Air Pollution

According to Krzyzannowski et al., on a global level, air pollution is the biggest environmental detriment to health. In particular, cities with a population of 10 million are susceptible to unhealthy air quality due to the concentration of vehicles, factories, and other sources of emissions.

Mega-Cities and Air Pollution

High population density coupled with high pollution levels can cause a disproportionate number of deaths. In 2004, it was estimated that over 800,000 premature deaths were caused by $PM_{2.5}$ pollution. Over 500,000 occurred in Asia, where they experienced fast growth and exceptionally high air pollution levels concentrated in mega-cities.

In "Air Pollution in Mega-Cities," Kryzannowski et al. looked at ways to monitor the pollution levels in these cities, both by direct measurement and by estimation through satellite data, since some cities, especially those in developing countries, did not have direct measurement readings.

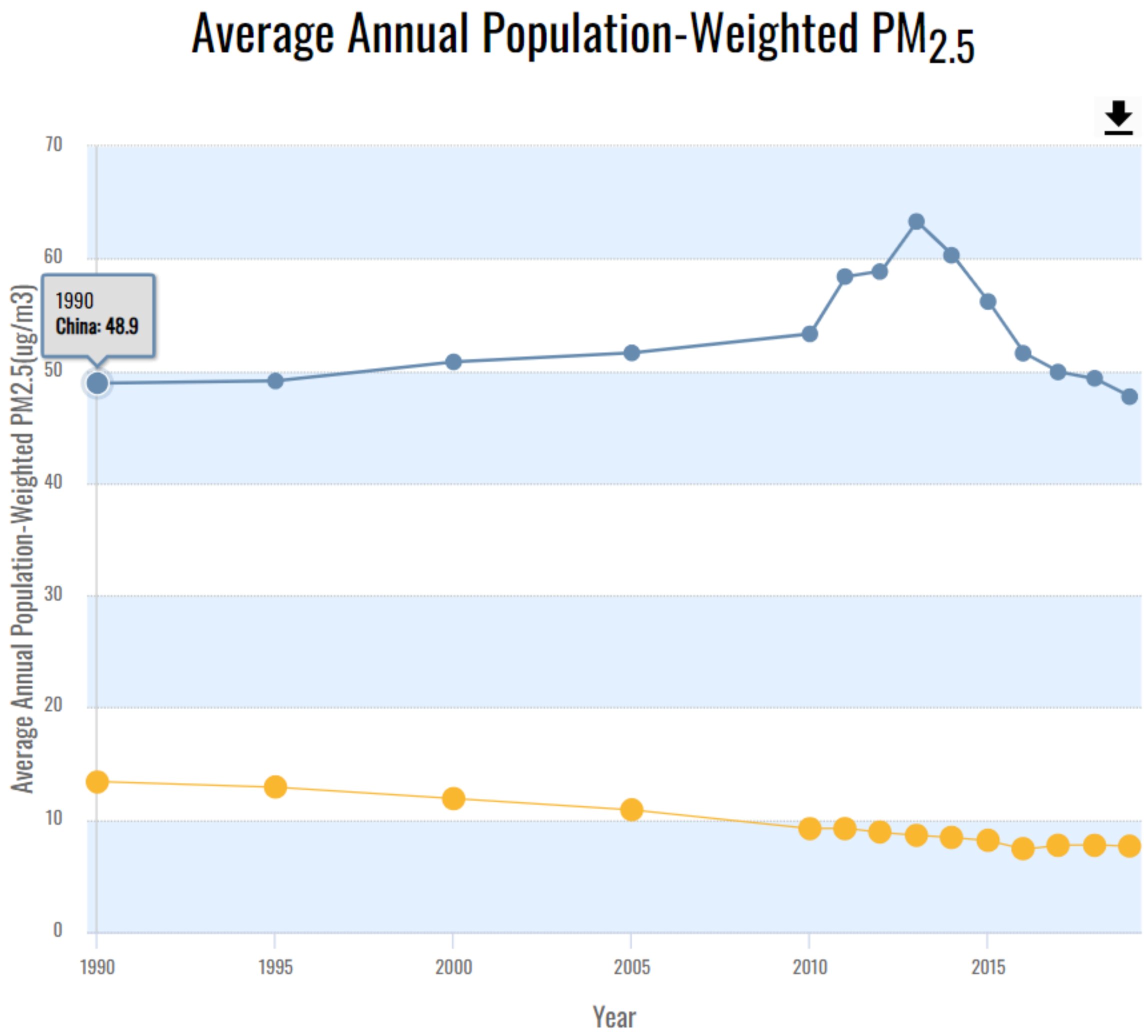


Annual average PM2.5 concentration in cities estimated from surface monitoring and GBD2010 model

("Air Pollution in Mega-Cities")

This graph shows $PM_{2.5}$ levels measured in two different ways for mega-cities worldwide. The blue lines represent monitored $PM_{2.5}$ levels, while the red lines represent modeled $PM_{2.5}$ levels. There were significant discrepancies between the actual measured and modeled. This difference reinforces the importance of direct monitoring of $PM_{2.5}$ levels because it is challenging to estimate the actual levels. Another takeaway is the highest levels of pollution are in the least developed countries, which is consistent with what other researchers have found.

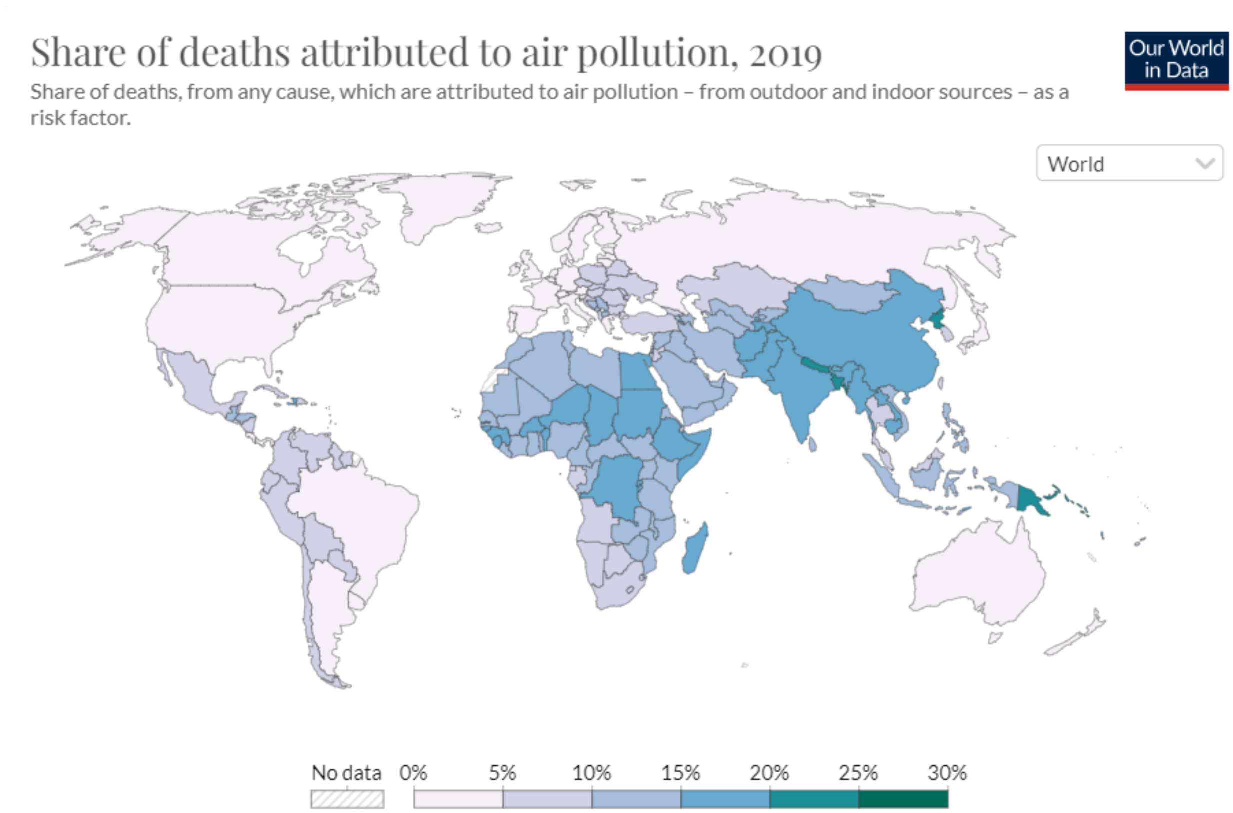
Population-Weighted $PM_{2.5}$



("State of Global Air")

This graph shows China (on top) and the US at the bottom. This graph shows China has had high and increasing pollution levels until recently. The concept of population-weighted $PM_{2.5}$ levels is important because it provides a more accurate representation of the exposure to $PM_{2.5}$ that the population in a particular area experiences. Instead of treating all locations equally, it considers that people living in densely populated areas will have more people affected by their pollution level.

Deaths from Air Pollution Worldwide

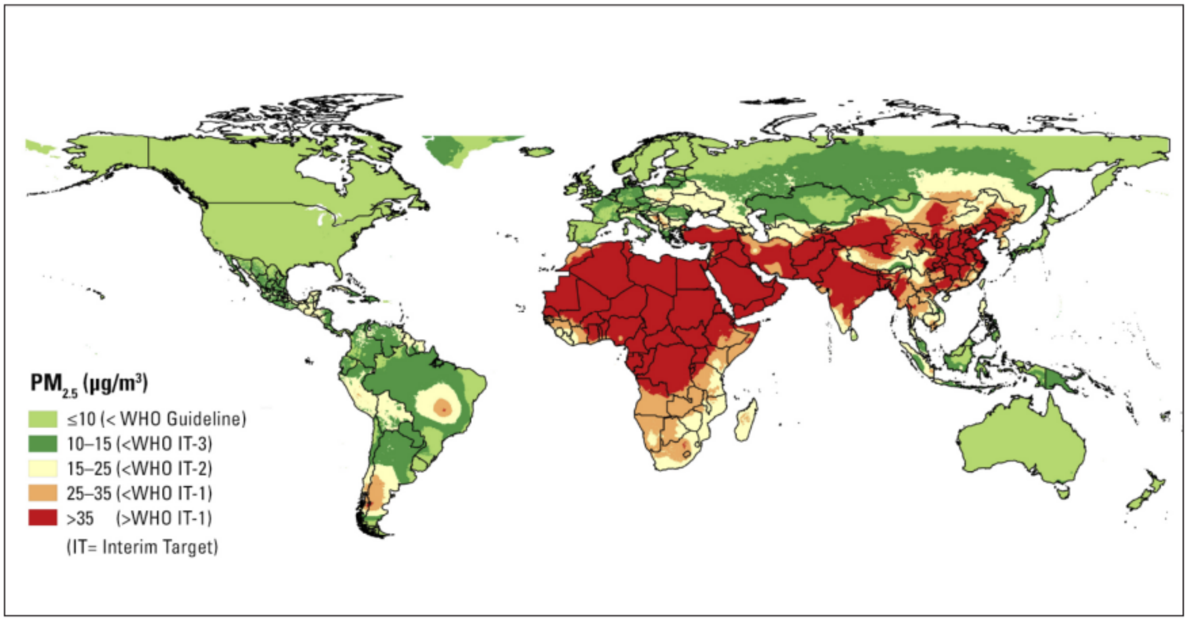


(*State of Global Air/2019*)

As the map above shows, China has some of the highest air pollution rates in the world, causing a disproportionate number of deaths. Studies have looked at the effect of this pollution on economic development. Hao et al. determined that $PM_{2.5}$ levels correspond with the level of haze in large cities in China, and they found a 1% drop in $PM_{2.5}$ levels would result in a 0.5% increase in GDP, which shows that air pollution mitigation is advantageous to a country's economy as a whole and their people.

$PM_{2.5}$ Air Pollution Levels Worldwide

Figure 2. Annual average $PM_{2.5}$ concentrations in 2017 relative to the WHO Air Quality Guideline.



3 STATE OF GLOBAL AIR / 2019

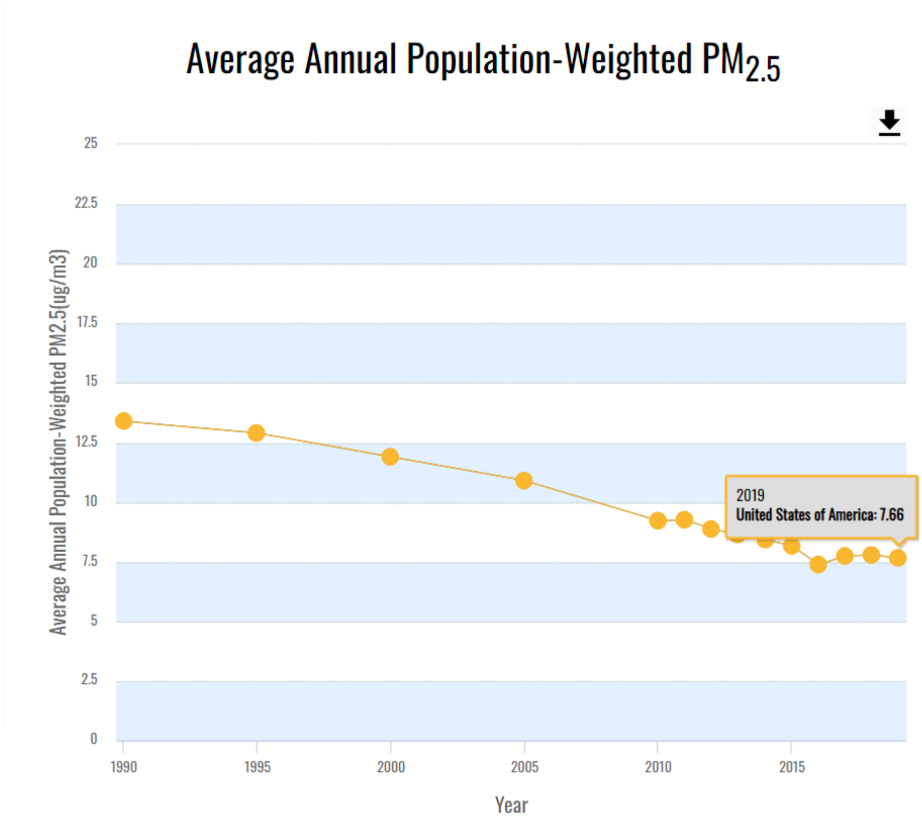
(*State of Global Air/2019*)

This map highlights that most areas with the worst air pollution are developing countries. Hao et al. discussed the idea of an inverted U-shaped curve that often occurs when graphing pollution over time in developing countries. Countries new to development pay little attention to the air pollution generated by factories and vehicles. So pollution levels rise quickly at the beginning and then peak. Then, as air pollution takes a significant toll and becomes more evident through poor air quality, countries suffer from decreased economic growth. However, they have more wealth at that point, so they can invest money to reduce emissions and improve air quality.

Chapter 7: Strategies for Reducing $PM_{2.5}$ Air Pollution and Boosting GPD in the United States

History of Air Pollution in the US

In the past, the US had high levels of air pollution. Some areas of the US even had air pollution as high as modern-day Beijing ("United States"). However, in 1970 the Clean Air Act was passed, which moved regulation from the state to the federal level, specifically giving the Environmental Protection Agency (EPA) the power to regulate air pollution. Since then, there has been a steady decrease in air pollution levels in the US.



("State of Global Air")

This graph shows the decrease in $PM_{2.5}$ air pollution in the US from 1990-2019. While there has been a decrease in air pollution, there is still room for improvement.

As discussed in Chapter 5, Muller, in “Boosting GDP Growth by Accounting for the Environment,” used gross external damages (GED) to quantify air pollution effects over several years in the US. Then he used GDP minus GED to find the environmentally adjusted value added (EVA figure). This study showed decreased economic damage due to improved air pollution levels from 1999-2008. The table below summarizes their findings.

Aggregate levels and annual rates of growth

Levels	1999	2002	2005	2008
GED	589 [768]	478 [661]	443 [632]	351 [535]
EVA	8,575 [8,395]	9,399 [9,216]	10,276 [10,086]	10,750 [10,566]
GDP	9,164	9,877	10,718	11,101
GED/GDP	0.064 [0.084]	0.048 [0.067]	0.041 [0.059]	0.032 [0.048]
Growth	**1999**	**2002**	**2005**	**2008**
GED	*	−6.75 [−4.91]	−2.53 [−1.49]	−7.46 [−5.39]
EVA	*	3.11 [3.16]	3.02 [3.05]	1.52 [1.56]
GDP	*	2.53	2.76	1.18

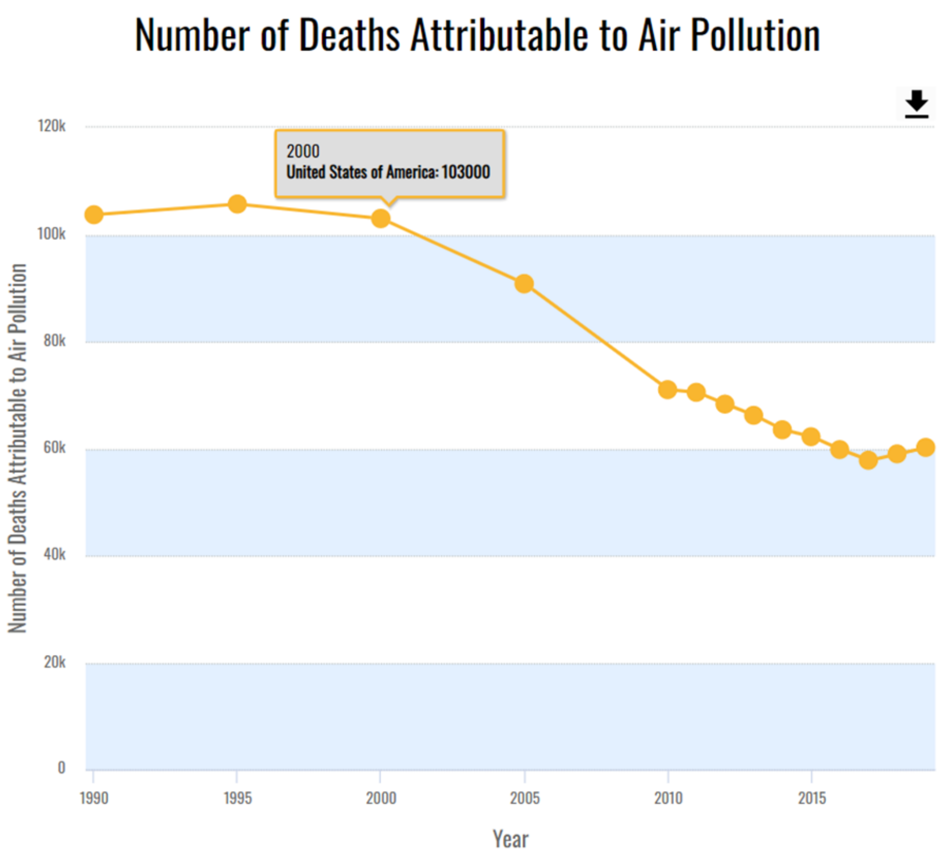
(Muller, “Boosting GDP Growth by Accounting for the Environment”)

This table shows decreased economic damage due to improved air pollution levels from 1999-2008. Specifically, in 1999, the GED was $589 billion, and by 2008, the GED had dropped to $351 billion. The amounts in brackets include damages from carbon dioxide production. Looking at the growth section, the GED had a 6.57% decrease from 1999 to 2002 (a 4.91% decrease when damage from carbon dioxide was included). Each period’s GED growth rate is negative, reflecting the damage reduction over time.

Furthermore, Hao et al., in "How Harmful Is Air Pollution to Economic Development?" found that a one percent decrease in $PM_{2.5}$ levels could increase GDP by half a percent.

Improving Life Expectancy

Pope et al., in "Fine-particulate air pollution and life expectancy in the United States," analyzed what happens when air pollution levels improve. They found significant improvements in life expectancy when there was a drop in $PM_{2.5}$ levels. Specifically, by decreasing $PM_{2.5}$ levels by 10 µg per meter cubed, life expectancy was increased by about seven months. These findings are encouraging because they reinforce the idea that improving air quality can prolong life. This fact can give officials a tangible metric to weigh the cost/benefit of air pollution control.



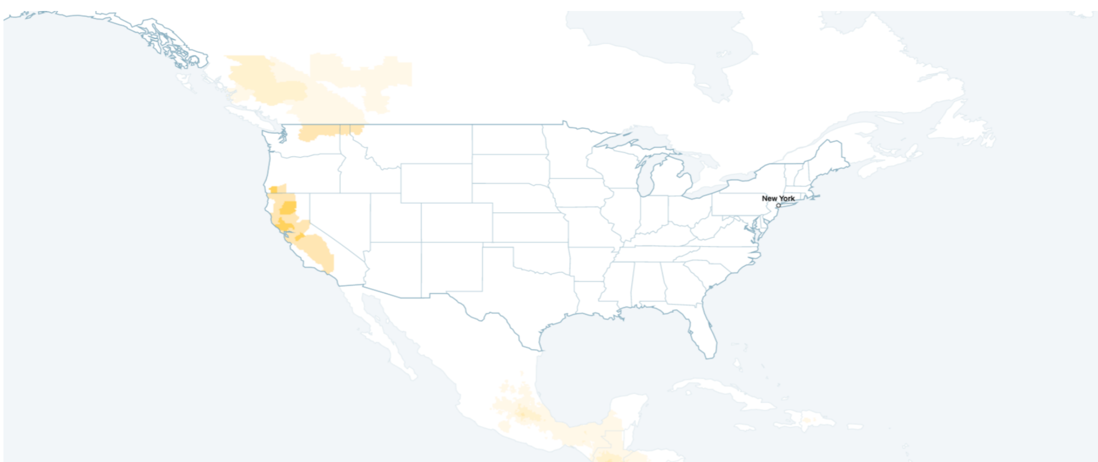
("State of Global Air")

This graph shows that deaths caused by air pollution in the United States have decreased as cleaner energy sources, technology advances, and environmental regulations have increased (*State of Global Air/2019)*.

Targeting Population-Dense Areas with Highest Air Pollution

One strategy to maximize impact while keeping costs low is to concentrate on population-dense areas with high levels of air pollution, such as Los Angeles. The map below highlights the areas of the US with the highest pollution, which are concentrated primarily in California ("United States")**.** While this area has experienced a 60% decrease in air pollution over the last 50 years, there is room for improvement to reach WHO air quality standards.

Areas of Highest Air Pollution in the United States

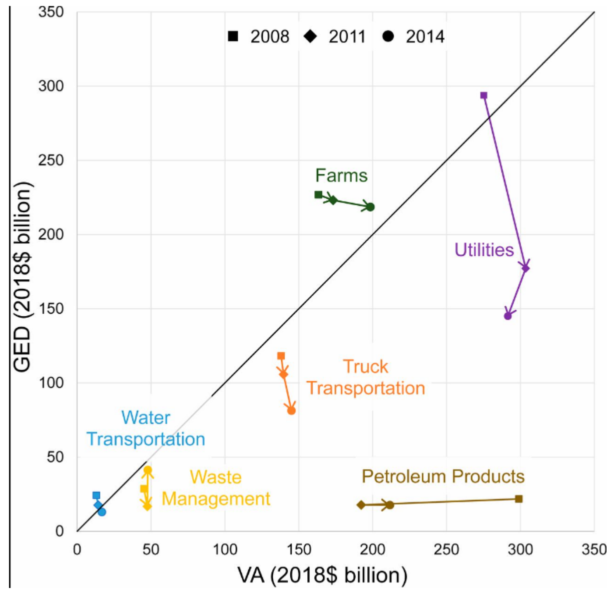


("United States")

This map shows the areas of the US with the highest levels of air pollution. California has the highest levels of pollution and high population density, which makes California a logical location to target to get the most significant overall economic benefit from air pollution improvements.

Economic Damage by Industry

Gross Economic Damages vs. Value Added by Industry Type 2018



(Tschofen, Peter, et al.)

Another way to look at target areas for improvement is by analyzing different industries and the damage they cause vs. their contribution to the economy. The graph above shows the notable industries in the US and their economic contribution vs. their ecological costs (gross economic damages). Companies above the line create more damage than the value they add. Larger ratios mean the industry has a large environmental effect compared to the value it adds to the economy. It also shows the improvement over time from 2008-2014. Farms are a major source of pollution. Even though farms are usually located in rural areas, the fact that they are such a significant source of pollution means that it could be helpful to look for cost-effective strategies to decrease the environmental impact of the agricultural industry.

Decreasing Infant Mortality and Prematurity Due to Air Pollution

Air pollution has a negative effect on high-risk pregnancies, particularly those with maternal age of thirty-five or older and pregnancies where the mother smokes (DeCicca and Malak). Targeting these populations allows for an enormous economic payoff since the medical costs for a premature infant in the first year (in 2011) were $50,000 more than a full-term infant and since premature infants require other specialized care over their lifetime (which totaled approximately $26 billion in 2005). Therefore, improvement in air pollution in areas with high-risk expectant mothers would have the potential for huge cost savings.

Maximizing Economic Return of Air Pollution Control

Improvements in small particulate air pollution can positively affect the economy. If efforts were made to maximize the effects, for example, by focusing efforts on areas that have high-population areas with the highest $PM_{2.5}$ air pollution levels, targeting industries that cause a disproportionate amount of air pollution, and concentrating on increasing life expectancy, including improving maternal health in high-risk mothers, cost-effective strategies could be implemented, which would maximize economic improvement while minimizing the cost.

Conclusion

In summary, this study outlined the types of air pollution and then focused on fine particulate matter ($PM_{2.5}$) because it is associated with the most significant health consequences. It looked at the sources of the different types of air pollution and described how air pollution can be detrimental to health and even cause premature death. Then, it explored how deadly air pollution is because premature deaths account for over 70% of the reduction in gross domestic product (GDP) from air pollution (Muller 8).

Next, this study looked at the effect of air pollution on the GDP in the United States. Specifically, it looked at different metrics used to quantify the impact of air pollution, such as gross annual damages (GAD), gross external damages (GED), and environmentally adjusted value added (EVA). Then, it explored the global effects of air pollution. It looked at mega-cities that have populations over 10 million, high pollution levels, and a disproportionate number of deaths due to air pollution. The concept of population-weighted $PM_{2.5}$ was introduced, accounting for population density and pollution levels. Next, it looked at deaths from air pollution worldwide, which are disproportionally located in developing countries. Finally, the study looked at strategies for reducing $PM_{2.5}$ air pollution and boosting GDP in the United States. These strategies included focusing on high-population areas with the highest $PM_{2.5}$ air pollution levels, targeting industries that cause a disproportionate amount of air pollution, and increasing life expectancy, including improving maternal health in high-risk mothers. If these cost-effective strategies were implemented, the US could maximize the increase in GDP while minimizing the costs, resulting in prudent air pollution control.

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